

Quenching Oils and Water-Miscible Polymer Quenchants – Selection Criteria and Influencing Parameters



Influences and Selection Criteria.

Fluids have a particular significance in the area of heat treatment. The influence of a quenching medium is directly reflected in the transformation of the metal and is thus decisive to the success of the heat treatment. Quenching or cooling characteristics affect the metallurgical structure, the properties of the material and thus the subsequent application of the component. Knowledge about the characteristics and influences of quenchants help to avoid costly and always time-consuming heat treatment faults. Processes optimized to the demands of components always increase the efficiency and profitability of heat treatment plants.

The following information should give users an overview of the normal quenching fluids and their quenching characteristics. As successful heat treatment not only requires the correct quenchant to be used but also that various process parameters such as fluid temperature, flow rates and concentration are of fundamental importance, these are also dealt with.

Up to now, many heat treatment processes used quenching oils to influence hardness. However, water-miscible, polymer quenchants are increasingly being used which can significantly moderate quenching characteristics. The advantages of these water-miscible products lie in their non-flammability, lower misting and thus less pollution of workshop environments but also that they save resources. For this reason, polymer quenchants have been in the focus of developments in recent years. The principal disadvantage of polymer quenchants up to now was their relatively abrupt cooling so that typical „oil-hardened“ components could only be quenched in high polymer concentrations and only to a limited degree. A new generation of polymer quenchants with very moderate cooling rates now allow typical oil applications to be performed economically at low concentrations.

1. Quenching Oils

1.1. Types of Quenching Oils and Their Characteristics

In principle, quenching oils are divided into three categories:

a) Bright Quenching Oils

Bright quenching oils are not accelerated oils based on conventional solvent extracts. Bright quenching oils are normally used for the quenching of simple-geometry, high-alloy materials.

Above all, they are used for the heat treatment of components which are not prone to warping.

b) High Performance Quenching Oils

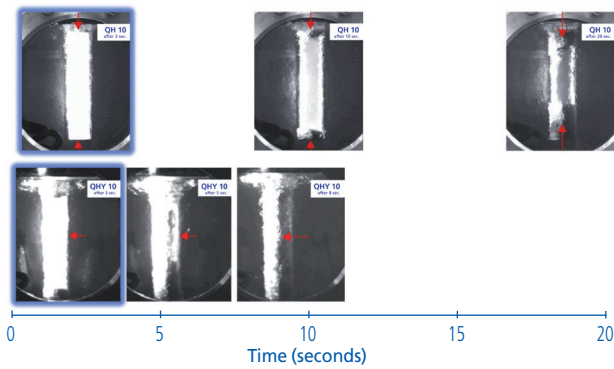
High-performance quenchants are high-additive quenching oils which contain agents to accelerate component wetting. Depending on their quality, high-performance quenching oils can either be based on solvent extracts or hydrocracked components. High performance quenchants are widely used because their optimized wetting properties make them suitable for distortion-prone parts.

c) Synthetic High Performance Quenching Oils

These synthetic ester-based quenchants are recommended for particularly distortion-prone components. Apart from sustainability considerations, these high-performance quenchants offer a series of other advantages.

The wetting properties of synthetic, high-performance quenchants differ greatly from conventional high-performance quenching oils. The excellent wetting ensures that vapour layer which covers the whole surface of the component during quenching breaks down very quickly. As a result of this almost simultaneous wetting of the entire surface of the component, temperature gradients during quenching are significantly reduced and distortion caused by uneven cooling thus avoided. Figure 1 shows a direct comparison between the wetting characteristics of a conventional quenching oil and a synthetic, high-performance quenchant of the same viscosity grade. (Top: Mineral oil-based, high-performance quenching oil / Bottom: Synthetic, High-performance quenchant.

Figure 1:
Trials by the IWT in Bremen (2010 / 11) – austenitic steel
(L200/D50mm/60 °C/the same flowing conditions)



1.2. Properties of the Different Base Oils

As already mentioned in 1.1., three different types of base oils are used for the manufacture of quenching oils:

- a) Conventional solvent extracts (Group 1)
- b) Hydrocracked oils (Group 3)
- c) Synthetic esters

These three types of oils differ greatly, above all, the high-temperature relevant physical characteristics of “evaporation loss” and “flashpoint”. Although both solvent extracts and hydrocracked cuts are mineral oils and in the same viscosity grades, both groups display greatly differing characteristics.

