Water Purification by Ion Exchange Resin

Lifan Yue

Academy of International Program, Shenzhen Foreign Languages School, Shenzhen, 518000, China

*Corresponding author email: livianyuelifan@163.com

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Abstract: Ion exchange resin is a kind of artificial polymer contains different functional groups that are able to remove cations or anions dissolved in water, according to the type. After a series of pre-treatment, including general processes like screening, coagulation, precipitation, and sterilization, the water could reach the standard of drinking water. Ion exchange resin, like this kind of artificial polymer, could substitute ions to produce water at very high purity. This paper introduces the structure and function of ion exchange resin and its industrial usage. To further increase the efficiency and regenerate the resin while working, the combination of ion exchange and electro dialysis(EDI) has the advantages of both of them.

1. Introduction

There are different sources of water raw materials, such as lake water [1-2], seawater [3-4], glacier meltwater [5-6] ,and so on. The most widely used sources of water are rivers and lakes, mainly contain calcium ions dissolved in water. We judge the term hardness of water with the concentration of calcium ion in water.

Ion exchange resin is a kind of artificial polymer contains different functional groups that are able to remove cations or anions dissolved in water, according to the type. After a series of pre-treatment, including general processes like screening, coagulation, precipitation, and sterilization, the water could reach the standard of drinking water. But drinking water could not be used in some of the factories, since the ions remain (mainly HCO_3^- and Ca^{2+}) might form sediments when heated, and this will cause damage to boilers and tubes. Also, due to the low heat conductivity of the solid sediment, there could be the risk of explosion of boilers in power stations. Nowadays, in many countries and regions, ion exchange resin is widely used to remove the ions dissociated in water in order to reduce the damage to the facilities or other uses.

2. Pre-Treatment

Before removing the ions in water, a succession of treatment should be employed. General water purification that aims to produce clean water needs several steps, which are screening, coagulation, filtration, and disinfection or sterilization, depends on the standard.

First of all, the quality of water is evaluated. Turbidity, which affects the transparency of water, gives the amount of suspended solid particles present. Other qualities include pH, taste, bacteria concentration are also measured. Usually, underground water is not proper raw material for ultrapure water production, since the concentration of ion is too high.

Then the water is screened to detach some insoluble big particles floating in it. After that, the sample is still a kind of suspension, and the solid particles can’t be removed easily by screening, so flocculating agent is used to absorbing and separating the solid. The mechanism of flocculating agent is, when the chemicals dissolve into water, it forms a positively charged colloid which can attract the small particles and sediment. This step can reduce the turbidity of water dramatically. In today’s factories, some kinds of polymers like poly-iron(III) sulfate and poly-aluminum chloride are used as a better choice than potassium aluminum sulfate, which is widely used in the past but with a lot of possible harms to human. After adding the agent, sedimentation, and eliminating the flocculation, the water is generally colorless and transparent, but it still contains various microbe.

The next step is disinfection or sterilization. In many waterworks, UV light is usually chosen in the disinfection step, and chemicals like chlorine gas, sodium hypochlorite, and ozone are also used. However, as a toxic gas, the usage of chlorine will also lead to the formation of trichloromethane, which could produce an extremely hazardous gas called phosgene under sunlight. But compared to the risk of being infected by pathogen in water, this method is still used worldwide.

Considering these harms and drawbacks, in some developed countries and regions, bio-film reactor will be a replacement of traditional chemical disinfecting methods in the future. It uses the salutary microbes to remove harmful bacteria, such as dysentery bacillus. As a kind of new technology, bio-film reactors has great potential, but it still needs a lot of test and improvement.

when all of these are finished, the water is pure enough for daily uses, but to reach a higher standard we need further purification.

3. Ion Exchange Resin

Ion exchange resin is a kind of artificial polymers contains different functional groups.[9-10] By replacing the ions with H^+ or OH^-, the resin can remove ions dissolved in water and get pure water.

