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Standard Guide for Evaluation of Aqueous Polymer Quenchants¹

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1. Scope

1.1 This guide provides information, without specific limits, for selecting standard test methods for testing aqueous polymer quenchants for initial qualification, determining quality, and the effect of aging.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 ASTM Standards:²

- D95 Test Method for Water in Petroleum Products and Bituminous Materials by Distillation
- D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
- D892 Test Method for Foaming Characteristics of Lubricating Oils
- D1744 Test Method for Determination of Water in Liquid Petroleum Products by Karl Fischer Reagent (Withdrawn 2000)³
- D1747 Test Method for Refractive Index of Viscous Materials
- D1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)
- D2624 Test Methods for Electrical Conductivity of Aviation and Distillate Fuels
- D3519 Test Method for Foam in Aqueous Media (Blender Test)
- D3601 Test Method for Foam In Aqueous Media (Bottle Test)

¹ This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.L0.06 on Non-Lubricating Process Fluids.

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² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

³ The last approved version of this historical standard is referenced on www.astm.org.

- D3867 Test Methods for Nitrite-Nitrate in Water
- D4327 Test Method for Anions in Water by Suppressed Ion Chromatography
- D5296 Test Method for Molecular Weight Averages and Molecular Weight Distribution of Polystyrene by High Performance Size-Exclusion Chromatography
- D6482 Test Method for Determination of Cooling Characteristics of Aqueous Polymer Quenchants by Cooling Curve Analysis with Agitation (Tensi Method)
- D6549 Test Method for Determination of Cooling Characteristics of Quenchants by Cooling Curve Analysis with Agitation (Drayton Unit)
- E70 Test Method for pH of Aqueous Solutions With the Glass Electrode
- E979 Practice for Evaluation of Antimicrobial Agents as Preservatives for Invert Emulsion and Other Water Containing Hydraulic Fluids
- E2275 Practice for Evaluating Water-Miscible Metalworking Fluid Bioresistance and Antimicrobial Pesticide Performance

3. Terminology

3.1 Definitions of Terms Specific to This Standard:

3.1.1 *austenite, n*—solid solution of one or more elements in face-centered cubic iron (gamma iron) and unless otherwise designated, the solute is generally assumed to be carbon **(1)**.⁴

3.1.2 *austenitizing, n*—forming austenite by heating a ferrous alloy into the transformation range (partial austenitizing) or above the transformation range (complete austenitizing). When used without qualification, the term implies complete austenitizing **(1)**.

3.1.3 *aqueous polymer quenchant, n*—a solution containing water, and one or more water-soluble polymers including poly(alkylene glycol), poly(vinyl pyrrolidone), poly(sodium acrylate), and poly(ethyl oxazoline) **(2, 3)** and additives for corrosion and foam control, if needed.

3.1.4 *biodegradation, n*—the process by which a substrate is converted by biological, usually microbiological, agents into simple, environmentally acceptable derivatives. **(4)**

⁴ The boldface numbers in parentheses refer to the list of references at the end of this standard.

