Molten salt is an ideal medium for interrupted quenching processes. Nitrate-based salt, the most widely used, blankets the quench temperature range of 150 to 595°C (300 to 1100°F).

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The wide operating temperature range and other characteristics of molten salts make them ideally suited to low-distortion quenching of iron, steel, and tool steel. Thanks to advances in salt quality, pollution abatement, and material handling, salt bath quenching is more efficient and economical than ever before.

A properly selected salt can be used for processes such as martempering and austempering in a single bath. Excellent thermal stability and tolerance for contaminants make salt quenching systems almost maintenance-free. And baths can provide satisfactory performance for many years simply by adding salt to replace that which is dragged out.

The focus of this article is on nitrate-based salts for quenching iron and steel parts, since this constitutes the largest portion of molten salt quenching applications. Chloride-based salts used for quenching tool steels also are briefly covered.

Controlling distortion
Quenching in water, brine, a water-based polymer solution, or oil can cause distortion and in some cases, nonuniform hardness or cracks. This tendency increases with increasing hardenability of the steel. Causes of distortion usually can be traced to uneven or nonuniform quenching, thermal stresses, and phase transformation stresses.

These causes can be largely overcome by interrupting the quenching process with a salt bath. This is achieved by rapidly cooling the parts from the austenitizing temperature to a point above the martensite formation or start temperature (M_s). The parts are held at that temperature for a specified time, and then cooled (usually in air) to room temperature. The interruption in quenching considerably reduces thermal stresses and, thereby, distortion. Processes in this category are martempering, austempering, and their variations.

For most carbon and low-alloy steels, the temperature at which the quench is interrupted is usually in the 175 to 370°C (350 to 700°F) range. A nitrate-based salt is the best choice here. A chloride-based salt is selected for high-alloy and tool steels, where the interruption temperature range is 480 to 705°C (900 to 1300°F).

Continued
Molten salt's advantages

The most distinct advantage of salt quenching is its wide operating temperature range — 150 to 595°C (300 to 1100°F) for a typical nitrate-based salt, which is unmatched by any other quench medium.

The quenching mechanism also is considerably different. In most liquid quenchants, heat extraction occurs throughout the three stages of vapor, boiling, and convection. Salt quenching has no vapor phase, so problems with vapor phase barriers are avoided. Most of the heat extraction is by convection. As a result, distortion is minimized and the hardness achieved is more uniform and consistent.

Other important advantages of salt quenching include:

- Quench severity can be controlled by varying the temperature, agitation, and water content of the salt bath.
- Productivity in salt quenching is high because parts rapidly attain temperature equalization.
- Due to excellent thermal and chemical stability, salt baths can provide consistent quenching performance for many years. Ordinarily, the only maintenance required is to replace salt that is dragged out.
- Salt can be easily washed off with water and recovered for reuse. Choosing to recover salt eliminates disposal and reduces operating costs.
- The same salt bath can be used for tempering.

Limitations: Salt has to be used above its melting point of about 150°C (300°F), and, because of its oxidizing nature, combustible or incompatible materials should definitely be kept out of the salt bath to avoid the possibility of violent reactions.

Salt used to present safety and environmental problems, but technology for dealing with them is now well developed and they are no longer considered deterrents to its use.

Quench process variables

Quench severity is a measure of the ability of a quenchant or quenching system to extract heat from a test specimen, part, or workload. Among the various methods, cooling curve analysis is the most useful tool for measuring quench severity, as well as for understanding the quenching mechanism and studying the effects of quench variables.

Typical cooling and cooling rate curves for a nitrate-based salt bath are shown in Fig. 1. The cooling rate curve clearly shows that no vapor phase is present and that the cooling rate varies uniformly with temperature. This is in sharp contrast to oil, polymer, or brine quenchants.

The main operating variables in salt quenching processes are temperature, agitation, water content, and residence time.

Temperature: Although primarily governed by the Ms temperature of the steel, there is some room for varying salt bath temperature. In general and regardless of medium, the lower the bath temperature, the faster is the cooling rate. In salt bath quenching, the effect of this variable is marginal, but it still can be optimized. The recommended practice is to start at the lowest temperature and incrementally increase it until the best combination of hardness and distortion is obtained.

