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Oil Quenching

by

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“The Heat Treat Doctor”[®]

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This is the twentieth in a series of articles about Vacuum Heat Treatment. Here we discuss oil quenching in vacuum furnaces a technology that has been used for over 50 years and has both broad appeal and some very unique characteristics.

Why Oil Quenching?

Many components use oil quenching to achieve consistent and repeatable mechanical and metallurgical properties and predictable distortion patterns. The reason oil quenching is so popular is due to its excellent performance results and stability over a broad range of operating conditions. Oil quenching facilitates hardening of steel by controlling heat transfer during quenching, and it enhances wetting of steel during quenching to minimize the formation of undesirable thermal and transformational gradients which may lead to increased distortion and cracking. For many, the choice of oil is the result of an evaluation of a number of factors including ^[1]:

- Economics/cost (initial investment, maintenance, upkeep, life)
- Performance (cooling rate/quench severity)
- Minimization of distortion (quench system)
- Variability (controllable cooling rates)
- Environmental concerns (recycling, waste disposal, etc.)

Oil Quenching in Vacuum

Oil quench vacuum systems offer an attractive alternative to other technologies given their ability to control the various quench variables. In addition, one can vary and control the pressure over the oil. This technique can extend the range of part cross-sections and materials that can be processed. In addition, the use of a vacuum oil quenching has been found to reduce distortion in a wide variety of components such as gears, shafts, and ball bearings.

Distortion minimization techniques using pressure variation have proved effective ^[2,3].

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Altering pressure over the quench oil allows for a change in the boiling point of the quenchant. The position of the boiling point, i.e. ‘characteristic temperature’, determines where and for how long the various stages of oil cooling take place. The lower pressure allows for longer “vapor blanket” stages and a somewhat long “vapor transfer” stage, due to the reduced boiling point of the oil. This has been found to reduce distortion in some part geometries and provide the sought after hardness, provided the material’s hardenability is suitable.

Distortion minimization methods have been used in combination with changes to flow characteristics (for example, some manufacturers pull oil down through the workload as opposed to pushing it upward) and oil compositions specially blended for use in vacuum having low vapor pressure oils so that they are easily degassed (Table 1).

Table 1 ^[4]
Vacuum Quench Oils

Characteristic	H – 1	H – 2	H – 3	No. 420 ^[a]	H – 4	Accelerator
Maximum Operating Temperature, °F (°C)	140 (60)	180 (82)	180 (82)	250 (120)	450 (230)	-
Normal Operating Range, °F (°C)	90 – 140 (32 – 60)	120 – 150 (50 – 65)	120 – 150 (50 – 65)	180 – 220 (82 – 105)	225 – 275 (105 – 175)	-
GM Quench-O-Meter	9 – 11 @140°F (60°C)	13 – 15 @140°F (60°C)	12 – 14 @140°F (60°C)	-	27 – 28 @ 300°F (150°C)	n/a
Hot wire (amps)	34.0 @140°F (60°C)	32.5 @140°F (60°C)	34.0 @140°F (60°C)	31.0 @ 140°F (60°C)	n/a	n/a
Specific Gravity	0.87 @60°F (16°C)	0.86 @ 77°F (25°C)	0.86 @ 77°F (25°C)	-	0.90 @60°F (16°C)	0.92 @60°F (16°C)
Viscosity (SUS)						
@70°F (21°C)	-	-	-	-	6500	-
@100°F (38°C)	93	115	130	260	1800	3100
@130°F (55°C)	58	-	-	-	-	-
@180°F (82°C)	42	-	-	-	-	-
@210°F (99°F)	-	-	-	73	120	-
Flash Point	340 (170)	380 (193)	385 (196)	430 (221)	575 (300)	340 (170)