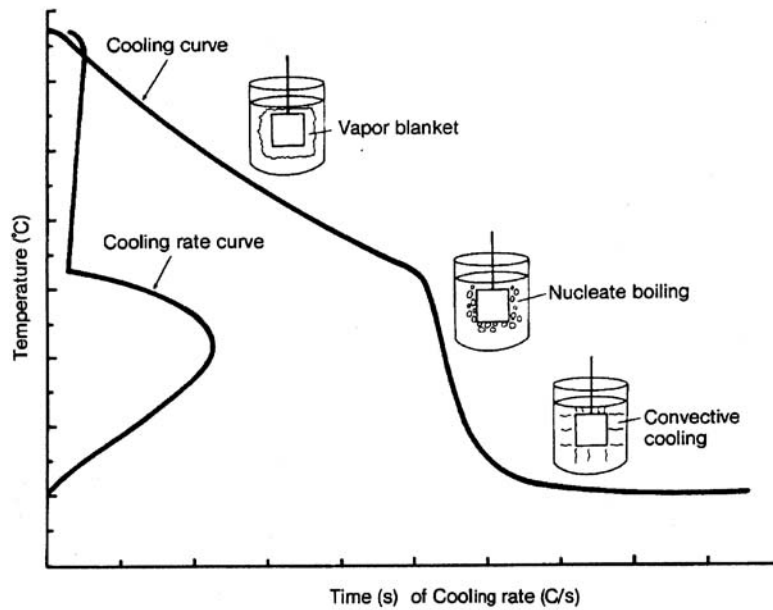


FIG. 1 Cooling Mechanisms of the Quenching Process

3.1.5 *biodeterioration, n*—loss of product quality and performance and could be regarded as the initial stages of biodegradation (see 3.1.4), but in the wrong place at the wrong time, that is when the product is stored or in use. (4)

3.1.6 *convective cooling, n*—after continued cooling, and the interfacial temperature between the cooling metal and the aqueous polymer quenchant is less than the boiling point of the water in the quenchant solution at which point cooling occurs by a convective cooling process. For convective cooling, fluid motion is due to density differences and the action of gravity and includes both natural motion and forced circulation (1, 5). This process is illustrated in Fig. 1.

3.1.7 *cooling curve, n*—a graphical representation of the cooling time (t)—temperature (T) response of the probe such as that shown in Fig. 1. (5)

3.1.8 *cooling curve analysis, n*—the process of quantifying the cooling characteristics of a quenchant medium based on the temperature versus time profile obtained by cooling a pre-heated metal probe assembly (see Fig. 2) under specified conditions which include: probe alloy and dimensions, probe and bath temperature, agitation rate, and aqueous polymer quenchant concentration.

3.1.9 *cooling rate curve, n*—obtained by calculating the first derivative (dT/dt) of the cooling time-temperature curve as illustrated in Fig. 1. (5)

3.1.10 *dragout, n*—solution carried out of a bath on the metal being quenched and associated handling equipment. (1)

3.1.11 *full-film boiling, n*—upon initial immersion of hot steel into a quenchant solution, a vapor blanket surrounds the metal surface resulting in full-film boiling as shown in Fig. 1. (5)

3.1.12 *nucleate boiling, n*—when the vapor blanket surrounding the hot metal collapses and a nucleate boiling process occurs as illustrated in Fig. 1. (5)

3.1.13 *quenchant medium, n*—any liquid or gas, or mixture, used to control the cooling of a metal to facilitate the formation of the desired microstructure and properties. (1)

3.1.14 *quench severity, n*—the ability of a quenchant medium to extract heat from hot metal. (6)

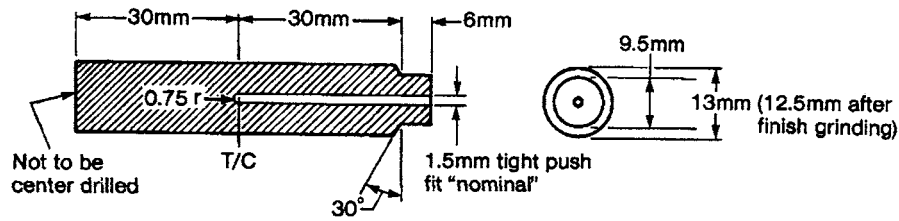
3.1.15 *transformation temperatures, n*—characteristic temperatures that are important in the formation of martensitic microstructure of steel including: A_{e1} —equilibrium austenitization phase change temperature; M_s —temperature at which transformation of austenite to martensite starts during cooling and M_f —temperature at which transformation of austenite to martensite is completed during cooling. (1)

4. Significance and Use

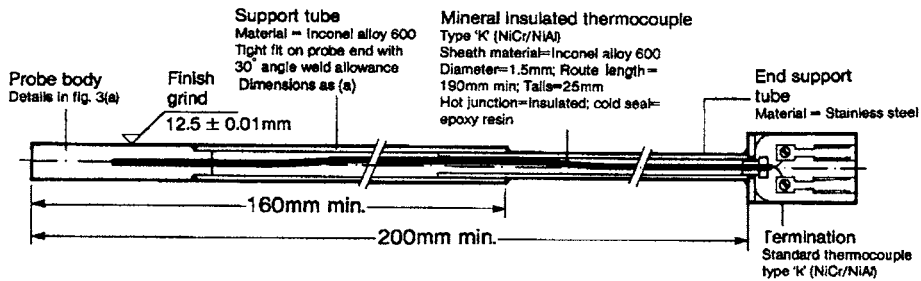
4.1 The significance and use of each test method will depend on the system in use and the purpose of the test method listed under Section 7. Use the most recent editions of the test methods.