3.1 The Mechanism of Ion Exchange Resin

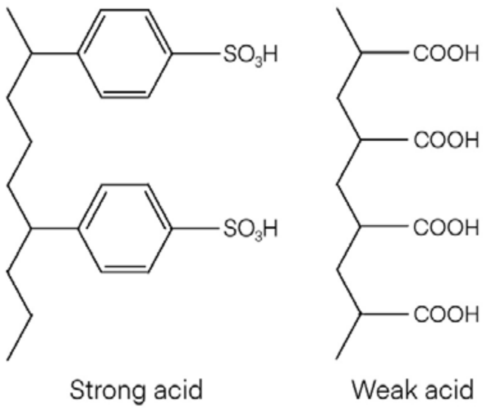

Fig.1 The Structure of Cation Exchange Resin

According to the type of ion they can remove, ion exchange resins are generally divided into cation exchange resin and anion exchange resin. Cation exchange resins, usually acidic, are polymers synthesized from monomers like crylic acid and styrene.

When contacting with metal cations dissociated in water, the ions are able to replace the H+ attached to the resin, and hydrogen ion is released. Similarly, anion exchange resins are polymers with OH- ions, which can replace anions in water.

After the process, the various ions absorbed by the resins are also able to be eliminated and regain their function by disposing with strong acid or base (in industrial production hydrochloride acid or sulfuric acid, and sodium hydroxide are usually used). This step called regeneration is actually the recovery of effective functional group of the resin.

3.2 Features and Classification of Ion Exchange Resins

Ion exchange resins are generally divided into several kinds, and the most common kinds are strong acid resins, weak acid resins, strong base resins, and weak base resins. Acid kinds are cation exchange resins, while base types are anion exchange resins.

For strong acid cation exchange resins, the most widely used type contains sulfonic acid functional groups. These resins are small sphere beads with pale yellow color and radius about 0.4-0.6mm, and their stiffness is relatively high, due to the benzene groups they contain. A significant advantage of this kind of resins is they can deeply remove the ions in water. Usually, the sulfonic acid resins have a capacity of 4-5mmol/g.

Another kind of resin contains carboxylic acid groups, which is a kind of weak acid. This kind gives a deeper yellow color, and they are more fragile than sulfonic acid type. The capacity is significantly higher than the previous type, but there would be a higher concentration of dissolved ions remain in water after the process.

Fig.2 Photo of Ion Exchange Resins

There are also several kinds of anion exchange resins that are used in industry. The first kind is produced by connecting hydroxide to the amine groups on the carbon chain. However, amine groups could be oxidized easily in contact with air, so the hydrogen atoms are replaced by methyl groups to increase their chemical stability. The strong base exchange resins now we are using are usually with trimethyl ammonium groups(fig. 3 shown below) or adimethylethanol ammonium groups, which are stable and gives a high exchange rate for various pH meanwhile the regeneration efficiency is also high.

The second kind is a weak base ion exchange resin. If only one or two hydrogen atoms are replaced by methyl group, the resin only shows weak basicity.

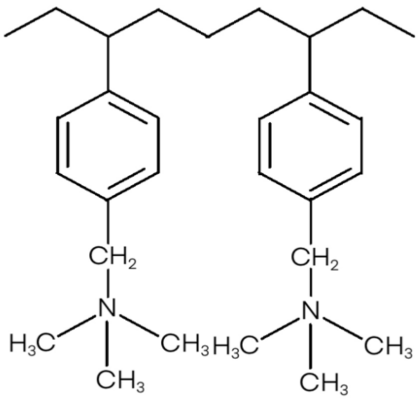

Fig.3 The Structure of Anion Exchange Resin

In general, the anion exchange resins have a slightly smaller capacity than acid kinds. For example, a specific kind of anion exchange resin could have a capacity of around 3.5mmol/g.

4. The Usage in Industrial Production

Ion exchange resin plays an essential role in many fields of modern industry, especially metallurgy, chemical industry, food industry, and environmental protection, etc.

In this paper, we focus on the function of ion exchange resin in water purification, especially the production of ultrapure water with ppm-ppb level.

4.1 The System

When producing pure water in industries, the process of ion exchange happens in ion exchange beds.

The ion exchange beds are connected in a certain order to maximize efficiency while minimizing both the cost and difficulty of the process. Unpurified water first goes through the cation exchange bed, then is heated in a boiler, and next flows through the anion exchange bed.

