The latest quenchants are less hazardous in the workplace and friendlier to the environment.

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In tune with tightening environmental and health and safety legislation, new liquid quenchants continue to be developed. New products like polymer and vegetable oil quenchants not only reduce the environmental and safety concerns of quenching oils, but also offer performance, cost, and production advantages. This article also addresses: how more environmentally friendly raw materials and base oils are now being used; how new quenchants reduce hazards in the workplace; how quenchant product life can be increased; and how to incorporate recycling technology in a heat treat facility.

Need for new quenchants

Starting with the Industrial Revolution, mankind has polluted the environment and continues to do so. Rising from a population of 1.2 billion people in 1900 to about 6 billion in 2000 and on to a staggering 39 billion estimated for 2030, earth cannot withstand much more pollution. And, certainly, heat treaters have been called do their part, too, and act now. Fortunately, industry as a whole and the heat treatment industry in particular is now paying greater attention to using environmentally friendly materials. One of the areas of focus is quenching media. (Quenching, in fact, is now one of the subjects being researched by the Center for Heat Treat Excellence, in which various heat treating industry groups are now working together to meet environmental and other concerns — see sidebar).

Over the years a great variety of fluids have been used for quenching, including water, brine solutions (generally 8-10%), caustic solutions (generally 3%), other salt solutions (nitrites/nitrates), molten salts, molten metals, animal oils, fish oils, mineral oils, and polymer quenchants. Most commonly used today are mineral oils and polymer quenchants. Determining which are the most environmentally friendly and which quenchants are now being developed for the 21st Century has been the focus of technological initiatives of suppliers like Houghton Durferrit.

Using safe and friendly materials

Environmental considerations begin when quenching fluids are formulated. Today, they must be formulated using materials that are not only environmentally friendly, but also safe to handle and process in the workplace. At Houghton, all the raw materials used are assessed in accordance with the Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA). When a choice of raw materials exists, those having the lowest risk are utilized. In addition, solvent-refined heavily hydro-treated base oils are used to provide finished prod-

Fig. 1 — Quenching of carburized transmission shafts into 25% PAG polymer. Photo, courtesy Houghton.
In practice, polymer quenchants are more cost effective to use. They cost less initially, have reduced drag-out, top off mainly with water to compensate for evaporation losses, and have low viscosity.

The CHTE: Government, academia and industry working together to ensure safe, effective heat treating products

Houghton International and other corporate leaders in the heat treating industry joined the Metal Treating Institute, Heat Treating Network, and ASM Heat Treating Society to launch the Center for Heat Treating Excellence (CHTE) in 1999. The CHTE, located at the Worcester Polytechnic Institute (WPI) in Worcester, MA, is dedicated to the advancement of the heat treating industry through collaborative research and development.

One of the four key areas selected by the CHTE for research is quenching. In its current research project, “Quenching: Control of the Process,” the CHTE research team and industry focus group seek to develop a thorough understanding of the performance of quenching fluids as a function of the fluids physical properties and part orientation. They will use this information to develop proprietary computational fluid dynamics software to be used to predict the performance of quenching fluids.

Key to developing the fluid dynamics software will be building a database for heat transfer coefficients for steels and aluminum alloys in a wide variety of quenching fluids. These heat transfer coefficients will be evaluated as a function of metal surface temperature, fluid temperature, agitation, metal surface finish, and part orientation. The CHTE will get this data from a combination of literature search, review of current processes, and proprietary research.

“Heat treating has long been an art, and like art, it has not been fully appreciated by the masses,” said Joe Warchol, V.P. Technical for Houghton International, a founding member of the CHTE. “The CHTE will try to turn this ‘art’ into more of a science, which will hopefully result in more widespread acceptance and appreciation for the benefits and applications for heat treating in industry today. By developing more accurate heat treating methods, the process will be more predictable.”

The CHTE will make a significant contribution to our industry. As more of industry understands and adapts heat treating technology, there will be more jobs available in this field. With more jobs available, there will be more educational resources available to turn out engineers with a greater understanding of the intricacies of heat treating. That, in turn will lead to better, more environmentally safe products being developed in the future.