5. Quenching Process

5.1 *Aqueous Polymer Quenchant Cooling Mechanisms*—Upon initial immersion of a heated metal into a solution of an aqueous polymer quenchant, an insulating polymer film, which controls the heat transfer rate from the hot metal into the cooler quenchant solution, forms around the hot metal which is separated by a vapor film (Fig. 3) (7) for the quenching process in a poly(alkylene glycol) quenchant. The overall heat transfer mediating properties of the film are dependent on both the film thickness (a function of polymer concentration) and interfacial film viscosity (a function of polymer type and bath temperature). The timing of film formation and subsequent film rupture and removal is dependent on the film strength of the polymer, agitation (both direction and mass flow), and turbulence of the polymer solution surrounding the cooling metal.



(a) Probe details



(b) General assembly

NOTE 1—From Wolfson Engineering Group Specification, available from Wolfson Heat Treatment Centre, Aston University, Aston Triangle, Birmingham B4 7ET, England, 1980.

FIG. 2 Schematic Illustration of the Probe Details and Probe Assembly

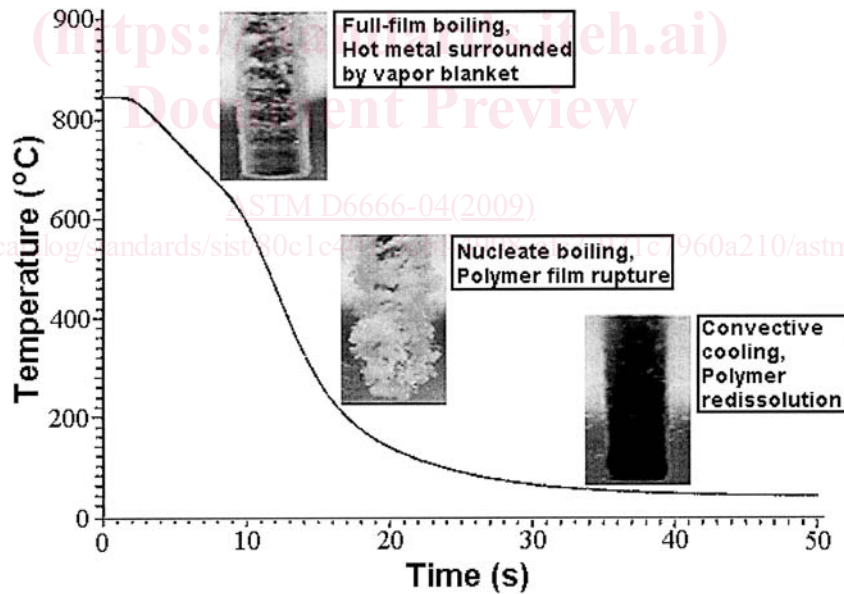


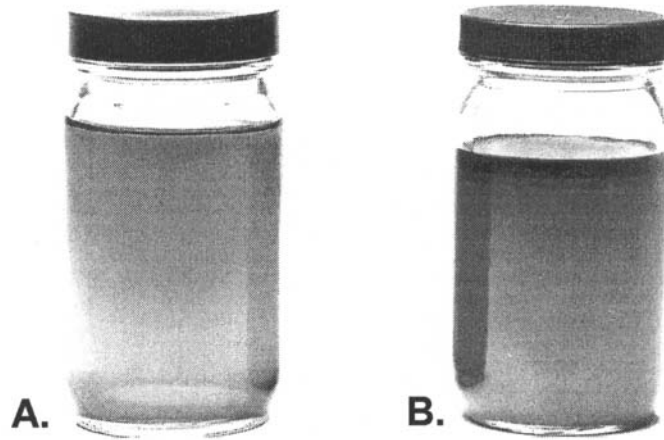
FIG. 3 Illustration of the Three Phases of Cooling

