International Journal of Science and Engineering Applications
Volume 12-Issue 09, 156 - 162, 2023, ISSN:- 2319 - 7560
DOI:10.7753/IJSEA1209.1047

Moisture beyond Hygroscopicity- The Chemist Understanding

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Abstract

In this review paper, hygroscopicity was briefly analyzed within the context of the role water molecules in the air plays in causing moisture. Some material substances that absorb or adsorb water molecules from the air were highlighted, like salts, sucrose, ethanol, sulphuric acid and cellulose fibre. The chemistry origin of hygroscopy was x-rayed through an attempt to explain the polar nature of water and some hygroscopic substances and the important role of hydrogen bonding. While highlighting the disadvantages of hygroscopy in food materials and other raw materials for production.

Key Words: Hygroscopicity, Water Molecule, Salt, Sucrose, Food materials & Chemistry

Introduction

Hygroscopicity is defined as the ability of a substance to absorb moisture from its surroundings.Hygroscopicity, a physical property of a material, it is a measure of how well the material can absorb and release water molecules. Certain materials may expand or deform upon exposure to water molecules. (Wei *et. al.,* 2011). Water is an important solvent, so it's unsurprising that there is a term specifically related to water absorption which is Hygroscopy. Hygroscopy is the phenomenon of attracting and holding water molecules via either absorption or adsorption from the surrounding environment, which is usually at normal or room temperature. Most hygroscopic materials are salts, but many other materials display this property. A material which gains moisture from the atmosphere as the relative humidity increases is said to be hygroscopic. The more hygroscopic a material is, the more moisture it will pick up during periods of high humidity. (Wirth *et. al.,* 2017)

A Surface contaminants in which moisture can be present can be classified in two categories: hygroscopic and non-hygroscopic. (Gysel*et. al.,* 2004) Examples of hygroscopic materials are salts, vegetal fibers, most metal oxides, many polymers, etc. Examples of non-hygroscopic surface contaminants are metal powders, glass granules, etc. If water molecules become suspended among the substance's molecules, adsorbing substances can become physically changed, e.g., changing in volume, boiling point, viscosity or some other physical characteristic or property of the substance (Choi and Chan, 2002).

Hygroscopic substances include cellulose fibers (such as cotton and paper), sugar, caramel, honey, glycerol, ethanol, wood, methanol, sulfuric acid, many fertilizer chemicals, many salts (like calcium chloride, bases like sodium hydroxide etc.), and a wide variety of other substances. (Madsen and Lilholt 2003)

If a compound dissolves in water, then it is considered to be hydrophilic. The term hydrophilic can be broken down into two parts. The prefix "hydro" means water and the suffix "philic" means loving. Thus hydrophilic means water-loving. A hydrophilic molecule is a molecule that can mix and interact with water. (Ahmad *et. al.,* 2018). Zinc chloride and calcium chloride, as well as potassium hydroxide and sodium hydroxide (and many different salts), are so hygroscopic that they readily dissolve in the water they absorb: this property is called deliquescence. Not only is sulfuric acid hygroscopic in concentrated form but its solutions are hygroscopic down to concentrations of 10% v/v or below. A hygroscopic material will tend to become damp and cakey when exposed to moist air (such as the salt inside salt shakers during humid weather). (Randall, 2007) Because of their affinity for atmospheric moisture, hygroscopic materials might require storage in sealed containers. Materials and compounds exhibit different hygroscopic properties, and this difference can lead to detrimental effects, such as stress concentration in composite materials.

Differences in hygroscopy can be observed in plastic-laminated paperback book covers—often, in a suddenly moist environment, the book cover will curl away from the rest of the book. The un-laminated side of the cover absorbs more moisture than the laminated side and increases in area, causing a stress that curls the cover toward the laminated side. (Mohanty*et.al.,* 2000)

Examples of Hygroscopic Materials

Zinc chloride, sodium chloride, and sodium hydroxide crystals are hygroscopic, as are silica gel, honey, nylon, and ethanol. Sulfuric acid is hygroscopic, not only when concentrated but also when reduced down to a concentration of 10% v/v or even lower. (Gregorich*et. al.,* 2001)

Germinating seeds are hygroscopic. After seeds have dried, their outer coating becomes hygroscopic and begins absorbing the moisture required for germination. Some seeds have hygroscopic portions that cause the shape of the seed to change when moisture is absorbed. The seed of Hesperostipacomata twists and untwists, depending on its hydration level, drilling the seed into the soil. (Moiseev, 2008)

Animals can also have characteristic hygroscopic properties. For example, a species of lizard commonly called the thorny dragon has hygroscopic grooves between its spines. Water (dew) condenses on the spines at night and collects in the grooves. The lizard is then able to distribute water across its skin by means of capillary action. (Prakash and Sridharan 2002).

