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WATER - AN ENGINEERING RESOURCE

Almost everyone is intimately familiar with, and aware of the essential role that water plays in sustaining virtually every life form that exists on this planet. Its involvement in environmental and biological mechanisms is almost endless and a world without water for drinking, irrigating, washing, and recreational purposes is unimaginable. However, most of us don't usually think of water as an engineering material. Nevertheless, many properties of water that make it necessary to biological functions are also ideally suited for many manufacturing processes. These properties are primarily related to water's ability to store and convey energy in a very efficient manner. Specifically, water is the most suitable material we have ever found for heating, cooling, and steam generation processes. In this respect, two of its most important properties are **specific heat** and **latent heat of evaporation**.

Specific heat refers to water's outstanding capacity to absorb and store heat. In standard English units, the specific heat of water is 1 BTU/Lb./Deg F. This means that 1 BTU of heat energy put into one pound of water will only raise its temperature 1-degree F. By comparison, the same amount of heat put into one pound of steel would raise its temperature about 10 degrees F. This extraordinary capacity of water to hold heat, and the ease with which water can be pumped, make it a superb heat transfer medium. However, even more impressive, is the energy that water can hold when it is in vapor form. This is called the latent heat.

Latent heat is the amount of heat that one pound of water will absorb when it goes from a liquid to a vapor. This number varies slightly with pressure, but is about 970 Btu's per pound at one atmosphere. In other words, it takes 970 Btu's to evaporate one pound of water. Conversely, one pound of water will give up 970 Btu's when it is condensed. It should also be noted that water undergoes tremendous expansion when it is evaporated. For example, at atmospheric pressure, the volume of one pound of steam is about 1600 times the volume of an equal weight of water. Since one pound of water is about 1 pint; the equivalent volume of steam would occupy about 200 gallons--or about four 55 gallon drums. These properties not only make steam a superb mechanism for transporting heat, but also for converting heat into mechanical energy through the use of turbines and steam driven pumps.

Water also expands when frozen. However, in this case, the expansion is only about 11 per cent of its volume. It should also be noted that significant heat energy is required to convert ice back into water. This is called the **heat of fusion** and is about 144 BTU's per pound. This can be put to work in a variety of ways. For example, many large office buildings are now using ice for thermal storage. This is where water is frozen into ice during the night when power rates are lowest. The ice is then used to chill water used for building air conditioning during the daytime.

At normal atmospheric pressure, water freezes at 32 degrees F and boils at 212 degrees F. However, changing the pressure also changes these points. For example, under vacuum, we can cause water to boil as low as 35 degrees F, and by raising the pressure to 3200 psi (called the critical pressure), water boils at 704 degrees F. At 300 psi (the pressure of many industrial boilers) the corresponding temperature would be about 420 degrees. This is called the saturation temperature and means that the steam temperature is the same as the boiler water temperature. If the steam temperature is increased, the increase above saturation temperature is called superheat. For example, if the steam temperature at 300 psi were taken to 470 F, we would say that it had 50 degrees of superheat. In actual practice, the maximum temperature steam is ever taken to is about 1100 degrees F.

WATER - THE UNIVERSAL SOLVENT

Another important property of water is its extraordinary ability to dissolve almost everything that it comes into contact with. For this reason, water is often thought of as the "Universal Solvent". This is highly desirable when we want to use it for cleaning, but when it dissolves a steel boiler or heat exchanger, we call that solvent action by another name; corrosion. It also means that natural water supplies are not pure. That is, they do not just consist of H₂O; but in addition, contain various amounts of materials that the water has contacted along its journey to the point of use.

WATER IMPURITIES

Impurities in water are classified as:

- a) Suspended Solids
- b) Dissolved Solids
- c) Dissolved Gases

How these impurities are made up in any particular water depends on several factors, but in general, surface waters (such as from rivers or lakes), are higher in dissolved gases and suspended solids than are well waters. Conversely, well waters are usually higher in dissolved solids than are surface waters.

UNITS OF MEASUREMENT

The most common way of expressing impurities is parts per million (abbreviated ppm). This term refers to parts, in weight, of any impurity that is dissolved or suspended in one million parts of water. For example, 10 pounds of sugar dissolved in 1 million pounds of water (about 120,000 gallons) is 10 ppm. This term is used for all water impurities; suspended solids, dissolved solids, and dissolved gases.

Sometimes, water impurities are expressed in terms of milligrams/liter (mg/l). For all practical purposes, this is equivalent to parts per million and the two can be used interchangeably. At 4 Degrees C, they are exactly equal. This is the temperature where one liter of water weighs exactly one kilogram.

Another unit of measure that is used is grains/gallon; usually abbreviated to "grains". However, the use of this term is restricted to the field of water "softening" and is used only to express the amount of calcium and magnesium in water. It is never used to express the amount of any other type of impurity. It should be noted that calcium and magnesium are two metal contaminants that are found in most natural waters. Collectively, they are called Hardness. This term comes from the fact that calcium and magnesium have soap destroying properties. Large amounts of calcium and magnesium, therefore, make water "hard" to wash with. One grain per gallon of hardness is equivalent to 17.1 parts per million total hardness expressed as CaCO₃.

DISSOLVED SOLIDS

Calcium and Magnesium are but two examples of dissolved solids, and is the result of water having had contact with ground formations containing these minerals. This would include calcium carbonate (limestone), magnesium carbonate (dolomite), calcium sulfate (gypsum), and magnesium sulfate (Epsom salts). Other common minerals usually include silica (sand), and sodium sulfate (Glauber's salts). Typically, waters also contain small amounts of iron, manganese, fluorides, aluminum and other substances. Industrial and sanitary wastes can introduce a variety of other contaminants that might include such things as phosphate, ammonia, and nitrates.