5.1.1 The cooling process that occurs upon initial immersion of the hot metal into the aqueous polymer quenchant is full-film boiling. This is frequently referred to as the vapor blanket stage. Cooling is slowest in this region. When the metal has cooled sufficiently, the polymer film encapsulating the hot metal ruptures and a nucleate boiling process results. The temperature at the transition from full-film boiling to nucleate boiling is called the Leidenfrost temperature. Cooling is fastest

in this region. When the surface temperature of the cooling metal is less than the boiling temperature of water, convective cooling results. All three cooling mechanisms are superimposed on a cooling curve and illustrated in Fig. 3. (7)

6. Sampling

6.1 *Sampling*—Flow is never uniform in agitated quench tanks. There is always variation of flow rate and turbulence



(A) New aqueous polymer quenchant solution.
 (B) Used quenchant solution with oil contamination (see separated upper layer).

FIG. 4 Sample of Oil Contaminated Aqueous Polymer Quenchant

from top to bottom and across the tank. This means there may be significant variations of particulate contamination including carbon from the heat treating process and metal scale. For uniform sampling, a number of sampling recommendations have been developed.

6.1.1 *Sampling Recommendations:*

6.1.1.1 *Minimum Sampling Time*—The circulation pumps shall be in operation for at least 1 h prior to taking a sample from the quench system.

6.1.1.2 *Sampling Position*—For each system, the well-mixed sample shall be taken from the same position each time that system is sampled. The position in the tank where the sample is taken shall be recorded.

6.1.1.3 *Sampling Values*—If a sample is taken from a sampling valve, then sufficient quenchant should be taken and discarded to ensure that the sampling valve and associated piping has been flushed before the sample is taken.

6.1.1.4 *Effect of Quenchant Addition as Make-Up due to Dragout*—It is important to determine the quantity and frequency of new quenchant additions, as large additions of new quenchant solution will have an effect on the test results, in particular, the cooling curve. If a sample was taken just after a large addition of new quenchant, this shall be taken into consideration when interpreting the cooling curve for this sample.

6.1.1.5 *Sampling Containers*—Samples shall be collected in new containers. Under no circumstances shall used beverage or food containers be used because of the potential for fluid contamination and leakage.

7. Recommended Test Procedures

7.1 *Performance-Related Physical and Chemical Properties:*

7.1.1 *Appearance*—Contamination of aqueous polymer quenchants by such fluids as hydraulic or quench oils may result in a non-uniform quench with thermal gradients sufficient to cause cracking or increased distortion, or possible staining, of the metal being quenched. The simplest test (and an excellent test) is to examine the appearance of an aqueous

polymer quenchant in a clear glass container, such as a bottle. A sample of an oil-contaminated fluid is illustrated in Fig. 4. (7) However, if the oil readily separates from the aqueous polymer quenchant solution (Fig. 4), it may be removed by skimming. On the other hand, oil may form a milky-white emulsion which is not readily reclaimed by heat treaters.

7.1.1.1 Other problems that are easy to identify visually include carbon and sludge contamination which often results in cracking problems. Metal scale contamination is often identifiable by its magnetic properties by placing a magnet on the outside of the bottle next to the scale and determining if the scale exhibits any attraction for the magnet. Carbon, sludge, and scale may be removed from the quenchant by filtration or centrifugation. Alternatively, the quenchant mixture may be allowed to settle, the quenchant solution pumped off, and the separated solids then removed by shoveling. The amount of insoluble suspended solids or tramp oils may be quantified by a modification of Test Method D1796 where the aqueous quenchant is centrifuged without further dilution as described in the method. The amount of tramp oil in the quenchant is determined from the insoluble liquid layer at the top of the centrifuge tube and the volume of the insoluble sediment is taken from the bottom of the centrifuge tube.

