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Review Article

Varied Applications of Hydrogels Based on Their Smart Properties: A Review

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ABSTRACT

Hydrogels now play a more crucial role than ever thanks to the development of technology. Because of their unique properties, hydrogels can withstand high water and biological fluid concentrations without losing their ability to hold them in their three-dimensional networks. Typically, hydrogels are wet, rubbery, and soft materials. Additionally, they can respond to fluctuations in environmental stimuli. Hydrogels can swell in the solvent or shrink in the state of non-solubility. Moreover, they can even undergo shape volume changes of external stimuli like pH, temperature, light, and electric signals. They are highly regarded as a versatile product and can be used in a variety of medical and industrial settings, including agriculture, the food industry, wound dressing, and implants, because of their hydrophilic structure. In recent years, the development of smart hydrogels that can respond to changes in the environment has been enhanced in a myriad range of applications. This study offers a review of the various ways that hydrogels have been used in two distinct fields, particularly the medical one.

Keywords: Hydrogel, Smart hydrogel, Properties of smart hydrogels, Stimuli-responsive hydrogels, Hydrogel's Medical application, Hydrogel's industrial application, Stimuli-responsive hydrogels

Introduction

The reality that hydrogels are insoluble in water is imperative to note. Hydrogels are three-dimensional systems that are created by utilizing physically and/or chemically cross-linked polymers that have been swelled in a fluid medium. Hydrogels have a huge water retention capacity (between 10% and hundreds of times more prominent than their dry weight). As numerous diverse strategies have been utilized to make hydrogels for a long time, they may presently illustrate a wide assortment of abilities when they are utilized. Hydrogels in this way

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offer a part of the guarantee in a few zones [1]. Both hydrophilic and hydrophobic polymer systems are conceivable [2]. Whereas hydrophobic components are able to control the rate of hydrogel swelling, hydrophobic components cause the hydrogel to swell [3]. The utilization of a hydrogel is decided by the determination of appropriate materials, such as the sort of monomer, polymerization procedure, cross-link thickness, the degree of swelling, and the sort of medium in which the fabric swells [4]. A few monomers, such as 2-Hydroxyethyl methacrylate (HEMA), are not considered to be super absorbent. Subsequently, the rate of swelling is generally moo compared to polyethylene. In addition, in the event the thickness of the cross-linker operator increments altogether, the rate of swelling may diminish. With respect to the application, other than that, the sort of dissolvable can be chosen. For occurrence, water is essentially utilized to get ready hydrogels for clinical applications since this dissolvable encompasses a lower hundred toxicities than other solvents. Be that as it may, depending on the application, different solvents can be utilized to create various hydrogels [5]. Due to the truth that each of the previously mentioned substances includes a critical effect on the swelling rate and porosity, these substances are basic for the utilization of hydrogel. Another angle of polymerization method commendable of specify could (be) a homo-polymeric hydrogel [6], (b) co-polymeric hydrogel [7], (c) semi-inter entering arrange (Semi-IPN) [8], and (d) Associate Entering Arrange (IPN) [9]. In expansion, the hydrogel's capacity to hold water may be a significant characteristic of hydrogels. The characteristics of water in hydrogels depend on the amount of solutes, pH, and saltiness and besides, and the basic components of hydrogel capacities. The water in hydrogels can exist in two states: either emphatically (SBW) or pitifully (WBW) bound to the polymer organize; a parcel of the water carries on as free (non-bound) water[10]. The amount of water or other natural liquids within the structure of a hydrogel changes depending on the time of the drying operation, owing to the truth that hydrogels are utilized in a wide run of areas both mechanical and restorative sciences. In other words, the work of water capacity is noteworthy. Without dissolving in water, they are able to swell in water and hold a critical parcel of water inside their 3D structure. The words gels and hydrogels are utilized and traded by culinary and restorative specialists [11, 12]. The relationship between water bound and properties of hydrogels is accomplished by heap test strategies, for occurrence, NMR (Atomic Attractive Reverberation), DSC (Differential Checking Calorimetry), TSDS (Time Arrangement Information Stream), DRS (Diffuse Reflectance Spectroscopy). As well as this, they show a degree of versatility amazingly comparable to the normal tissue and human skin of an individual [13]. Hydrogels can be utilized in tissue building, inserts, medicate conveyance frameworks, biosensors, the nourishment industry, horticulture, etc. [1] The properties of hydrogels, and their employments in the medicine and industry are all secured in detail in this audit article.