“We truly believe that an investment in the CHTE is an investment in the future,” said Warchol. “Everyone stands to benefit from their work — industry, government, academia, the economy and the environment. We will continue to do everything we can to advance this effort.” For more information on the CHTE, call Prof. Diran Apelian at 508-831-5592 or visit http://www.wpi.edu/+mpi.

Advantages of polymer quenchants

- Lower cost
- Reduced drag-out
- Reduced evaporation losses
- Lower viscosity
- Lower environmental impact

In practice, polymer quenchants are more cost effective to use. They cost less initially, have reduced drag-out, top off mainly with water to compensate for evaporation losses, and have low viscosity.
quenchants, two major problems still remain: water contamination and smoke, plus fume and fire hazards (Fig. 2). Fortunately, these can be overcome by the use of nonflammable polymer quenchants. Polymer quenchants are nontoxic, which makes them safer to work with and easier to dispose of than traditional quenchants. They are also nonflammable, improving working conditions because there is no chance of fire, smoke, and fume during quenching. (Fig. 3) Eliminating this fire hazard results in additional savings in operations. There are lower insurance premiums. There is also no longer any need for protection equipment (e.g., dampers, gas curtains, etc.), making component entry into the quenchant less critical.

In practice, polymer quenchants are more cost effective to use. They cost less initially, have reduced drag-out, top off mainly with water to compensate for evaporation losses, and have low viscosity. Polymer quenchants also have a high specific heat, leading to reduced temperature rise during quenching, higher production rates, and lower cooler-rating requirements. Lastly, no cleaning is required before tempering, eliminatingalkali or solvent degreasing.

Polymer quenchants possess several technical advantages over mineral oils. First, quenching speed is flexible, which enables heat treaters to select a cooling rate that matches their specific requirements. It also allows leaner alloy steels to be used and results in better physical properties on some steels. Secondly, polymer quenchants improve tolerance to water contamination, as quenching speed is not influenced significantly compared with quenching oils. With all of these advantages, it is obvious that heat treaters should consider polymer quenchants whenever possible.

Polymer quenchant developments
Numerous polymer quenchants with varying characteristics are available, and how well they do their job depends on the application. Organic polymers used as a basis for water-based quenching fluids include: polyvinyl alcohol (PVA), polyalkylene glycol (PAG), acrylate (ACR), polyvinyl pyrrolidone (PVP), and polyethylene oxazoline (PEO).

Polyvinyl-alcohol-type quenchants have been replaced by polyalkylene glycols due to their greater flexibility and ease of control and maintenance. Available for many years, PAGs are still widely used in a variety of applications, including immersion quenching of steel, induction hardening and spray quenching, and the solution treatment of aluminum alloys. ACR, PVP, and PEO all represent the latest developments in polymer quenchant technology, providing more oil-like quenching characteristics than polyalkylene glycols. They are generally used for higher hardenability steel applications.

Selection of polymer type in relation to other quenching media can be illustrated schematically by considering a sensitivity band of steel hardenability and section complexity. Fig. 4 illustrates how ACR, PVP, and PEO extend the range of polymer applications to steels of higher hardenabilities and thinner sections than PAGs, while still maintaining the environmental benefits of polymer quenchants.

Comparing the cooling rate of various quenching fluids at 300°C (570°F), a typical martensite start (M_s) temperature for engineering steels demonstrates this point further (see Table). Shown graphically for agitated conditions in Fig. 5, PAG exhibits cooling rates between those of water and normal-speed oil, while ACR promotes slower cooling rates at 300°C (570°F) than normal-speed oil.

Future quenchant technology
While quenching fluids used today include water, salt, mineral oils (hot and cold), and polymer solutions, tomorrow’s quenchants could be based on vegetable oil. Initial interest in vegetable oil evolved following increased environmental concerns regarding the use of mineral-oil-based hydraulic fluids in mobile equipment, such as agricultural machinery and chain saws in forestry applications. Furthermore, more stringent controls and regulations are being enforced to minimize ground and water contamination, for example, the provision for double-walled bulk storage tanks for mineral-oil-based products. One of the targets in ASM Heat Treat Society’s declared vision for the year 2020 is “more environmentally friendly quenching media.” Not surprisingly, vegetable oils are prime contenders.