7.1.2 *Refractive Index, (Test Method D1747)*—One of the most common methods of monitoring the concentration of aqueous polymer quenchants formulated using poly(alkylene glycol) copolymers is refractive index. As Fig. 5 (7) shows, there is a linear relationship between quenchant concentration and refractive index. The refractive index of the quenchant solution is determined using an Abbé refractometer (Test Method D1747) equipped with a constant temperature bath. Although the refractive index could potentially be used at any temperature within the control limits of the constant temperature bath, typically either 40°C or 100°F is selected.

7.1.2.1 Although refractive index is a relatively simple and a rapid method for determination of polymer quenchant concentration, it is not sensitive to low levels of polymer degradation and it is often significantly affected by solution contamination.

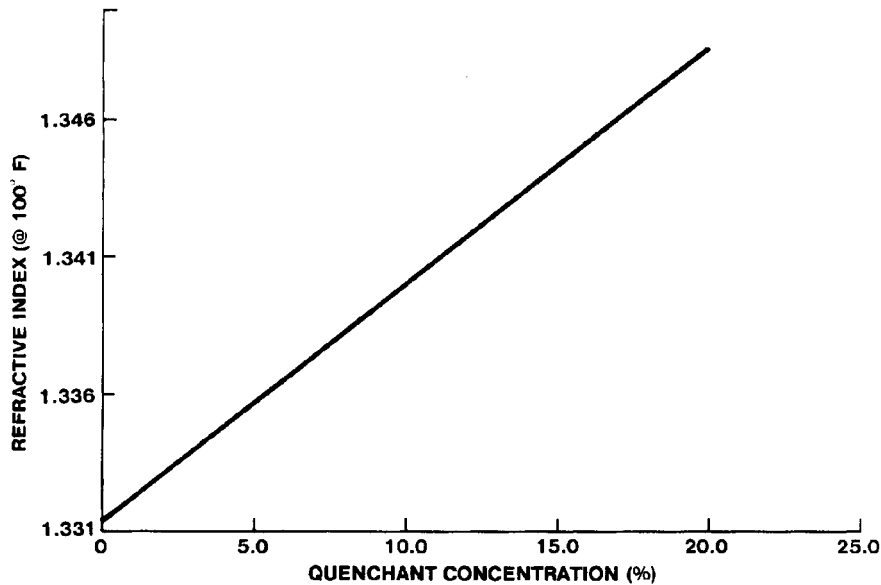


FIG. 5 Illustration of the Linear Relationship Between Refractive Index and Concentration

NOTE 1—Refractive index is typically unsuitable for aqueous polymer quenchant formulations with polymers with molecular weights greater than 50 000 to 60 000 because the total concentration is relatively low. Small changes in polymer concentration may result even from normal use which impart significant process effects but the corresponding variation in refractive index may not be detectable.

NOTE 2—Although it is most desirable to use an Abbé refractometer because of its sensitivity, this is only practical in a laboratory environment. In the heat treating industry, for tankside monitoring and control, a temperature-compensated handheld refractometer (similar to the one illustrated in Fig. 6) is used. The hand-held refractometer is self-compensated for temperatures between 60 and 100°F. Although there are various models available, the most common models provide arbitrary refractive index readings in Brix units over a 0 to 30° range. Typically, the smallest scale that can be read directly is in divisions of 0.2° as shown in Fig. 7. A concentration-refractive index curve obtained by a hand-held refractometer is shown in Fig. 8. (7) Hand-held refractometers are available whose scale readings correlate directly to the concentration of the polymer quenchant being used. This is particularly convenient for industrial tank-side use. However, since refractive index varies with contamination (such as dissolved salts) that may accumulate from evaporation of hard water, the actual quenchant concentration shall be verified periodically by other methods, and appropriate correction factors applied. In this case, the refractometer reading multiplied by the correction factor equals actual concentration.

7.1.3 *Viscosity, (Test Method D445)*—Aqueous polymer quenchant viscosity depends on the quenchant concentration and temperature as shown in Fig. 9. (7) Viscosity is readily determined using a Cannon-Fenske tube (see Fig. 10), stopwatch and constant temperature bath as described in Test Method D445.