The boiler between two ion exchange bed is aimed to eliminate HCO3-/H2CO3. After cation exchange, these ions present in water in the form of carbonic acid, which decomposes to give carbon dioxide. This boiling process could easily reduce a large percentage of anions to be eliminated in unpurified water since calcium carbonate is one of the major impurities naturally present in water sources.

In industry production water should also goes through the cation exchange bed first. That's because some metal cations, like iron or magnesium, might form precipitation if the anions in water are replaced by hydroxide groups, which could cause corrosion and damage the facilities.

Fig.4 Shows How the Set of Equipment Works.

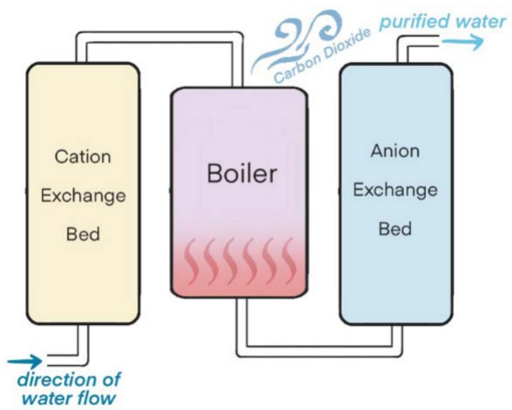

Fig.4 The Desalination by Ion Exchanging Treatment

4.2 Ion Exchange Bed

As shown in fig.5, the resin is filled in beds and water flows downward while working. The functional groups are substituted from above, for both working and regenerating.

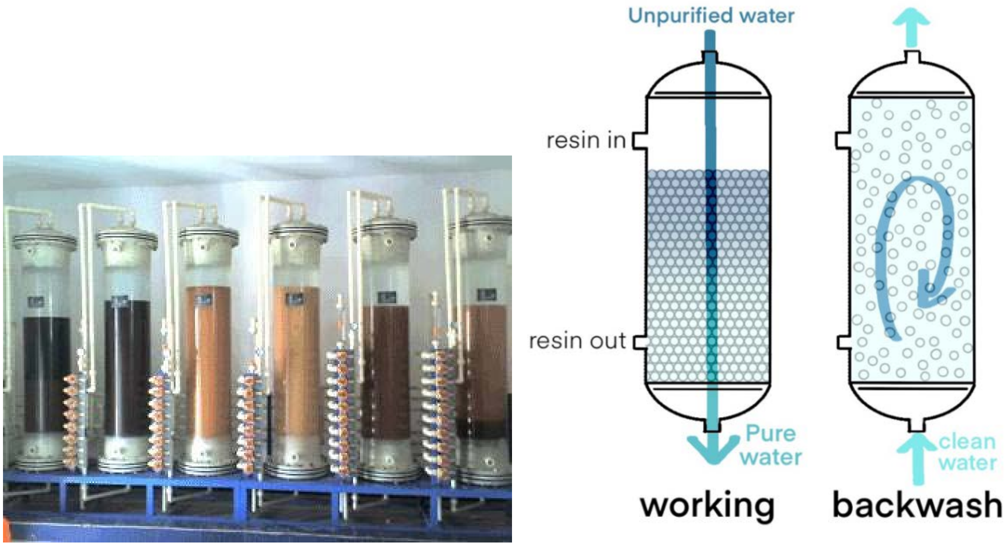

Fig.5 Ion Exchange Bed

4.3 Regeneration

For the regeneration of ion exchange resin, the chemicals we use are strong acids or strong bases, e.g. HCl(or H_2SO_4) and NaOH.

According to the character of resins, they show various effective capacities, which is usually around 30% to 80%, since in industrial production the functional groups seldom react completely. Also, because of the presence of macromolecules, the actual efficiency might further decrease.

When regenerating the acid or base goes along the same direction as working. However, another process called backwash, which is mentioned before, needs clean water to flow along opposite directions. This can reuniform the resin, mix the beads, and prolong working life.

5. Ion Exchange Technique Combined with Ion Exchange Membranes and Electro Dialysis

5.1 Ion Exchange Membranes and Electro Dialysis

Besides beads, the polymers are also made into different shapes, such as membranes. These are known as ion exchange membranes, also divided into cation and anion kinds, with some fibers to make them stronger.