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(COC), °F (°C)						
Free Fatty Acid	Nil	Nil	Nil	Nil	Nil	Nil
Conradson Carbon Residue	0.01	0.01	0.01	0.01	0.40	-
Color (ASTM), Hellige	1.5	1.5	1.5	1.5	-	-
Ash Content (ASTM)	Trace	Trace	Trace	Trace		Trace
Pour Point, °F (°C)	+20 (-7)	0 (-18)	0 (-18)	-	0 (-18)	+25 (-4)
Vapor Pressure (mm Hg)	-	-	-		-	-
@100°F (38°C)	0.002	0.0001	0.0001	-	-	-
@200°F (93°C)	0/1000	0.0103	0.0103	-	-	-
@300°F (150°C)	2.00	0.45	0.45	-	0.25[b]	-
@400°F (205°C)	-	-	-	-	4.0 [c]	-
Active Sulfur	Nil	Nil	Nil	Nil	Nil	Nil
Halogens	Nil	Nil	Nil	Nil	Nil	Nil
% Additive	10.0	7.2	10.7	-	0.0	-

Notes:

- [a] Park Chemical oil product
- [b] Reduced by 25% distilled off to 0.0012
- [c] Reduced by 25% distilled off to 0.050

The design of an integral vacuum oil quench system requires considerations beyond those of atmosphere oil quenching. For example, the boiling point and vapor pressure of the base oil as well as the accelerate additives characteristics must be taken into consideration along with the quench oil temperature, agitation, cleanliness, pH and viscosity. Also, the vapor pressure of the quench oil must be compatible with the selected operating vacuum level.

Finally, vacuum systems do not permit the buildup of water in the quench tanks. In a vacuum furnace system, where vacuum is used to process the work or purge the quench environment, moisture will be removed as the system is evacuated and the oil circulated. The circulated oil brings any moisture to the surface where it is vaporized and removed from the oil by the pumping system.



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Cooling Rate Characterization

Measuring the efficiency, or “speed” of an oil quench can be done one of two ways, by measuring the oil’s ‘hardening power”, that is its ability to harden a steel or by measuring the cooling ability of the liquid. Since cooling ability is independent of steel selection (composition and grain size) this method is popular since it provides information about the oil itself independent of its end use application.

The preferred test method today is cooling curve analysis (ISO 9950) that involves a laboratory test using a nickel-alloy probe for the determination of the cooling characteristics of industrial quenching oils. The test is conducted in non-agitated oils and thus is able to rank the cooling characteristics of the different oils under standard conditions, providing information on the cooling pathway (which must be known if the ability of quench oil to harden steel is to be determined). Older methods such as the GM Quench-O-Meter (ASTM D3520) or the hot wire test are still in common use. The GM Quench-O-Meter method for example measures the overall time to cool a 7/8” (22 mm) nickel ball from 1625°F (885°C) to 670°F (355°C) while the hot wire test is influenced by the heat extraction rate of the oil at temperatures close to the melting point of Nichrome, about 2750°F (1510°C).

Oils are generally classified by their ability to transfer heat as fast, medium, or slow “speed” oils (Table 2). Fast (8-10 second) oils are used for low hardenability alloys, carburized and carbonitrided parts, and large cross sections that require high cooling rates to produce maximum properties. Medium (11 – 14 second) oils are typically used to quench medium to high hardenability steels. Slow (15-20 second) oils are used where hardenability of a steel is high enough to compensate for the slow cooling aspects of this medium ^[2].

Table 2 ^[5]
Classification of Quench Oils

Type	GM Quench-O-Meter Rating, seconds
Fast Oil	8 – 10
Medium Oil	11 – 14

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Slow Oil	15 - 20
Marquench Oil	18 - 25

Mechanisms of Heat Removal During Quenching

The mechanism of cooling a gear in liquid is largely dependent on geometry for a given material that dictates the requirements of the quench system.