In some cases, salt bath temperature can be manipulated to achieve remarkable results. For example, large sections can be martempered by first quenching in water or brine for a short time and then transferring them to a salt bath. This helps achieve higher hardness to a greater depth. Similarly, low-hardenability steels can be austempered by using two salt baths, the first bath at a lower temperature than the second. With such manipulations, cooling curves satisfy a key requirement of quenching: avoiding the pearlite nose of the TTT (time-temperature-transformation) diagram.

In most production setups, heat input to the salt from the work exceeds heat losses by radiation, necessitating a cooling system to maintain bath temperature within the required range. Solutions include external cooling fins and/or a heat exchanger inside the bath.

Agitation: The effect of bath agitation is greater than that of temperature. Increasing agitation results in a considerable increase in quench severity, as shown in Fig. 2. The cooling rate plotted on the vertical axis is the average of the cooling rates determined at every 55.5°C (100°F) interval between 650 and 260°C (1200 and 500°F). This temperature range is chosen because it spans the pearlite

![Typical cooling and cooling rate curves for a nitrate-based molten salt bath at 253°C (495°F). The cooling rate curve shows that no vapor phase is present and that the cooling rate varies uniformly with temperature. No agitation or water addition. Average cooling rate from 650 to 260°C (1200 to 500°F): 33.6°C/s (60.5°F/s). Ref. 1.](image1)

![Increasing agitation results in considerable increase in quench severity (cooling rate). Temperature of the low-melting-point salt bath: 175°C (350°F). The cooling rate plotted on the vertical axis is the average of the rates determined at every 55.5°C (100°F) interval between 650 and 260°C (1200 and 500°F). Ref. 1.](image2)
Agitation can be provided by propeller-type agitators or by a pump with a draft tube. As many as four propellers with single or dual impellers may be required, depending on bath size. If a pump is used, salt flow from bottom to top is preferable.

In some instances, vigorous agitation increases distortion considerably. Thus, mild agitation is often used in combination with a water addition to minimize distortion without sacrificing hardness. Agitation must be maintained while water additions are made.

Like temperature, agitation also can be manipulated to advantage. An example: austempering of thin-walled parts such as cylinder liners. To minimize thermal shock, agitation is not used during the first 15 to 20 seconds of the quench. It is then initiated automatically and continued until completion of the standard austempering operation. This procedure helps minimize distortion without adversely affecting mechanical properties.

**Water content**: A small addition of water to a salt bath produces a significant increase in its quench severity, as shown in Fig. 3. Note that the combination of agitation (50 cm/s [100 ft/min]) and a water addition (~3%) increases quench severity three-fold, compared with that of a nonagitated, “dry” salt bath. The practical result is a significantly increased surface hardness and depth of hardness. Achieving similar results with increased agitation alone would cause greater distortion. Water content of the bath typically varies from 2 to 3% at 150°C (300°F) to about 0.5% at 350°C (600°F).

Safety considerations dictate that water is added only to a bath having sufficient agitation — never to a still bath — and it should be added very slowly, as a fine stream or spray, directly into the vortex created by agitation. Instead of fresh water, salt solution from the washing operation or low-pressure steam also can be used. Note that agitation also helps disperse the water uniformly throughout the bath.

A fringe benefit of water addition is that it lowers salt’s freezing point, further increasing its working range. For example, a 1% water addition lowers the freezing point by 11°C (20°F), while 2% water lowers it by 19°C (35°F).

**Residence time**: The time that parts remain in the bath depends on steel composition, section thickness, quench severity, and the process being performed. In martempering, a few minutes are generally sufficient for temperature to equalize throughout the section. A water addition significantly reduces this time, increasing productivity. Too long a residence time may produce a microstructure other than martensite and affect its quench severity. And separation and removal of barium chloride from a nitrate-based salt bath is difficult. But if parts are austenitized in a barium-chloride-free, chloride-based bath, then a nitrate-based quenching salt should be chosen.

**Salt selection considerations**: The selection of a quenching salt is governed primarily by the austenitizing temperature, austenitizing medium, and quenching temperature. There are two main categories of quenching salts: nitrate-based and chloride-based. Depending on working ranges of 150 to 995°C (300 to 1100°F) and 425 to 705°C (800 to 1300°F), respectively. Hydroxide- and carbonate-based salts are not recommended for quenching or austenitizing, because these materials adversely affect surface chemistry.

A nitrate-based salt is suitable for quenching from austenitizing temperatures up to 900°C (1650°F). Quenching from a higher temperature is not recommended unless parts are small and well separated. Even then, parts should first pass through a neutral salt bath maintained at a lower temperature. A chloride-based salt is recommended when quenching from high austenitizing temperatures like 980 to 1315°C (1800 to 2400°F), as are required for tool steels.