Chemistry of Hygroscopy

Hygroscopic substances are hydrophilic (water-loving). Chemically, they are polar or support hydrogen bonding. Some hygroscopic substances (like salt and alcohol) dissolve in water, while others do not (like nylon and silica gel). (Worthington and David, 2003)

Molecules are hygroscopic when they have charges or partial charges. These types of molecules are called polar. Water itself is a polar molecule, made up of one oxygen atom and two hydrogen atoms bonded together with covalent bonds. Covalent bonds are a type of bond that occurs when two atoms share electrons. However, oxygen is more electronegative than hydrogen and so it pulls the shared electrons in the bond closer towards its nucleus. This creates a partial charge called a dipole and a polar covalent bond. Oxygen has a negative dipole since the electrons are pulled closer and each hydrogen atom has a positive dipole since the electrons are further away. (Gubskaya*et. al.*, 2002)

Thus, since water has partial charges, other molecules that interact with water must also have charges. This creates energetically favorable interactions. Water also interacts with itself and the dipoles on water molecules are responsible for some of the incredible properties of water that allow it to support life, such as cohesion and adhesion. Cohesion is the ability of water to form bonds with itself, and adhesion is the ability of water to form bonds with other molecules due to the dipoles. (Batista *et. al.*, 2001)

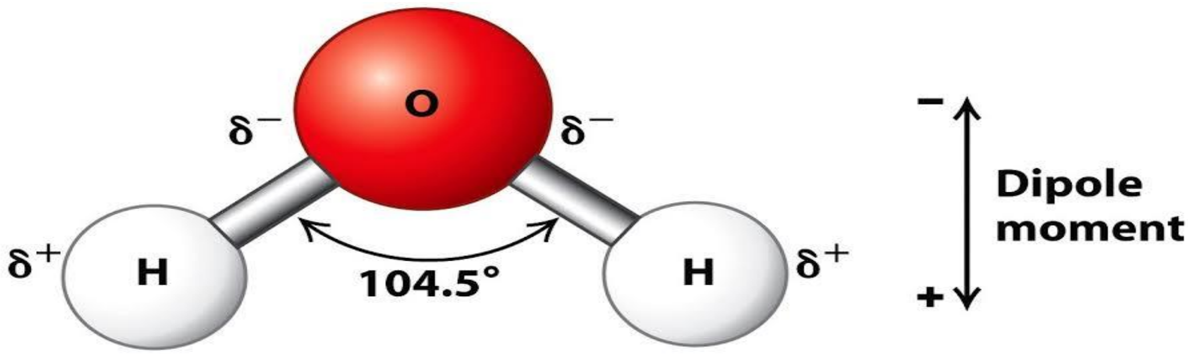

Figure 1: Polar Structure of Water

Hygroscopic molecules are basically polar compounds that have ionic groups. The polar nature of these hygroscopic molecules enables them to readily absorb water or polar solvent and eventually getting dissolved in polar solvents like water. Being a polar solvent, water is capable of forming a hydrogen bond (-H, -OH-). Hygroscopic molecules are polar in nature and easily form a hydrogen bond with water thereby getting absorbed or adsorbed. Notably, these interactions between the hydrophilic molecule and water are thermodynamically favored. In general, hydrophilic substances can easily form hydrogen bonds with polar solvents like water. The polarity of a substance usually defines its hygroscopicity.

Hygroscopy in Table Salt (Nacl)

Sodium Chloride NaCl molecule is comprised of a sodium cation Na^+ and a chloride anion Cl^-. The sodium cation and chloride anion are joined together through an ionic bond. It is a type of bond that is formed when two charged atoms attract one another. Salt easily get attracted to water, which should be expected since salt is highly polar. The water molecules pull apart the salt cations and anions, breaking their ionic bonds (Gupta,2015). The water's molecule negative specie (OH^-) attracts the positively charged cation, and the positive specie of the water molecule

(H^+) attracts the negatively charged chloride. Once Na^+ and Cl^- come apart, the water molecules surrounds them. The sodium cations are surrounded by the water's oxygens, and the chloride anions are surrounded by the hydrogens. This makes salt a Hygroscopic Substance (Ming, 2001)