Traditionally we talk about three distinct stages of cooling (Fig. 1). Stage A is called the “vapor blanket” (or “film boiling”) stage. It is characterized by the Leidenfrost phenomenon, which is the formation of an unbroken vapor blanket that surrounds and insulates the work piece. It forms when the supply of heat from the surface of the part exceeds the amount of heat that can be carried away by the cooling medium. The stability of the vapor layer, and thus the ability of the oil to harden steel, is dependent on the metal’s surface irregularities, oxides present, surface-wetting additives which accelerate the wetting process and destabilize the vapor blanket, and the quench oil’s molecular composition, including the presence of more volatile oil degradation by-products^[6]. In this stage the cooling rate is relatively slow in that the vapor envelope acts as an insulator and cooling is a function of conduction through the vapor envelope.

Stage B is the second stage of cooling known as the “vapor transport” (or “nucleate boiling” or “bubble boiling”) stage. It is during this portion of the cooling cycle that the highest heat transfer rates are produced. The point at which this transition occurs and the rate of heat transfer in this region depend on the oil’s overall molecular composition^[6]. It begins when the surface temperature of the part has cooled enough so that the vapor envelope formed in Stage A collapses. Violent boiling of the quenching liquid results, and heat is removed from the metal at a very rapid rate, largely due to heat of vaporization. The boiling point of the quenchant determines the conclusion of this stage. Size and shape of the vapor bubbles are important in controlling the duration of this stage. The majority of gear distortion occurs during this stage.

Stage C is the third stage of cooling called the “liquid” (or “convection”) cooling stage. The cooling rate during this stage is slower than that developed in the second stage and is exponentially dependent on the oil’s viscosity, which will vary with the degree of oil decomposition. Increasing oil decomposition will result initially in a reduction of oil viscosity followed by increasing viscosity as the degradation process increases. Heat transfer rates increase with lower viscosities and decrease with increasing viscosity^[6].

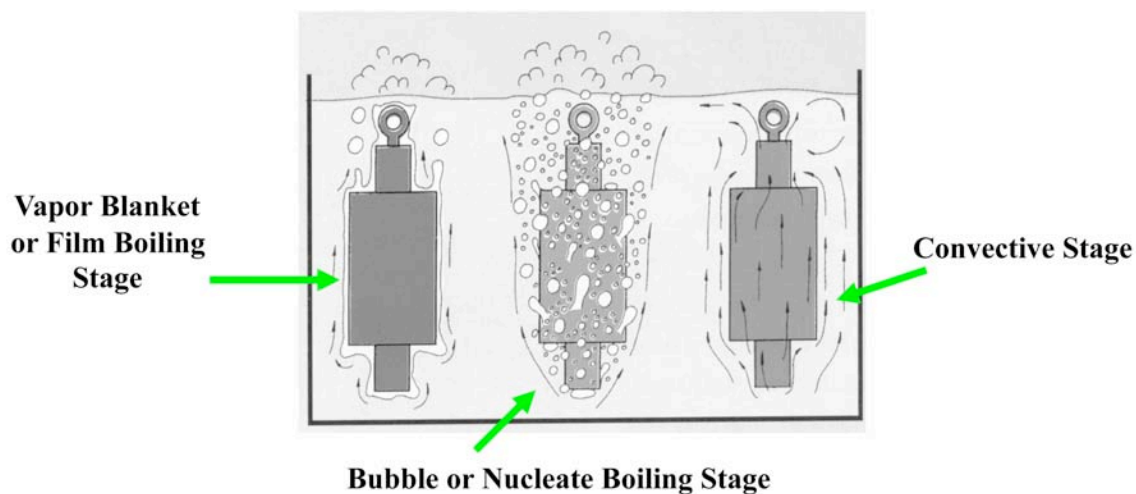


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This final stage, begins when the temperature of the metal surface is reduced to the boiling point (or boiling range) of the quenching liquid. Below this temperature, boiling stops and slow cooling takes place by conduction and convection. The difference in temperature between the boiling point of the liquid and the bath temperature is a major factor influencing the rate of heat transfer in liquid quenching. Viscosity of the quenchant plays a major role in the cooling rate in this stage.