Table 1:
Physical Properties of base oils of similar viscosity grades

Base oil type	Kinematic viscosity at 40 °C [mm ² /s]	Evaporation loss [%] Noack – 250 °C	Flashpoint [°C]
Conventional solvent extracts	11	70	160
Hydrocracked oils	11	60	170
Synthetic esters	11	19	204
Conventional solvent extracts	42	15	216
Hydrocracked oils	41	7	236
Synthetic esters	34	1,3	302

1.3. Influence of Viscosity on the Cooling Characteristics of High-Performance Quenchants

Figure 2:
Cooling rate in relation to viscosity
Oil temperature: 60 °C, without circulation
Test sample: ISO / DIN 9950, Inconel 600, ø 12.5 mm

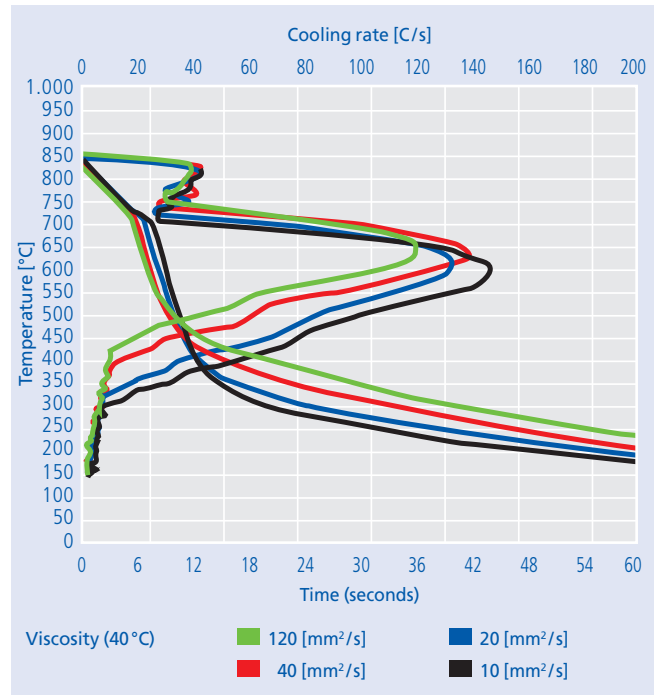


Figure 2 shows the differences in cooling rates as viscosity increases within a grade of high-performance quenchants. Selecting a higher viscosity always lowers the cooling rate, i.e. higher viscosity delays the reaching of the temperature range in which martensite is formed.

1.4. Applications of Quenching Oils in Relation to Viscosity and Quality

In 1.1 to 1.2, the most important and generally-applicable differences between the quenching oil types and the base oils are dealt with. Based on the characteristics shown, the following basic principles apply to all applications:

- The higher the viscosity in a series of quenching oils and the higher the "quality" of the oil in equiviscous comparison, the higher the flashpoint and the lower the evaporation losses.
- The better the "quality" of the quenching oil, the better the wetting properties.
- The higher the viscosity in a series of quenching oils, the slower the cooling progression down to the temperature range where martensite is formed.

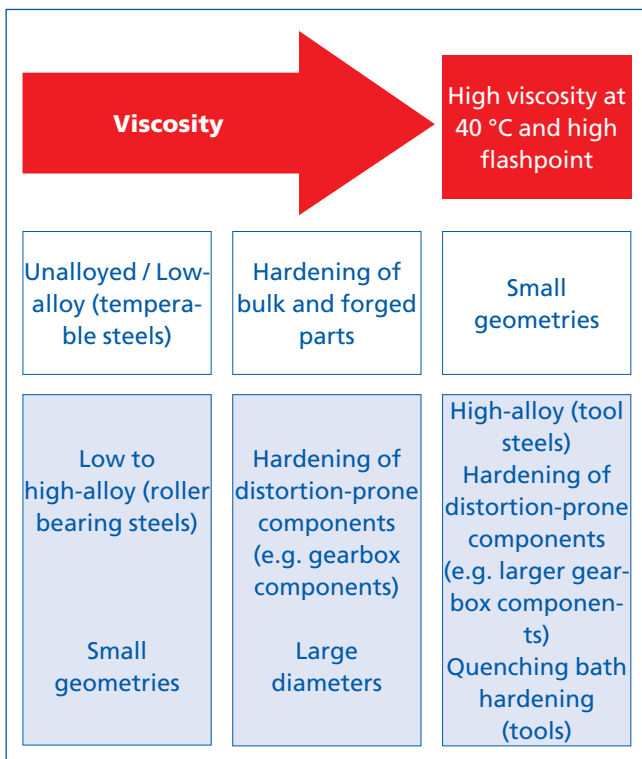
Combined with the quenching principle of hardenable materials