If parts are austenitized in an atmosphere, air, or vacuum furnace, either type of salt can be used for quenching, depending on the required quench temperature. But if the austenitization process is carried out in a salt bath, the following selection criteria are recommended:

- When quenching from a barium-chloride-based neutral salt bath, a chlorate-based quenching salt is the appropriate choice. If nitrate-based quenching salt is used, barium chloride carryover thickens the bath, affecting its quench severity. And separation and removal of barium chloride from a nitrate-based salt bath is difficult. But if parts are austenitized in a barium-chloride-free, chloride-based bath, then a nitrate-based quenching salt should be chosen.

- If quenching is to follow carburizing or carbonitriding in a cyanide-based salt bath, safety is the primary concern. Quenching directly from a cyanide-based bath into a nitrate-based bath causes a violent explosion and must never be done. The safe practice is to transfer parts from the cyanide bath into a neutral salt bath and then quench them into a nitrate-base bath. This practice causes a gradual buildup of cyanide in the neutral salt bath — cyanide content should not exceed 5% for safe operation. Alternatively, parts can be air cooled, washed to completely remove cyanide salts that would carryover, austenitized in a neutral salt bath, and quenched.

- If carburizing is carried out in a cyanide-free salt bath, then direct quenching into a nitrate-based salt bath can be performed without risking an explosion.

**Nitrate-based salts**: Once you’ve settled on the type of quenching salt, selection of a specific salt within that category is also important. Nitrate-based salts are either binary or ternary mixtures of nitrate and nitrite of sodium and potassium. There are nearly a dozen compositions available, varying primarily in melting point.
point, but also by degree of purity and physical form.

**Melting point:** Nitrate-based salts have melting points that span the 135 to 330°C (275 to 630°F) temperature range. Selection of a specific salt depends on the lowest temperature at which it will be operated and its melting point. The difference between the two temperatures should be at least 55°C (100°F). Selecting a salt having the lowest possible melting temperature, however, offers several advantages:

- It provides the flexibility to change quench severity simply by changing its operating temperature.
- The same salt bath can be used for a high-temperature process as well as a low-temperature process, including tempering.
- Dragout losses could conceivably be low, since salt would take longer to freeze after the parts are removed from the bath.

**Product form:** Quenching salts were formerly available only in granular or crystalline form, which caused dusting when added to a quench bath, and also caused frothing and scum. Quench severity was adversely affected until the bath stabilized. These problems can now be avoided by selecting salt in briquette or flake form.

Once molten, all nitrate-based quenching salts have nearly the same physical properties (Table 1).

**Salt system maintenance**

Salt quenching systems are generally maintenance-free, due primarily to salt's excellent thermal stability and ability to tolerate contaminants. A salt bath can provide consistently satisfactory performance for many years simply by adding new or recovered salt to replace that dragged out. The amount of dragout depends on the mass and configuration of the parts and the fixtures or conveying system, but generally is in the range of 50 to 100 g/m² (1 to 2 lb/100 ft²).

**Contaminants:** If general cleanliness guidelines are not followed, soil, scale, metallic debris from parts, or other foreign materials may get into the bath and accumulate over time. Fine contaminants remain in suspension due to bath agitation, and when they exceed about 0.5%, quench severity decreases.

Formation of carbonate is another concern, particularly if salt is used at a high temperature. Within its solubility limit, carbonate does not substantially affect quench severity. But if its level exceeds the solubility limit, quench speed begins to drop.

If the austenitizing medium is a neutral salt bath, chloride gradually builds up in the quench bath due to carryover. Here, too, quench severity is little affected within the solubility limit but will start to decline if the limit is exceeded.

These contaminants, both soluble and insoluble, can be at least partially removed by desludging the bath. The best method is to reduce bath temperature as much as possible so as to lower the solubility limits. This helps in precipitating excess carbonate and chloride. Agitation and heating are turned off and the contaminants are allowed to settle to the bottom of the salt quench tank, from where they are removed.

Contaminants can also be continuously removed, if the furnace is equipped with a separating chamber. Contaminated salt is circulated through this chamber, where the contaminants settle to the bottom and are periodically removed.

Continuous filtration is another method of removing insoluble contaminants. In this method, salt is continuously passed through filter baskets, which are periodically removed and emptied.