Figure 1 ^[7]
Three Stages of Liquid Quenching

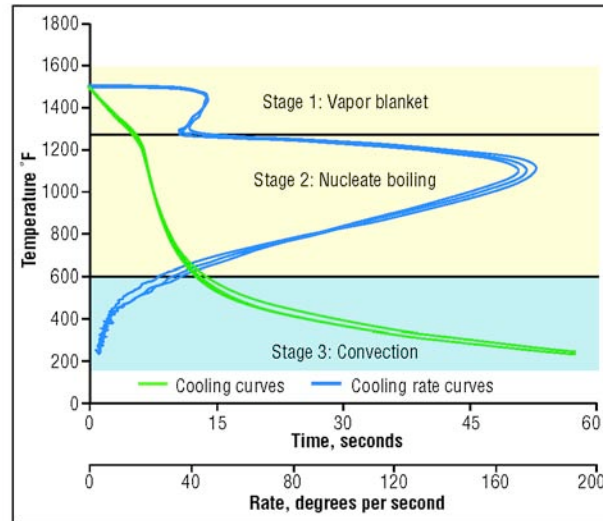




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Figure 2 ^[8]
 Typical Cooling Curves and Cooling-Rate Curves for New Oils



According to an investigation by N. I. Kobasko ^[9], there are four (4) modes of heat transfer around a part being quenched, namely “shock film” boiling, full film boiling, nucleate boiling and convection (Fig. 3a). For any vaporizable liquid there are at quenching two critical heat flux densities q_{cr1} and q_{cr2} (Fig. 3b). The first critical heat flux density q_{cr1} is the heat transfer rate necessary to form the compact vapor film around the part.

Due to the large temperature difference between the very hot surface of the part and the quench bath temperature, the liquid layer in contact with the hot part's surface heats up to boiling temperature in about one tenth (1/10) of a second. First, small vapor bubbles occur, then larger bubbles that grow in size and number, until they detach from the part surface forming the vapor blanket. This is the "shock film" boiling stage. The second critical heat flux density q_{cr2} is the minimal heat flux at which the transition from full film boiling to nucleate boiling occurs. According to Tolubinski ^[9] the critical heat flux density q_{cr1} is given as (Equation 1)

$$(1) \quad q_{cr1} = 7r (af\rho' \rho'')^{0.5}$$



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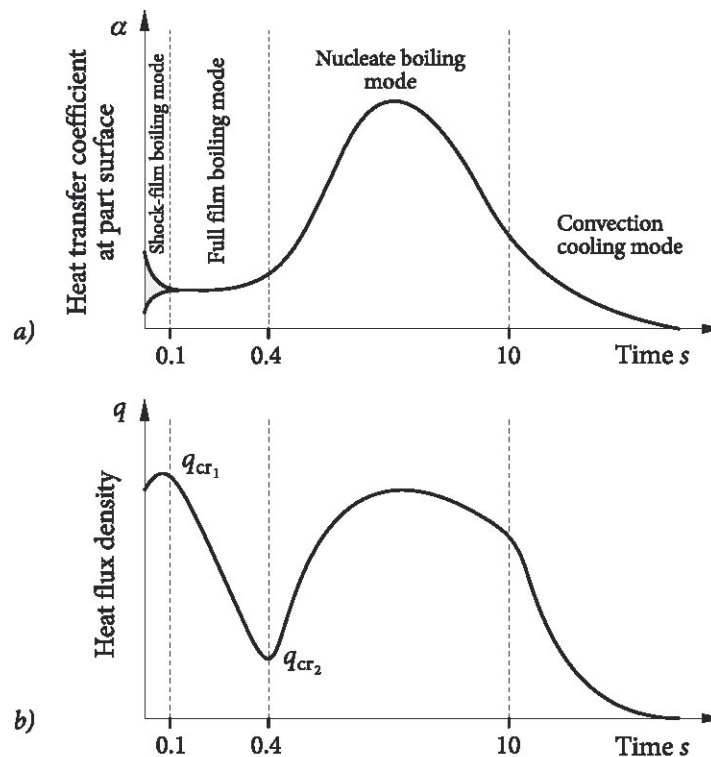
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where

r = heat of vaporization
 $a = \lambda/\rho c =$ thermal diffusivity
 f = frequency of vapor bubble detachment
 ρ' = density of the liquid
 ρ'' = density of the liquid's vapor.