„As fast as necessary but as slow as possible“

the most suitable quenching oil can be selected for the metal and process in question.

To illustrate this better, Figure 3 shows applications of high-performance quenchants in relation to viscosity.

Figure 3: Applications of high-performance quenchants in relation to viscosity



2. Polymer Quenchants

2.1. Polymer Types and their Characteristics

The use of polymer solutions is based on the premise that cracking and brittleness caused by too abrupt cooling can be avoided.

In addition, the distortion which often accompanies heat treatment process can be reduced by selecting the optimum polymer quenchant and by matching process parameters to the components being treated.

The majority of water-miscible polymer quenchants on the market are based on polyalkylene glycols (PAG) and polyvinyl pyrrolidones (PVP). Both types of polymers reduce the very abrupt cooling of water alone. Both types of polymers reduce the cooling rate by forming a vapour film on the surface of the hot component. However, the two polymers form very different types of films. Structurally, PAGs and PVPs offer greatly differing quenching characteristics.

a) Polyalkylene Glycols (PAG)

As opposed to PVPs, polyalkylene glycols have a turbidity point. Depending on molecule chain length, this lies between 63 °C and 85 °C. PAGs are regarded reversibly insoluble. Characteristic for PAGs is the calm collapse of the vapour phase, which as a whitish film, dissolves back into the polymer solution when the temperature fall below the turbidity point. The collapse of the vapour phase can be registered acoustically as a light "hissing".

Figure 4: PAG-collapse of the vapour phase (concentration > 20 %)



However, very high fluid concentrations are necessary to achieve a longer stable vapour phase with this type of polymer. Another disadvantage of this type of polymer is the limited "softening" of the quenching rate in the temperature range where martensite is formed (range in question: 200 – 350 °C).

For this reason, PAG-based products for certain materials and at economical concentrations oil are not a viable alternative to the milder quenching rates offered by quenching.

PAG applications:

- Induction hardening
- Flame hardening
- Bath quenching of unalloyed and low-alloy steels
- Quenching of aluminium alloys after solution annealing

b) Polyvinyl Pyrrolidones (PVP)

Polyvinyl pyrrolidones form a significantly more “stable” vapour phase. The duration of the vapour phase is largely dependent on concentration. Apart from a more stable vapour phase, PVP-based solutions also offer a considerably milder cooling rate in the martensitic temperature range. This milder cooling at lower temperatures is also found in viscosity-related oil hardening. This has resulted in the trend to use PVP quenchants as direct substitutes for quenching oils.

A characteristic of the vapour phase of these products is the sudden and “bubbly” collapse of the polymer film over the whole of the component’s surface. The effect can also be registered as a noticeable “bursting” of the polymer film.

Figure 5:
PVP collapse of the vapour phase



PVP applications:

- Bath quenching of low to high-alloy steels
- Oil hardened steels in the drop-forging industry
- Quenching while formed components are still hot

2.2. Parameters for the Setting of Quenching Characteristics

2.2.1. Concentration

Increasing the concentration of a polymer quenchant fundamentally lowers its quenching rate characteristics. This polymer-related “slowing” of the quenching rate is achieved by influencing the vapour phase and the quenching characteristics in the martensitic temperature range. **Figures 6 and 7** show the different, concentration-dependent cooling curves of both polymer types.