Hydrogel Properties

Properties of hydrogels based on conventional and Smart hydrogels

Hydrogels are water-swollen polymer networks, as was previously described. The point is that there is a distinctive difference between traditional and smart hydrogel. Traditional hydrogels have a limited ability to swell in response to environmental conditions; stimuli-responsive hydrogels (smart hydrogels) may swell or deswell abruptly in response to changes in condition[14].

Properties of smart hydrogel or environment-sensitive

The properties of naturally delicate hydrogels have been secured in this area. Hydrogels, as was already famous, have three-dimensional structures that are impermeable to water. As a result, a few of them are respected as keen materials that react to boosts since they may involve very considerable and sudden volume changes in response to modifications in their environment. The categories for stimulus-response hydrogel are numerous. For occasion, atomic intuition between polymer chains or between polymer chains and fluids is influenced by pH, ionic factors, chemical operators, and physical jolts like temperature and electrical areas. Moreover, because of their contrasts, mechanical push has an effect on the number of diverse vitality sources. Applications for stimuli-responsive hydrogels within the therapeutic field are numerous, especially within the biomedical and pharmaceutical areas. For occasion, they utilize (HEMA), manufactured ligaments and tissue, and control pharmaceuticals[15].

Properties of pH-responsive hydrogels

Polymeric hydrogels containing ionic pendant bunches were created by Patel and Mequanint [16] and may collect or grant protons in reaction to changes in the pH of the environment. The level of ionization, now and then alluded to as pka or pkb, changes significantly at a given pH. By making electrostatic ghastly intuitive between the ionized gather, which in turn produces a noteworthy osmotic swelling drive, this unexpected move interior the net charge of the ionized pendant gathers actuates a quick volume move. Agreeing with Gupta et al. [17], essential factors oversee how much ionic hydrogels extend. The concentration, crosslink thickness, ionic charge, hydrophilicity or hydrophobicity, and degree of ionization of the polymers are the most important determinants. The parameters of the swelling media, comprehensive of pH and ionic control, are the moment though.

Properties of temperature-responsive hydrogels

The structure of hydrogels react to temperature incorporates both hydrophilic and hydrophobic components. In common, the sensitive adjustment between the hydrophobic and hydrophilic parts of the polymer monomer is where the marvels of temperature reaction begin [18]. The interaction of the polymer's hydrophilic and hydrophilic fragments with water particles changes with temperature. As a result, it may cause a move within the cross-linked network's solvency, coming about within the sol-gel stage move. The gel stage is non-flowing and keeps up its astuteness, whereas the sol stage is portrayed as a liquid that streams [19].

Properties of light-sensitive hydrogels

Two sorts of light-sensitive hydrogels are recognized: Hydrogels that are responsive to obvious and UV light are moreover accessible [20]. Leoco cyanide, for illustration, could be a chemical found in a few UV light-sensitive hydrogels that are ionized by UV light. In UV light, cyanide particles increment osmotic weight, causing the gel to extend. The photosensitive hydrogels have chromophores in them. It has the capacity to both retain and after that radiate light that causes a rise in gel temperature and at long last causes gel deswelling, much like temperature-sensitive hydrogels [21].

Electro-responsive hydrogels

Comparable to circuitous misshaping activated by light, hydrogels that are responsive to electric boosts may react in an unexpected way to changes in temperature, pH, or redox state. For illustration, an electric field may cause a temperature increment and the ensuing misshaping of a hydrogel delicate to temperature in comparison to Joule warming or dielectric warming. Additionally, electrochemical interaction close the cathode may create hydroxyl particles and the coming about rise in pH esteem, which can advance the distortion of a pH-responsive hydrogel [22].

Hydrogels for medical applications

In 1960, due to their hydrophilic nature and potential for biocompatibility, cross-linked HEMA hydrogels speeded by Wichterle and Lim got to be critical within the restorative region [23]. Since hydrogels can imitate how human organs carry on in reaction to changes in natural components like pH, temperature, proteins, and electric areas, as well as based on their physical states, which incorporate strong, semi-solid, and fluid hydrogels Figure 5, this has led to their utiliztlization within the restorative industry. Polymeric hydrogels have highlights that are comparative to delicate tissue in that they are flexible, non-toxic, biodegradable, and stimulus-sensitive. They are frequently utilized in biomedical utilizations, for illustration, eye contact focal points, medicate conveyance frameworks, self-healing, and wound dressing, tissue designing, inserts, and diagnostics since of the previously mentioned highlights [24]. Also, they have diverse physical properties, which are utilized in different areas. In Figure 1, hydrogels based on physical properties are illustrated [7].

