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SYNTHESIS AND APPLICATIONS OF POLYACRYLAMIDE

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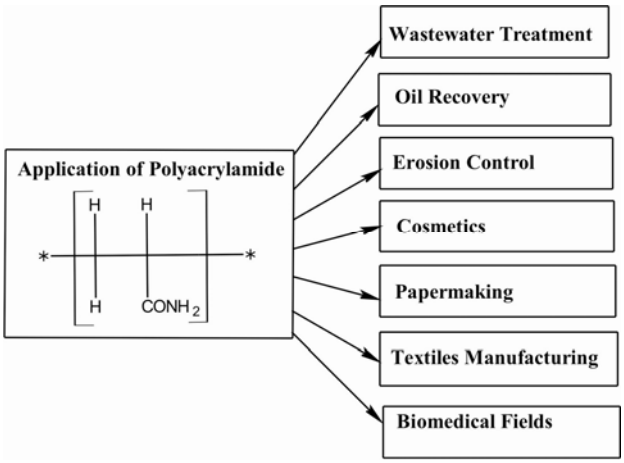
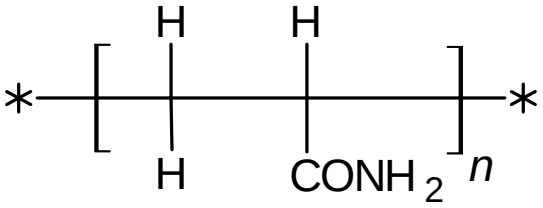
Polyacrylamide (PAAm) is a white coloured, water-soluble polymer. It is prepared by polymerizing acrylamide monomer. Polyacrylamide can be synthesized as a linear chain polymer or a branched chain polymer. It can be synthesized as a high molecular weight polymer with wide range of physical and chemical properties. Due to its high water absorbing and gel forming properties it is used in many applications, mainly as adhesive, additive for flocculation and thickener. PAAm is a very useful polymeric material and its application cover broad areas *viz.* waste water treatment, oil recovery, gel electrophoresis, DNA sequencing, medical treatment, etc. In this paper, we present a review of the synthesis, properties and applications of polyacrylamide.



SYNTHESIS OF POLYACRYLAMIDE

Polyacrylamide is an acrylic resin which is soluble in water. In 1893, acrylamide polymers were first synthesized. The monomer has been commercially available since the early 1950's. Several techniques have been examined for the production of polyacrylamide such as, solution,[1-5] emulsion,[6-8] and dispersion polymerization.[9-10] The water-soluble polymers are produced by polymerization of acrylamide (that is obtained by hydration of acrylonitrile). The monomer acrylamide is polymerized by the action of free radical initiator. The repeating unit has the following structure:



Polyacrylamide does not occur naturally. The commercial production of the polymer is through vinyl monomer. The polymer is hydrophilic in nature which, after dissolution, can form highly concentrated aqueous solutions. It has high water absorbing and gel forming capacity. It is employed as flocculant in sewage treatment, and for industrial water supply. The natural water treatment and sewage water treatment has been closely linked to the preservation of the environment. It is largely used as a flocculator (substance that aids the separation of suspended solids from aqueous systems). The smart polymer polyacrylamide has various applications such as in paper mills,[11] ore processing, oil recovery,[12-14] crude oil production processes, cosmetics additives,[15] contact lenses, production of organic chemicals and other polymers, synthesis of dyes, photographic emulsions, adhesive manufacture and food processing. It also has important applications in biomedical fields[16-19] *viz.* in genetics, genetic engineering and molecular biology laboratory as a matrix for DNA sequence analysis and protein identification.

PROPERTIES

Polyacrylamide is an odorless, hard glassy white polymer. The water-soluble monomer