Figure 3

- a) Four Modes of Cooling During Quenching
b) Critical Heat Flux Densities



The only variable in Equation 1, on which q_{cr1} depends is f , that is, the frequency of vapor bubbles detaching from the surface. In other words, a compact vapor film around the part will be formed only if the critical heat flux density, q_{cr1} is attained (which



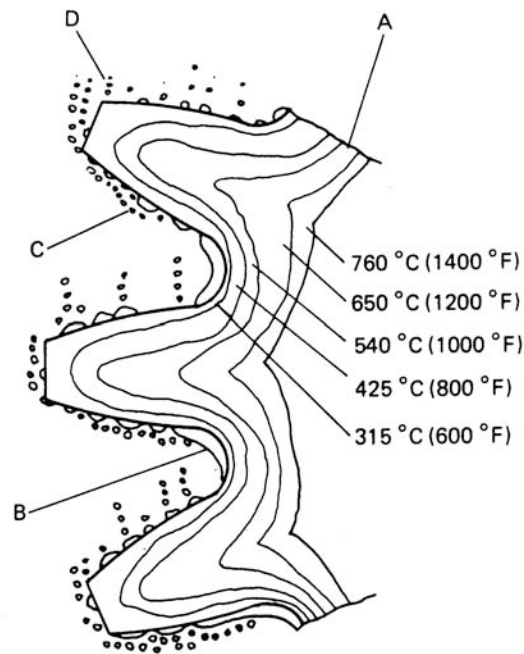
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depends on the number of vapor bubbles and the frequency with which they detach from the part's surface.

In addition, these stages of cooling may not occur at all points on a part at the same time (Fig. 4). As the internal heat moves to the surface differences in heat rejection may vary based on the surface configuration. Consequently, the need for a uniform and controllable agitation of liquid 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.

Figure 4 ^[10]
The Influence of Part Geometry on Cooling





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Properties of an Ideal Quenching Medium

The ideal quenching medium is one that would exhibit high initial quenching speed in the critical hardening range (through Stage A & B) and a slow final quenching speed through the lower temperature range (Stage C). Thus the ideal quenchant is one that exhibits little or no vapor stage, a rapid nucleated boiling stage, and a slow rate during convective cooling. The high initial cooling rates allow for the development of full hardness by getting the steel past the ‘nose’ of the isothermal transformation diagram (quenching faster than the so-called critical transformation rate) and then cooling at a slower rate beginning at the time the steel is forming martensite. This allows stress equalization; thus, distortion and cracking are reduced. The first criterion that any quenchant must meet is its ability to approach this ideal quenching mechanism.

When conventional quenching oils are used, the duration of Stage A is longer; the cooling rate in Stage B is considerably slower; and the duration of Stage C is shorter. As such, the “quenching power” of oil is far less drastic than that of water. Water and water solutions exhibit high initial cooling rates. Unfortunately, because of water’s low boiling point, this fast cooling persists until the steel is cooled to below 300°F (150°C). As most steels have formed or are forming martensite by this point, stresses are given little time to equalize. Thus water is typically limited to simple shapes or low hardenability materials.

Oil has a major advantage over water due to its higher boiling range. A typical oil has a boiling range between 450°F (230°C) and 900°F (480°C). This causes the slower convective cooling stage to start sooner enabling the release of transformation stresses. Oil is, therefore, able to quench intricate shapes and high hardenability alloys successfully.