Figure 6:
PAG-based quenchant – concentration-dependent cooling rates
5–15 % in tap water, fluid temperature 35 °C, with circulation
Test sample: ISO / DIN 9950, Inconel 600, \varnothing 12.5 mm

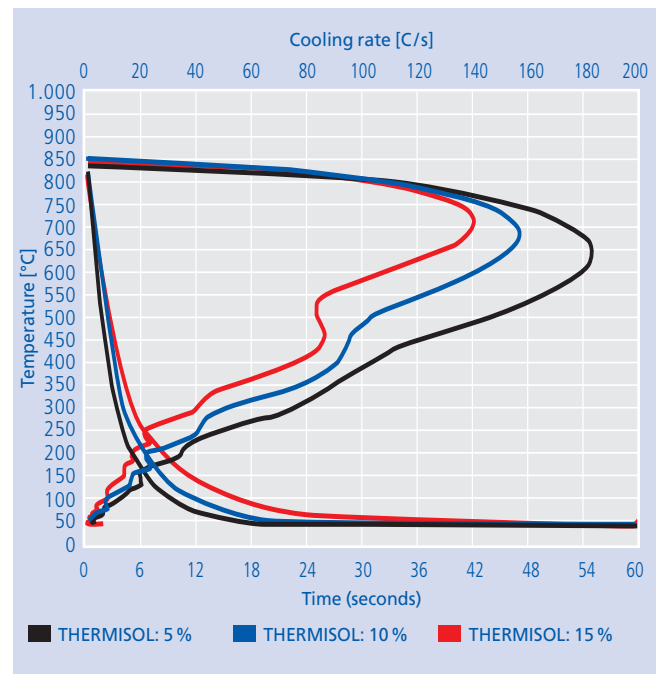
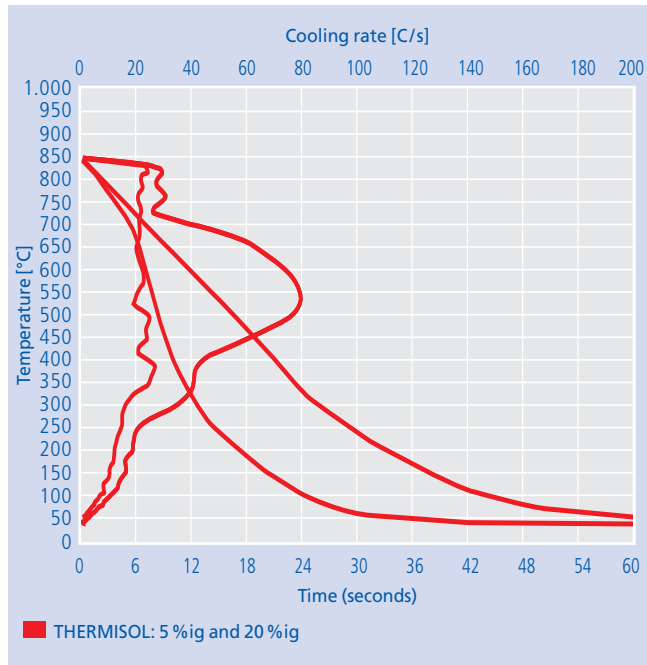


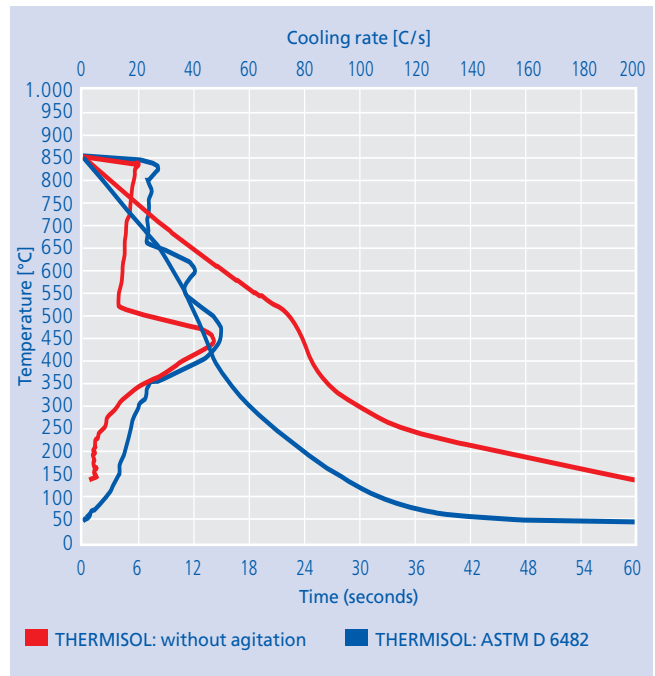
Figure 7:
PVP-based quenchant – concentration-dependent cooling rates
5 % and 20 % in tap water, fluid temperature 35 °C,
with circulation
Test sample: ISO / DIN 9950, Inconel 600, ø 12.5 mm



2.2.2. Circulation

Directing the quenchant flow towards the component significantly accelerates the cooling rate. A strong quenchant flow shortens or even eliminates the vapour phase formation. The cooling rate increases as the flow increases. The effect of directing the quenchant flow is shown with the example of a PVP-based medium in **Figure 8**.