7.1.4 *Comparison of Concentration by Refractive Index and Viscosity*—A useful procedure for monitoring variations in aqueous polymer quenchants, particularly poly(alkylene glycol) quenchants, is to compare the difference (delta) in the quenchant concentration value obtained by refractive index (C_R) and viscosity (C_V). (8)

$$\Delta = C_R - C_V \quad (1)$$

If the absolute value of the difference in delta is greater than 6-8, the source of this difference, contamination or degradation, should be determined.

7.1.5 *Water Content (Test Methods D95 and D1744)*—Aqueous polymer quenchants are composed of water, a water soluble polymer and an additive package to provide corrosion inhibition, foam control, and so forth. Therefore, determination of water content is necessary to establish the concentration of the quenchant in a way that is relatively insensitive to polymer degradation.

7.1.5.1 Water content may be determined by Karl Fisher analysis (Test Method D1744). The advantage of Karl Fisher analysis is that it is a direct measure of water content, whereas refractive index and viscosity are both indirect measurements that are substantially affected by either contamination (refractive index) or degradation (viscosity). In some cases, interferences may arise with Karl Fisher analysis and an alternative procedure is necessary such as distillation from toluene or some other water-insoluble solvent (Test Method D95), or evaporation.

7.1.6 *pH Determination, (Test Method E70)*—The performance of an aqueous polymer quench bath may be critically dependent on its pH. The pH of a quenchant solution may be determined by Test Method E70. There are many excellent commercially available sources of pH meters and glass electrodes. The choice of the instrument will be primarily affected by the desired precision of measurement. Electrodes used for pH measurement are designed for specific pH ranges and temperature; therefore, the solution pH and temperature shall be considered when the electrodes are selected for use.

7.1.6.1 For example, solution pH values of >10 for quenchants used in aluminum heat treating applications may be disastrous in view of potential caustic corrosion processes which may occur. The relatively simple determination of pH of



(A) Application of the aqueous polymer quenchant to the refractometer.
 (B) Visual reading of the refractometer scale to determine refractance value.

FIG. 6 Typical Hand-Held Refractometer

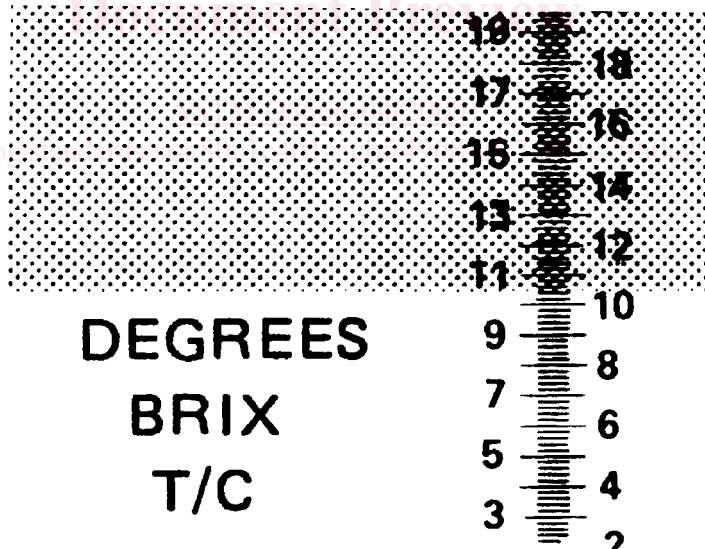


FIG. 7 Illustration of the Degrees Brix Refractive Index Scale Used for the Hand-Held Refractometer

an aqueous polymer quenchant may provide significant insight into potential polymer degradation, corrosion inhibitor depletion, and contamination.

7.1.6.2 Polymer degradation is typically accompanied by the formation of acidic by-products which will decrease pH. Some polymer quenchants, particularly when containing sodium nitrite as a corrosion inhibitor, cannot be used below pH 7.0 without increasing the polymer degradation rate.

7.1.6.3 Some aqueous polymer quenchants contain amine or amine/fatty acid mixtures as corrosion inhibitors. If a substantial decrease in the concentration of these inhibitors occurs, a decrease in pH will result. Thus, pH determination may be a useful indicator of corrosion protection of some quenchants.

7.1.6.4 In some cases, the quench bath may be contaminated by ammonia which is used in some heat treatment processes. Clearly, pH is an excellent indicator of potential ammonia