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acrylamide is toxic and carcinogenic. So, it has to be handled with special protection, but polyacrylamide as such has no toxic effects. It contains highly reactive amide group and can produce cationic polymers (positively charged) or anionic polymers (negatively charged). Ionic polymers are very useful in separation and metallurgical operations. The dry form of polymer is available in a powder or granule form with different particle sizes, depending on the type of polymerization in which drying, and grinding processes are used. It has a good thermal stability, but at higher temperature it decomposes into acrylamide. At 220°C polyacrylamide starts to decompose, above this temperature ammonia gas is released due to an imidic reaction. The molecular weight range of the polacrylamide is 10^4-10^7 and density is 1.302 g/cm^3 (at 30°C). The glass transition temperature is 153°C. Polyacrylamide is soluble in water, morpholine, formamide, and ethylene glycol, and partially soluble in acetic acid, lactic acid, glycerol, dimethyl sulfoxide, and dimethylformamide. It is insoluble in acetone, dioxane, alcohol, hexane, and heptane. The important characteristic of aqueous solutions of polymer is viscosity. When the viscosity of aqueous solutions of polyacrylamide increases then concentration and molecular weight increases and temperature decreases. The degradation of the polymer can be initiated by free radicals, ionizing radiation, light, heat, shear, and high speed stirring of aqueous solution of polyacrylamide.

The chemical properties of polyacrylamide are that the solution of it undergoes general reactions of the aliphatic amide group. The important reaction of this polymer is hydrolysis, which is carried out in an acidic or a basic medium.

APPLICATIONS

The important applications of polyacrylamide are in wastewater treatment, oil recovery, control of soil erosion, cosmetics, paper-making, ore processing, textile manufacturing, in biomedical fields and as food additive. Some of the applications are discussed below.

1. Wastewater Treatment

In treatment of wastewater polyacrylamide can be used as a coagulant or flocculant.[20-22] The application of polyacrylamide as flocculant has been reviewed by Myagchenkov *et. al.* and Hocking *et. al*.[23,24] It can be used in different types of wastewater. When polyacrylamide (a chemical flocculating agent) is added in wastewater then suspended particles aggregate. The smaller particles are converted to big particles, enough in size which settle out or get captured by filters. Now, the floc can be easily removed from wastewater. The polymer can also be used in municipal wastewater treatment as in activated sludge treatment, digested sludge treatment and primary sewage treatment. In industrial wastewater treatment, polyacrylamide is used in various areas which include petrochemical, paper, breweries wineries, oilfield chemical food, electroplating, textiles, pharmaceutical, leather, and slaughterhouses. It can also be used to treat water from mineral mining processes that contain production of coal, gold, lead dioxide, nickel, silver, zinc, titanium, iron, copper, sand, phosphoric acid, gravel, steel, alumina, uranium as well as potash processing.

2. Oil Recovery

Polyacrylamides are used in subsurface applications as in enhanced oil recovery.[25-28] In oil extraction, the polymer is used to improve the effectiveness of the water flooding process to increase the viscosity of water. Historically, polyacrylamide has been used as a solid powder in oilfield projects. Nowadays, it can be used in emulsion form as liquid for rapid action. Energy crisis is one of the most important problems in many countries. For solving this problem, Enhanced Oil Recovery (EOR) technology is widely used. In this technology polyacrylamide is introduced to the reservoir to decrease an interfacial tension between oil and water. It can drain out the entrenched oil from the reservoir rock and increase the oil productivity.

3. Erosion Control

Soil erosion or degradation is a significant problem throughout the world. In 1950s, research began with the study of polyacrylamide as soil conditioner. For protecting soil, Polyacrylamide is one of the better options. It is used as a soil conditioner to stabilize and flocculate suspended particles. The polymer is used in furrow irrigation where it reduces erosion and runoff. It can stabilize the structure of soil that leads to increased infiltration, decrease in the use of water and less erosion on furrow irrigated fields.[29-31] Polyacrylamide is used

to maintain infiltration at regions encountering heavy rainfall, especially in the presence of an electrolyte.[12,13,32] The polymer is also used in steep slopes construction, highway cuts and other conditions.[14]

4. Cosmetics

Polyacrylamide is used in cosmetics as a binder, film former, stabilizer and thickener. It has foaming, anti-static and lubricating properties which makes it useful in cosmetics. It is used in facial moisturizers, color cosmetics, lotion, anti-aging products, hair products, sunscreens, creams, skin cleansers; self-tanning products make up, nail care products and so many other cosmetic products. In cosmetics and beauty products, the polymer is used in two different forms as a soft gel and as a thickener and suspending agent. In soft gel, the polymer is in cross linked form in which it has high water absorbent property. In thickener, the polymer is in straight chain form. Recently, polyacrylamide is used as an active ingredient in the subdermal wrinkle filler that absorbs moisture in hair care products to help hair hold its style. The polymer holds together the ingredients of a compressed tablet or cake in makeup products. The small amount of polyacrylamide is used as an abrasive in skin cleansing products. According to the Experts Panel Cosmetics Ingredient Review (CIR), the maximum permissible amount of acrylamide in cosmetic products is 5ppm.[15]