$NaCl_{(s)} + H_2O = Na^+_{(aq)} + Cl^-_{(aq)}$

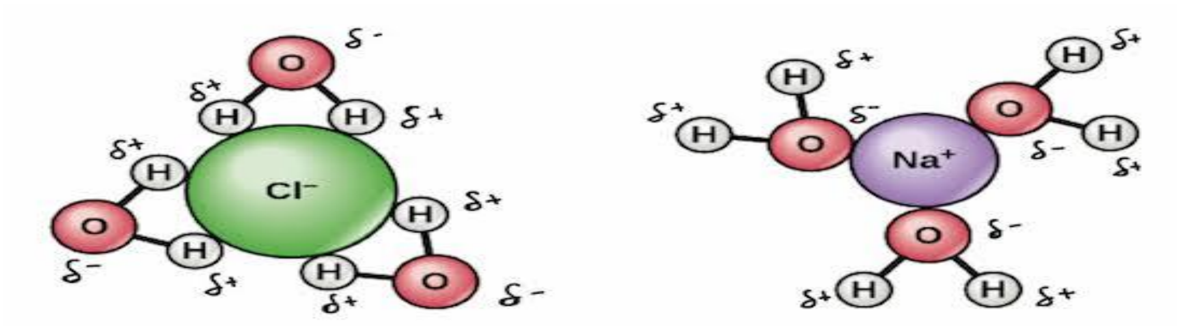

Figure 2: Visual Representation of Sodium Chloride Hygroscopicity

Hygroscopy in Sucrose

Sucrose is a molecule that consists of carbon, hydrogen, and oxygen altogether. Each O-H bond becomes a site for hydrogen bonding with water. Generally, because of that oxygen-hydrogen bonding (OH), it is a "water-loving" species which makes it a Hygroscopic Substance. Sugar is made up of carbon, hydrogen and oxygen, and contains a hydroxyl group, which makes the molecule very polar and therefore very soluble. Sugar also easily bonds with other molecules, and in doing so helps to hold on to the moisture of foods (which also makes it a natural preservative).

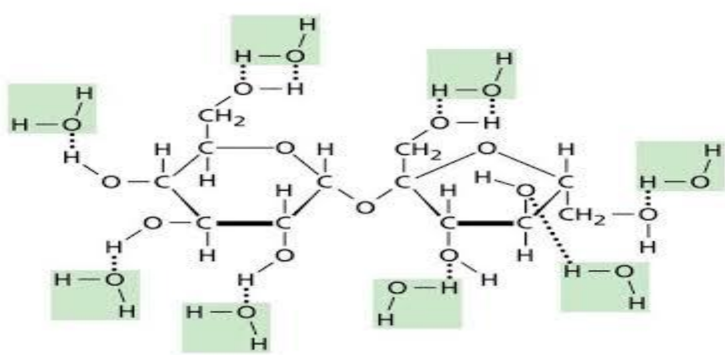

Figure 3: Sucrose Molecule showing how water molecules interact via Hydrogen bonding

Aside from polarity, there are three main processes, which may work together:

Absorption: Absorption is when a substance enters the body of a material. For example, cotton absorbs water.

Adsorption: Adsorption is when molecules adhere or stick to surface. For example, water adsorbs onto Plexiglas.

Capillary Action: Capillary action draws water through pores and narrow spaces due to the adhesive and cohesive properties of water. Silica gel beads are hygroscopic because silica attracts water, while tiny pores and irregularities collect it via capillary action. (Taib and Kumar, 2019)

Applications of Hygroscopic Substances

Hygroscopic polymers and molecules are widely utilized in the field of physics, chemistry, engineering, biomedical, drug delivery, food, pharmaceuticals, paint, textiles, paper, constructions, adhesives, coatings, water treatment, dispersing and suspending agents, stabilizers, thickeners, gelants, flocculants and coagulants, film-formers, humectants, binders and lubricants, personal care, building products, detergents, oil field products, and mineral processing, etc. (Tavana *et. al.*, 2004). Hygroscopic polymers exhibit good water vapor permeability due to ionic groups. Clothing or apparel that is required to be breathable is made up of hygroscopic fibers. Hygroscopic polymers like, Cellulose, Alginate, and chitosan are the most extensively used in the food industry wherein they are used as a thickening agent, stabilizer, and gelling agent (Erothu and Kumar, 2016)

Hygroscopic substances have the ability to absorb and hold water. Hydrogels are a type of hygroscopic polymers that are widely utilized in sanitary products, biomedical engineering, bio separation, agriculture, food processing, and oil recovery.

Disadvantages of Hygroscopy

Corrosion - Being exposed to moisture can lead to rusting for items with components that are made of iron. Rust is not easy to remove, and in most cases, doing so will cause further damage to the items.

Dampening - Exposure to moisture can lead to dampened items, especially those that are highly absorbent of moisture such as paper and garments. This in turn can cause the items to soften and become discoloured.

Musty smell - Increased moisture levels can cause some products to smell funky as a result of the growth of moulds, fungus and bacteria. Getting rid of the smell is not easy, especially if the products that are affected are books and clothing.

Conclusion

Hygroscopy is caused by the presence of water molecules in the air, known as moisture and being either absorbed or adsorbed. To fully understand hygroscopy or prevent it when it is un wanted, some of its chemistry was looked at. It was seen that the polar nature of the water molecule and some other substance coupled with hydrogen bonding plays a major role in understanding the origins of hygroscopy and how it may be prevented.

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