Multiple advantages apply to vegetable oil-based quenchants. First and foremost, they are readily biodegradable, meaning they are greater than 75% biodegradable. As determined by the European CEC Test, the biodegradability of vegetable oil is 80 to 100%, in contrast to 10 to 40% for min-

<table>
<thead>
<tr>
<th>Quenchant</th>
<th>Cooling rate at 300°C, °C/s</th>
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<tbody>
<tr>
<td>Water</td>
<td>80–140</td>
</tr>
<tr>
<td>Polyalkylene glycol (PAG)</td>
<td>40–60</td>
</tr>
<tr>
<td>Acrylate (ACR)</td>
<td>15–25</td>
</tr>
<tr>
<td>Polyvinyl pyrrolidone (PVP)</td>
<td>15–25</td>
</tr>
<tr>
<td>Polyethyl oxazoline (PEO)</td>
<td>15–25</td>
</tr>
<tr>
<td>Normal-speed mineral oil</td>
<td>10–20</td>
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</tbody>
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![Fig. 2 — Fire hazard during oil quenching. Photo, courtesy Houghton.](image-url)
eral oil. These quenchants also possess lower toxicological hazard potential, as well as high flash and boiling points. Last, but not least, they are a renewable resource with consistent and expandable supply.

Despite these significant advantages, there are concerns with vegetable oil quenchants, including: hydrolytic stability, oxidative instability, low-temperature properties, and a narrow viscosity range. Cost is also up to two times more than mineral oil. In order to be a viable alternative, quenchants must have even heat extraction, be stable during use, be usable for a long or indefinite time, be environmentally friendly, and achieve the desired quenching performance. Called Bio-Quench, a new quenching alternative based on vegetable oil has been developed by Houghton Durferrit to satisfy these needs.

**Demonstrative results**

Quench rate tests compare the quenching characteristics of the new vegetable oil quenchant with those of a moderately accelerated quenching oil (Fig. 6). These differences should provide a more efficient and uniform quench with less distortion. Increasing the operating temperature of the vegetable oil quenchant (via an enhanced anti-oxidation package) has no effect upon the maximum cooling rate. Minimal reduction of the cooling rate at lower workpiece temperatures is also apparent (Fig. 7).

Over a two-and-a-half year period, the vegetable oil quenchant went through a production trial in a sealed-quench furnace at a commercial heat treating facility. Treated steels included: oil-hardening tool steels, carburized and through-hardening alloy steels, and low/medium carbon steels. Additionally, component sections with various thicknesses — 0.4 to 100 mm (0.02 to 3.9 in.) — were treated using a 60 to 105°C (140 to 220°F) bath temperature. During the trial, the customer reported that hardness, mechanical properties, dimensional stability, and surface appearance were all within specification.

In a second production trial at a U.S. bearing manufacturer, the new vegetable oil quenchant was used at an elevated temperature of 120°C (250°F) in a continuous furnace for the quenching of SAE 52100 bearing rings. During a twelve-month trial period, component hardness and dimensional stability were directly compared with
results obtained using hot quenching oil at an equivalent temperature. While component hardness and roundness were comparable, component taper was found to be significantly less than with the conventional hot quenching oil (Fig. 8). Additional advantages of lower drag-out (approximately 60% less than hot oil), higher flash point, the product being biodegradable, nontoxic, and a renewable resource, prompted the customer to use it in a second system.

Comparative quenching characteristics for the vegetable oil quenchant and a conventional hot quenching oil are shown in Fig. 9. In the most recent trial, the vegetable oil quenchant was used for more than six months by a major American contract heat treater. In just one sealed-quench furnace, it has been successfully used at operating temperatures up to 70°C (160°F) as a cold quenching oil and up to 230°C (450°F) as a hot quenching oil, indicating a greater flexibility than mineral-oil-based products. Following this success, trials are being conducted in Europe.

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References