**Water content:** If addition of water to the salt bath is a common practice, its content should be periodically checked and adjusted to ensure the required quench severity. Water content can be determined by weighing a small salt sample both before and after drying it in a laboratory oven at 370 to 425°C (700 to 800°F). Water content generally varies from 2 to 3% at 150°C (300°F) to about 0.5% at 315°C (600°F).

The rate of water addition depends on the size and temperature of the bath, the amount of work being quenched, and the desired quench severity. It also depends on the evaporative loss. It has been observed that about 1 to 2% water evaporates in 24 hours from a bath at 205°C (400°F).

Such observations in combination with periodic hardness checks help in adjusting the rate of water addition. A recently introduced water controller eliminates manual adjustments by automatically maintaining water content at a preset level.

**Melting point:** This needs to be checked only occasionally, since it changes very little over time. A significant increase in melting point may indicate gross contamination or thermal breakdown of the salt, usually due to accidental overheating. In either case, depending upon the salt analysis, partial or complete replacement may become necessary. In case of overheating, its causes should be investigated and properly rectified.

**Salt bath safety:** Quenching salt is nonflammable and relatively nontoxic, and no toxic or hazardous fumes are given off by a salt quench bath. However, there are potential safety concerns related to the relatively high bath temperature, bath overheating, and incompatible materials. Precautions that should be taken to help ensure safe salt bath quenching are listed in Table 2.

**Post-quenching operations**

After quenching, parts are immersed in an agitated hot water bath, where most of the salt is dissolved. This helps remove salt from blind holes, crevices, ledges, and other recesses. Parts are then rinsed in a hot water spray to wash off any remaining salt. High-pressure steam can also be used.

Racks, baskets, fixtures, and the conveyor system should be thoroughly washed and dried before they reenter the austenitizing furnace or salt bath. Otherwise, carry-back of quenching salt can contaminate the austenitizing medium and cause pitting or decarburization of parts. It can also damage the furnace interior.

**Salt recovery:** Salt from wash water can be recovered by evaporation of its water content. What results is molten

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**Table 1 – Physical properties of nitrate-based quenching salt**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity</td>
<td>1.84–1.92</td>
</tr>
<tr>
<td>Specific heat</td>
<td>0.35–0.40</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>0.571 W/m·K (0.33 Btu·ft/h·ft²·°F)</td>
</tr>
<tr>
<td>Heat transfer coeff.</td>
<td>4.5–16.5 kW/m²·K (800–2900 Btu/ft²·°F)</td>
</tr>
<tr>
<td>Dragout rate</td>
<td>50–100 g/m² (1–2 lb/100 ft²)</td>
</tr>
</tbody>
</table>

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Table 2 — Guidelines for safe salt bath quenching*

<table>
<thead>
<tr>
<th>Area of concern</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidental burns</td>
<td>Although quenching salt is nonflammable and relatively nontoxic, concern for personnel safety arises due to the temperature at which it is used. Adequate precautions should therefore be taken to protect operating personnel from accidental burns. Personnel safety can be enhanced further by totally enclosing the entire salt quenching operation.</td>
</tr>
<tr>
<td>Fume exhaust</td>
<td>Although no toxic or hazardous fumes are given off by a salt quench bath, good exhaust around the bath is highly recommended. This is particularly helpful when charging with fresh salt and during the quenching operation, especially when the bath contains water.</td>
</tr>
<tr>
<td>Dry parts</td>
<td>Parts, fixtures, and conveyors should be absolutely dry and free of moisture, oil, or other liquid when entering the quench bath. Otherwise, rapid vaporization of such liquid may cause a sudden expulsion of molten salt, which could result in injury and damage.</td>
</tr>
<tr>
<td>Adding water</td>
<td>If water is added to increase quench severity, it should be trickled or atomized onto the surface of the bath. It should never be introduced below the surface or under pressure. Otherwise, spattering or eruption of molten salt can occur.</td>
</tr>
<tr>
<td>Extinguishing fires</td>
<td>Water sprinklers should not be installed in or around any molten salt system. There should be a clearly visible sign warning that water or any liquid-type extinguisher should not be used in case of fire. Carbon dioxide-type extinguishers and sand are the best means of fighting and containing fires in the vicinity of molten salt baths.</td>
</tr>
<tr>
<td>Overheating</td>
<td>The salt bath should be protected from accidental overheating by installing audio/video alarms that signal when temperatures exceed a preset limit. If the temperature of a nitrate-based salt continues to rise beyond 595°C (1100°F), it may break down, and reactions between the products of the breakdown and the bath container could result in leakage of salt.</td>
</tr>
<tr>
<td>Freezing and remelting</td>
<td>A steel wedge should be inserted to the bottom of the bath and maintained in position until salt is solidified. When remelting, heat salt slowly and remove the wedge as soon as the salt surrounding the wedge melts.</td>
</tr>
<tr>
<td>Incompatible materials</td>
<td>Combustible and incompatible materials such as cyanide salt should never be introduced into a chloride-based salt quench bath to avoid possible violent reactions which may result in an explosion.</td>
</tr>
<tr>
<td>Storage</td>
<td>Salt should be stored in well-marked, closed containers, which should be kept in a dry location segregated from incompatible materials such as cyanide salts.</td>
</tr>
</tbody>
</table>