As it is heated, oil has a proportional drop in viscosity. This allows the quenchant to move more freely, increasing, in general, the tendency to break the vapor blanket layer. The nucleate boiling stage is not drastically altered by changes in bath temperature. The cooling rate in the convection stage of an oil quench will slow as the bath temperature increases. This is advantageous for obtaining a slower rate of cooling through the austenite-to-martensite transformation range. In general, as the temperature of a quenching oil increases, the overall quenching rate increases.

Practical heat transfer coefficient (α) values in the 1000 to 2500 W/m²·K range can be achieved depending on oil characteristics and degree of agitation. Peak values of α in the



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cooling range of oil are 4000 to 6000 W/m²·K, or a cooling rate greater than 100°C/s (180°F/sec).

Effect of Increasing Bath Temperature

The temperature of the quenchant has dramatic influence on the rate of part cooling. Increasing the bath temperature, from say 70°F (21°C) to 250°F (120°C) produces a slightly faster cooling in Stage A because the viscosity of the oil decreases. In Stage B, cooling is only slightly increased and in Stage C, cooling decreases near the end of the quench because the temperature differential between the bath and the steel is decreased.

Quenching oils have various characteristics that allow for varying cooling rates as a function of not only their boiling point but also their temperature. This has a direct bearing on properties such as viscosity, conductivity and heat rejection (based on the log mean temperature differential, or LMTD) of the heat exchange system. Bubble size as well as the conductivity of the vapor barrier in all three stages of cooling are (to a degree) selectable by oil choice.

For most quench oils, other than marquench oils, the optimum rates of cooling are normally obtained when the bath temperature is between 120°F (50°C) and 150°F (65°C). In this temperature range, properly refined mineral oils are indefinitely stable, and the effect of viscosity is drastically reduced. Various manufacturers usually have an optimum temperature range for their product. The instantaneous rate of rise of the entire quench bath is also important. This is normally design dependent, but usually averages between 20°F (-7°C) to 40°F (4°C).

Effect of Increasing Degree of Agitation

Even with a properly selected oil and correct quench environment design, the stages of cooling described above may not occur at all points on a part configuration at the same time. Part cooling is a function of the quality of the oil as well as the part's geometry, fixturing and 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"

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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 that is, the oil 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. Oil break down on the part surface may occur if sufficient quenchant agitation is not provided.

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 ^[11]:

- 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)

Effect of Quench Tank Design

Draft tubes are just one component that highlights an often-overlooked aspect of quenching. 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. The volume of oil, the 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, and the overall maintenance of the tank, all influence quenching.



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The volume of oil contained in a quench tank is important for controlling the overall rate of temperature rise after quenching. The type (Fig. Nos. 5 – 6) and design of the equipment play an important role in the ability of the quench system to perform properly. The common “rule of thumb” for oil quench tanks is one gallon of oil per pound of steel. Quench tanks that utilize less than this ratio must be designed with highly effective agitation systems. Of course, having a large volume of oil is no guarantee of success if the quench tank design is inadequate for the job.

Figure 5
Typical Dual Chamber Horizontal Vacuum Oil Quench Furnace
(Photograph Courtesy of SECO/WARWICK Corporation)



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Figure 6
Typical Vertical Vacuum Oil Quench Furnace
(Photograph Courtesy of Vac-Aero International)



Distortion and Cracking

Another important advantage of oil quenching is that it minimizes the tendency to cause distortion and cracking. While 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.



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Fast oils that are highly agitated tend to produce the highest rates of distortion while slow (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 concerns regarding oil quenching is the presence of water in the quench oil. It is dangerous since, on quenching, it will form steam resulting in a 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 a sensitivity in the range of 0.2 -0.3%) 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.