DISSOLVED GASES

The most common dissolved gases in water are derived from contact with air. Air is composed of 78 % nitrogen, 21 % oxygen, and about 1 % other gases. Of these, the most important, because of its role in corrosion mechanisms, is oxygen. Oxygen is soluble in water to about 9 ppm at room temperature and atmospheric pressure. Like all gases, the solubility of oxygen goes down as water temperature rises. This property is the basis for steam deaeration of boiler feedwater.

SUSPENDED SOLIDS

Suspended solids are usually in the form of small particles of silt, clay, decaying organic matter, etc. that are primarily related to the water's source. For example, well waters are usually lower in suspended solids than surface waters.

TERMINOLOGY

We have already defined "Hardness" as being a measure of calcium and magnesium in water. Other definitions important to water treatment chemistry are Conductivity, pH, Alkalinity, and Turbidity.

Conductivity (Specific Conductance)

Conductivity is the measure of how easily water conducts an electrical current. Since pure water itself will not conduct electricity, the property then is related to the type and nature of impurities it contains. Specifically, most dissolved solids in water become ionized. In chemical jargon, an ion is any atom, or group of attached atoms that have an electrical charge. If the charge is positive (+) it is called a cation. If it is negative (-), it is called an anion. An example would be table salt, sodium chloride (NaCl). When table salt is dissolved in water, the sodium (Na) and chloride (Cl) disassociate to form a sodium cation (Na^+) and a chloride anion (Cl^-). It is the electrical conducting property of these ions that give waters a property called specific conductance. This property is expressed in micromhos/centimeter (or more properly, as microSiemens) and is a way of easily measuring the total ionized dissolved solids in the water. It is a very common measurement used in water treatment and is used primarily to control cycles of concentration in boiler and cooling water systems. In fresh water, specific conductance is used as a rough measure of total dissolved solids (TDS). In this case, conductance, multiplied by 0.7, will give an approximation of TDS in parts per million.

pH

The term, pH, is technically defined as the "inverse logarithm of the hydrogen ion concentration" and is a scale of numbers from 0 to 14. The midpoint is 7, and water with this pH is said to be neutral. pH values below 7.0 are acidic and pH values above 7.0 are alkaline. The further below 7 the pH becomes, the more acidic the water is. Conversely, the higher the pH value above 7, the more alkaline, or caustic, the water is.

The reason for building the scale around the number 7 is that pure water (without other ionized substances or contaminants) has a hydrogen ion concentration of 0.0000001 grams of hydrogen ion in each liter of water at 25 C. This number can be expressed as 1×10^{-7} , or on the pH scale, as 7.00--or "neutral". Each unit of pH below 7, such as 6, represents a 10-fold increase in hydrogen ion concentration from the unit above it. The reverse is also true. Each pH unit above 7 is a 10-fold decrease in hydrogen ion concentration from that of the previous unit.

Using this technical definition, an acidic water (low pH) has a higher hydrogen ion (H^+) concentration than does an alkaline water. The reason that acids such as hydrochloric (HCl) and Sulfuric (H_2SO_4) lower

pH is that they increase the hydrogen ion concentration when added to water (note the hydrogen in their formulas). Also, the reason that caustic soda (NaOH) neutralizes acid in water is that the OH^- from the caustic soda combines with the H^+ from the acid to form $\text{HOH} = \text{H}_2\text{O} = \text{water}$. This effectively removes hydrogen ions and the pH goes up.

Alkalinity

In water treatment, there are three chemical compounds that are defined as alkalinity. These are:

OH^-	Hydrate Alkalinity
CO_3^{-2}	Carbonate Alkalinity
HCO_3^-	Bicarbonate Alkalinity

In fresh and cooling tower waters, alkalinity is almost always in the bicarbonate form. In boilers, the primary forms of alkalinity are hydrate and carbonate. This is because the heat in a boiler environment breaks down most of the bicarbonate alkalinity. One of the byproducts of this decomposition is carbon dioxide, a primary cause of corrosion in steam condensate systems.

Analytically, alkalinity is measured in a water by running a phenolphthalein ('P') alkalinity and/or a methyl orange ('M') alkalinity. The difference is that 'P' alkalinity measures all of the hydrate and 1/2 of the carbonate content of the water. 'M' alkalinity measures all of the hydrate, all of the carbonate, and all of the bicarbonate present in the sample. For this reason, 'M' alkalinity is also called the "total alkalinity". Hydrate alkalinity is usually calculated from the formula $2P - M$, but it can also be determined directly by first treating the sample with barium chloride to remove carbonate alkalinity, and then titrating to the phenolphthalein endpoint with N/50 hydrochloric acid. However, the accuracy of this method is relatively poor and makes $2P - M$ the most common way to determine hydrate levels.

Turbidity

Turbidity is used to describe cloudiness, or alternatively, "lack of brightness" in water caused by the presence of finely divided suspended solids that do not readily settle out. This cloudiness is measured on the basis of impediment of light transmission in the water sample, and is expressed as Jackson Turbidity Units (JTU's), Formazin Turbidity Units (FTU's), or more commonly, as Nephelometric Turbidity Units (NTU's), the latter of which is based on light scattering properties of the suspended solids. Because of differences in the test methods, there is no established correlation between the three units of expression. NTU's are determined with a photometric type of instrument called a nephelometer.

Other Contaminants

Waters may contain many other types of contaminants that can cause scale and corrosion problems in boiler and cooling water systems. Some of the more common include silica, iron, copper, manganese, phosphate, ammonia, chloride, and sulfate. However, once their presence is recognized, corrective measures can be taken to minimize effects on system corrosion and fouling. The tools available to the plant operator range from a number of processes that remove contaminants, to specialty chemical treatments designed to minimize adverse effects these contaminants have on system efficiency and reliability.