* Applies to both nitrate- and chloride-based quenching salts, except where noted. However, concern for personnel safety is greater for chloride-based salt due to its higher operating temperature and toxicity. Chloride-based salt also rapidly absorbs moisture.

Chloride-based salts

Chloride-based quenching salts are eutectic mixtures of chlorides of calcium, barium, sodium, and potassium. Although there are many compositions in this category, the two most commonly used have melting points of 455°C (850°F) and 495°C (920°F) with respective working ranges of 495 to 675°C (925 to 1250°F) and 540 to 705°C (1000 to 1300°F). Here too, the lower melting salt has clear advantages over the higher melting composition. These salts have a specific gravity of 2.24 to 2.40 and a specific heat of about 0.27.

Maintenance: Quenching from a high-temperature salt bath at 980 to 1315°C (1800-2400°F) brings barium-chloride-rich salt into the quenching salt. This upset changes the composition and increases the melting point. The imbalance can be corrected by periodic additions of “melting point reducer,” a salt specifically formulated for this purpose. Frequently, after the initial meltdown, only appropriate additions of melting point reducer are required. The additions also restore quench bath fluidity.

In contrast to a nitrate-based salt, it is undesirable to have moisture or water in a chloride-based salt. However, due to the hygroscopic nature of this salt, it is probable that some moisture may be present in a freshly melted salt bath. Most of the moisture evaporates out in a few hours.

“Drying” of the bath can be speeded up by using the “aluminum sheeting” technique. Sheets of aluminum are placed in the bath and examined after 20 minutes. If the surface has darkened or has a heavy white layer on it, it means that moisture is still present in the bath and has reacted with the aluminum. The sheet is then cleaned by shot blasting or pickling, dried, and again immersed in the bath. The process is repeated until the aluminum no longer reacts with the bath (no dark or white layer is produced). The aluminum sheeting technique also helps remove metallic contaminants.

In some instances, a black material may be seen floating on or near the surface of freshly melted chloride-based salt. This is the thermal degradation product of the organic anti-caking agent used in raw-material production, and can accumulate to form a crust. The scum or crust usu-
The purpose of Corrosion: Fundamentals, Testing, and Protection is to help engineers and designers understand corrosion so that they can solve corrosion problems and prevent future ones. The coverage of the volume has been completely revised to ensure that it is the most comprehensive, practical, and up-to-date resource available. Each article is indexed to other appropriate sections of the ASM Handbook, and each provides a road map to the thousands of individual bibliographical references that were used to compile the information.

**Salt selection in a nutshell**

In summary, Molten salt is an ideal quenching medium for interrupted quenching processes using a nitrate-based salt in the 150 to 595°C (300 to 1100°F) temperature range, and a chloride-based salt in the 425 to 705°C (800 to 1300°F) range. Most quench requirements are met by nitrate-based salt, and selection of the lowest-melting-temperature composition is recommended. The salt’s quench severity can be adjusted to suit any process by altering temperature, agitation, or quenching medium. And excellent thermal stability means that consistent quenching performance can be maintained for many years simply by adding new or recovered salt to replace that which is dragged out. Spent salt is safe to work with and easy to recover or dispose of.

**References**


**High-temperature solutions**

Alloy Engineering (AE) has added to its heat and corrosion-resistant products by purchasing the fabrication business of TEI/Rolock. “This acquisition enhances our ability to provide engineered solutions to high-temperature challenges.” says president Lou Petonovich. AE now offers atmosphere generators and ammonia dissociators in addition to its other heat treating products. 

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