Relationship of Physical Properties of Quenching Oils to their Performance

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. Below is a listing of various test procedures and insights into the meaning of the results obtained. ^[12]

- **Viscosity.** As discussed earlier, quenching performance is dependent on the viscosity of the oil. Due to degradation (the formation of sludge and varnish), oil viscosity changes 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 that is ignitable but does not continue to burn when

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- 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 by-products 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 an oil degrades, it forms acidic by-products. The amount of these by-products 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. 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 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 (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 life.



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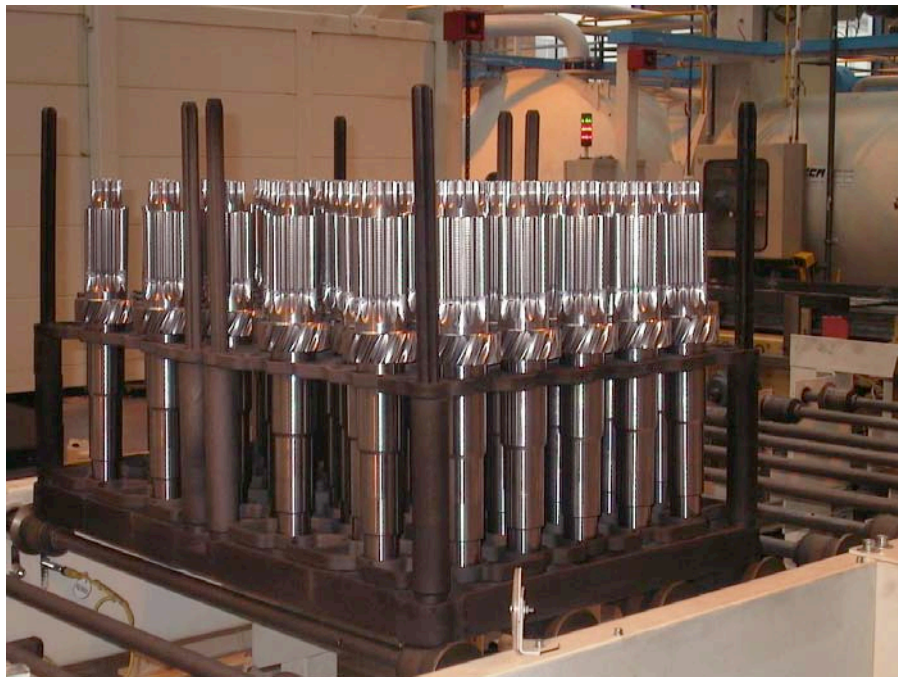
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- **Accelerator Performance.** Induction coupled plasma (ICP) spectroscopy is one of the most common methods for the analysis of quench oil additives. When additives (such as metal salts) are used as quench rate accelerators, their effectiveness can 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.

Application Examples

Truck transmission shafts (Fig. 7) of AISI 8620 material are oil quenched to develop the required properties. A core hardness of 25 HRC at mid-radius is achieved by quenching in 195 °F (90 °C) oil. The effective case depth developed was 0.50” (1.2 mm). Load weight was 1000 lbs (450 kg).