In the past, the membranes were used in electro dialysis equipment (fig.6) to electrolyze sodium chloride to get concentrated sodium hydroxide and chlorine gas for industrial use. The two electrodes attract ions with opposite charges, and the usage of membranes only allows certain kinds of ions to go through. Due to the limited attraction from the electrodes and high speed of water flow, this method is only efficient for producing concentrated solution, but weak when eliminating ions to get pure water, especially when the water is flowing between membranes.

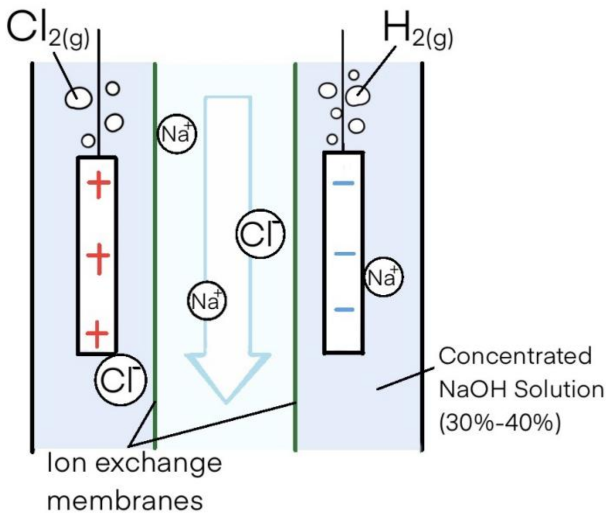

Fig.6 Diagram of Electro Dialysis

5.2 Electrical Deionization

The electrical deionization technique, which is a combination of ion exchange resin and electro dialysis, has the advantages of both of the methods.[11-12]

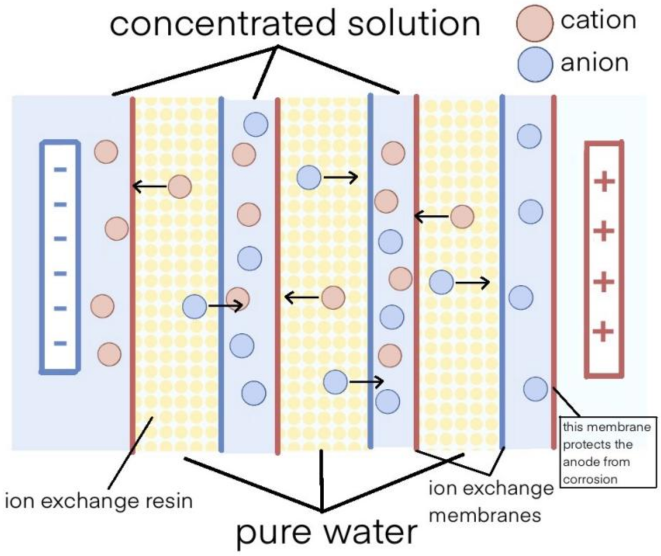

Fig.7 Diagram of Edi

The setting, as shown in fig.7, is made up of several parallel units, with ion exchange membranes and ion exchange resins filled inside.

The beads slow down the speed of water flow, giving enough time for reaction and ion displacement. Due to the complete contact between ion and resins, this method could reach an extremely high purity of ion concentration around 10-9μS/cm. The ultrapure water produced is used in electronic industry.

Another advantage of this process is its auto-regeneration during circulating. The mechanism is, while the hydrogen and hydroxide ions in resin are reacted, the impurities are attracted by electrodes at the same time, and the resin regenerates directly.

6. Conclusion

As a relatively new technology, ion exchange resin has shown great potential in many fields. Especially for metallurgy and electronic industry, the mass-produce of ultrapure water had significantly promoted the development.

The resins eliminate ions dissolved in water by replacing the cations and ions with hydrogen or hydroxide groups. During this process, the available functional groups are consumed continuously, which means resins need to be regenerated. To further increase the efficiency and regenerate the resin while working, the combination of ion exchange and electro dialysis(EDI) has the advantages of both of them.

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