Figure 8:
PVP-based quenchant – the influence of directing the flow
10 % in tap water, fluid temperature 35 °C,
Test sample: ISO / DIN 9950, Inconel 600, ø 12.5 mm



Note

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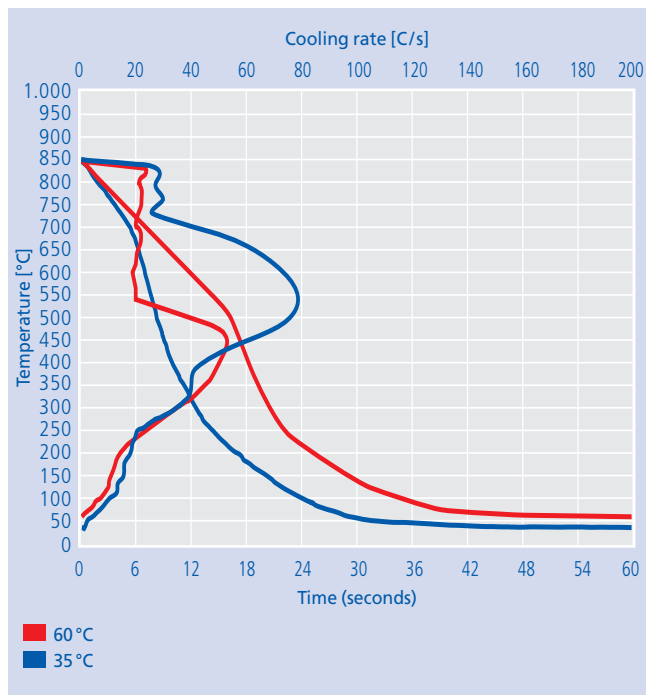
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2.2.3. Temperature

Increasing the temperature of the fluid can significantly lower the cooling rates of polymer solutions. The temperature range of PAG-based media is very restricted because of the reverse-solubility effect. The normally recommended application temperature is 25 – 40 °C.

On the other hand, PVP-based polymer quenchants can be used at a wider range of temperatures. These products can be used at temperatures of up to 70 °C without hesitation. An example of the influence of temperature is shown in **Figure 9**.

Figure 9:
PVP-based quenchant – Influence of temperature
5 % in tap water, with circulation



2.3. New Polymer Quenchants as Fully-Fledged Substitutes for Oil

As detailed in 2.1., PVP-based polymer quenchants are often used these days for materials which are commonly thought to be only suitable for oil hardening because of the mild cooling rates they offer in low-temperature applications. However, the behaviour of the vapour film has been seen as problematic. The vapour phase duration is also limited with common PVP-based quenchants. As a result, relatively high concentrations are needed for the treatment of high-alloy materials. When the vapour phase collapses, the polymer film comes into contact with the component's surface. PVP-based products developed in the past often left hard deposits on component surfaces. In addition, these products suffered from PVP-typical "bursting" of the vapour phase causing inconsistent cooling and thus some very serious problems in practical applications. Some extreme cases have been reported where the violent bursting of the vapour phase caused large forged components to be thrown off the batch frames.

These are also reasons for the development of a new generation of polymer quenchants.

The new generation of polymer quenchants are products which replicate the "oil-like" cooling of PVPs. The disadvantages of previous generations have been eliminated by certain modifications. This results in similarly even cooling as is the case with PAG-based products. In addition, developments significantly improved the effects of a long vapour phase. With these polymer quenchants, it is now also possible to treat high-alloy materials at application concentrations of about 5 – 7 %. Other positive side-effects are the significant reductions in polymer deposits and lower drag-out losses. Depending on the concentration, even tool steel applications are possible.

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