Figure 7 ^[13]
Load of Truck Transmission Shafts



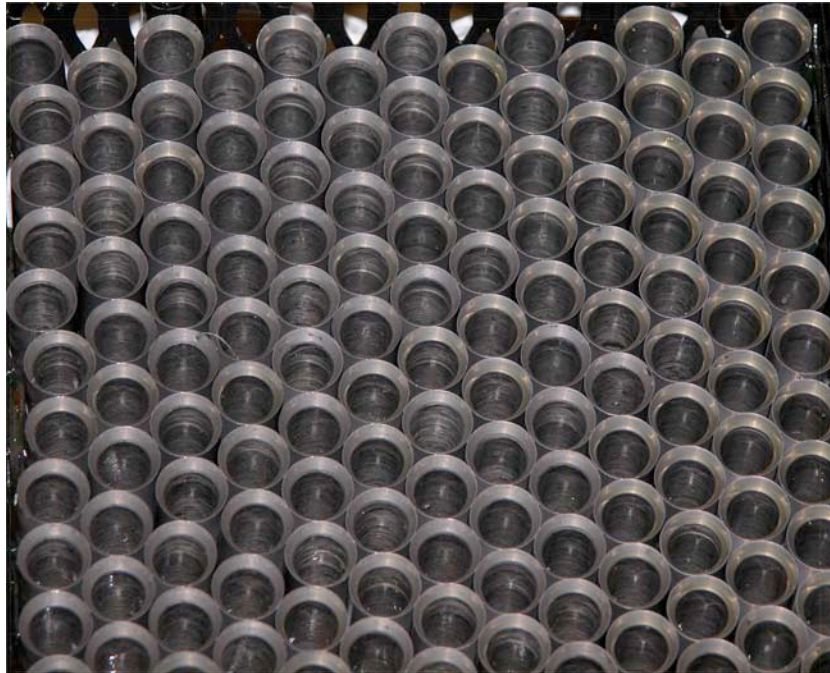


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Die cutting punches (Fig. 8) of AISI 1018 material are oil quenched after vacuum carbonitriding to develop the required properties. A core hardness of 25 HRC at mid-radius is achieved by quenching in 100 °F (38 °C) oil. The effective case depth developed was 0.003” (0.76 mm). Load weight was 150 lbs (68 kg).

Figure 8 ^[14]
Load of Die Cutting Punches





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Large marine transmission gears (Fig. 9) of 8620 weighing 64 lbs (29 kg) each are oil quenched to develop a surface hardness of 62 – 64 HRC and a core hardness greater than 25 HRC (typically 40 – 44 HRC). Load weight is approximately 1000 lbs (450 kg). The effective case depth is 0.045” – 0.065” (1.14 – 1.65 mm).

Figure 9 ^[15]
Marine Transmission Gears





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Locking pliers (Fig. 10) of 12L14 material are oil quenched after a combination vacuum (copper) brazing followed by vacuum carbonitriding cycle. Load weight is approximately 650 lbs (300 kg). The effective case depth is 0.010" – 0.015" (0.254 – 0.381 mm).

Figure 10 ^[14]
Locking Pliers





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Drive flange gears (Fig. 11) of 4620 weighing 4 lbs (1.8 kg) each are oil quenched to achieve a surface hardness of 61 – 63 HRC and a core hardness greater than 28 HRC. Load weight is approximately 780 lbs (350 kg). The effective case depth is 0.030” – 0.035” (0.076 – 0.89 mm).

Figure 11 ^[15]
Drive Flange Gears





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Pinion gears (Fig. 12) of 8822 weighing 1.7 lbs (0.75 kg) each are oil quenched to develop a surface hardness of 59 – 62 HRC and a core hardness greater than 35 HRC. Load weight is approximately 800 lbs (360 kg). The effective case depth is 0.025” – 0.035” (0.63 – 0.89 mm).

Figure 12 ^[15]
Marine Transmission Gears



Recent Developments

One example of the advances occurring today in quenching is in the area of sensor technology. In most heat-treating shops occasionally sample the oil, check the temperature and level and look to see that the oil agitators are rotating. These are operator dependent quality methods. Since heat removal from the parts is due in large part to the fluid flow activity, sensors have been designed to measure the heat transfer inside a quench bath ^[16]. They measure the difference between the temperature of the quenchant and a higher temperature produced by a constant power heat source inside the sensor



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itself so quench flow is monitored by measuring the heat produced by the sensor and the convective heat transferred to the quenchant.

These types of units are examples of tools that can be used to monitor quench intensity in the quench tank in real time as a quality control tool. This ensures that the quench conditions are known and corrective action or repairs can be implemented before more parts are quenched.

Summary

Oil quenching is a common practice in vacuum furnaces designed for this purpose. 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 end-use.

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Next Time: Part twenty-one of this series begins a discussion on various vacuum applications by discussing the hardening process.

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