5. Papermaking

The synthetic polymer, polyacrylamide is mostly used as an additive in papermaking.[11] It is worked as retention agent, increases the retention of fiber minimizing energy used for drying. The polymer may be used in the production of various types of paper products that use straw pulp, wood pulp or recycled paper as the raw material. The water-soluble polymer has large molecular weight which is suitable for retention of fiber, while the polymer having small molecular weight is suitable for filtration. Commonly, polyacrylamide may be used for solid or liquid separation in paper and pulp wastewater streams. It acts as flocculant and it can improve sheet drainage, formation and filler retention. The cationic polyacrylamide is used as strengthening agent to keep the tensile strength of paper.

6. Textiles manufacturing

As textile additive, polyacrylamide is used as chemical pulp with other chemicals. It may increase the permeability and stickiness. The polymer can make the textile to be anti-static, decrease the sizing, hard size and break rate. It is mainly used in feather sticking, pulp sticking, glue sticking, and as pulp in polyester and pure cotton fiber. The polymer can be used as dye leveler which improves the cloth quality, hardness and elasticity. Initial applications of polymers were as finishing and sizing agent for fabric post treatment. It can produce soft, anti-wrinkle and anti-mould protective layer. As an agent, polyacrylamide allows fabrics to give strong resistance to fire and static electricity.

7. Biomedical field

The first use of synthetic polyacrylamide as a support matrix for electrophoresis was reported by Raymond S. Weintraub in 1959.[29] In biomedical field, the polymer is used in genetics, genetic engineering and molecular biology laboratory as a matrix for DNA sequence analysis and protein identification. It is also used in contact lenses. The polymer can also play an important role in biomedical applications as in soft tissue fillers and augmentation materials as in breast augmentation and aesthetic corrections. It is a hydrogel that is a new, rapidly developing group of materials, gaining wide applications in many fields, especially medicine, pharmacy and agriculture. Due to its wide applicability and low cost, the polymer has found various applications ranging from microanalysis to macro-fractionation of nucleic acid, protein and other bimolecules. The water-soluble polymer is used in enzyme immobilization and delivery of drugs and bioactive compounds. Polyacrylamides are used as a carrier for other bioactive macro-molecules and cells to produce the desired effects[16,17] and for sustained antibiotic release.[34] These polymers are stable and chemically inert over various conditions, that is the reason behind their biomedical applications, *e.g.* as a useful matrix for different types of devices used for removal of toxins.[18,19]

Table 1

The application of polyacrylamide in various fields and their function

Various fields of application	Functions
Water treatment	Clarification of potable water, industrial effluents, municipal waste water; thickening and dewatering of sludge; filtration of primary sludge, digested sludge; food processing
Pulp and paper	Filler retention, binder pigments, dry and wet strengthening, sizing, coating, clarification of waste water, concentration and dewatering of sludge
Mining and ore processing	Setting slimes, flocculation of flotation waste, clarification of waste water from gravel wash, coal washeries, concentration and dewatering of sludges
Petroleum	Enhancing oil recovery, regulation of filterability and theological properties of drilling muds, thickening of water, soil structure formation, oil flotation
Agriculture	Soil stabilization; microencapsulation of mineral fertilizers, fungicides, and herbicides
Medicine	Microencapsulation of water soluble pharmacological preparates, non-thrombogenic granulated gels, contact lenses in ophthalmology, high-quality tampons, diapers, etc.
Construction	Soil stabilization; water absorber; water retention aids in cements, grouts, and tiles; improvement of mechanical properties of cement and gypsum plasters and water based paints

ADVERSE EFFECTS

Polyacrylamide is made up of repeating units of acrylamide monomer. Although polyacrylamide as such is not toxic but it can form the monomer acrylamide which has the following adverse effects:

a) Potent nerve toxin
b) Cellular necrosis
c) Cause birth defect
d) Effect male reproduction
e) Cause cancer in animals and potentially humans
f) Cause mammary tumors and so on

CONCLUSIONS

Polyacrylamide is a widely used polymer having widespread applications, such as in water treatment, pulp and paper, mining and ore processing, petroleum, agriculture, biotechnology, medicine and construction.

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