Figure 1. Physical state of hydrogels [1]

Eye contact lenses

In 1960, a synthetic biocompatible and down-to-earth fabric for contact focal point application, based on poly-2-hydroxy-ethyl methacrylate (PHEMA), was to begin with displayed by

Wichterle and Lim [25]. Eye contact focal points are regularly categorized as "difficult" or "delicate" materials based on their adaptability. In spite of the fact that difficult focal points final longer, they are regularly not well gotten by weavers and may require a longer adjustment period. Also, whereas delicate focal points are made based on hydrogels, difficult contact focal points are ordinarily created of hydrophobic materials such as poly (methyl methacrylate) (PMMA) or poly (hexa-fluoro isopropyl methacrylate) (HFIM) [26]. Delicate focal points that are appropriate for covering the full cornea and show sufficient oxygen penetrability for expanded client comfort are fabricated from different monomers coupled with 2-hydroxy-ethyl methacrylate (HEMA) or N-Vinylpyrrolidone (NVP). Around 38–40% percent of water in the totally hydrated frame is included in contact focal points based on the PHEMA equation. The chemical structure of p(HEMA) is outlined in Figure 2.

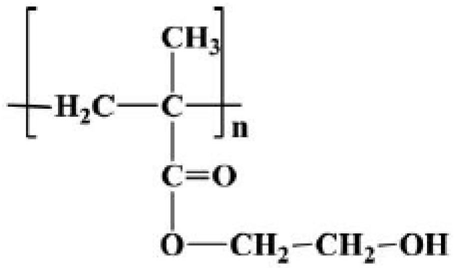

Figure 2. A schematic of the chemical structure of p(HMEA) [27]

A hydrogel contact focal point needs to have a wide assortment of properties, such as light transmission, refractive file, satisfactory oxygen porousness, wettability, solidness, superior mechanical behavior, and biocompatibility [4]. Because it was as of now famous, a polymeric hydrogel needs certain physical characteristics in order to be utilized as a contact focal point. One of the foremost significant is that a hydrogel's balance water substance (EWC), which may be an essential component, the definition of EWC is below:

$$EWC = m/m_{tot} \times 100\% \quad (1)$$

It should be noted that m belongs to the weight of water in polymer and m_{tot} belongs to the total weight of hydrated polymer [28].

EWC might change by some factors such as temperature, pH, and osmolality.

There are many ways to make soft contact lenses, including spin-casting, mold-casting, and lathe-cutting. In spin-and-mold casting, the lens is shaped by pouring a tiny amount of a liquid monomer mixture into particular optical molds that are "concave" [29]. Nowadays, silicone hydrogel (SiHy) lenses have increasingly become popular among people in terms of their high oxygen permeability and comfortable fit [29].

Drug delivery system

The thinking about shrewd or shrewdly hydrogels for sedate stacking in these frameworks is additionally developing as the center on medicate conveyance frameworks intensifies. Their common employments within the pharmaceutical industry incorporate the conveyance of drugs to particular tumors as well as to the stomach, liver, colon, brain, blood, and anxious framework. In these areas, controlled medication conveyance is basic [30]. Depending on the level of hydration, hydrogels can capture the medication and watch it from perilous encompassing for a relentless discharge through dissemination or disintegration. By modifying the structure in reaction to natural jolts like pH, temperature, electrical and attractive areas, dissolvable composition, light, particles, etc., they can moreover direct the rate of medicate conveyance [31]. One of the unused pH- and temperature-sensitive hydrogels has been created, and it contains six acrylic bunches, one cyclic phosphatize, and HAAP as a cross-linker for the amalgamation of p (NIPAM-co-VI). This hydrogel has been tried as a medicate show for the controlled discharge of rhodamine 6G. Agreeing to investigate, sedate discharge productivity is generally 94.2% and 87%, separately, at pH 1.2 and 5.5 [32]. Biodegradable materials like biodegradable polymers, lipids, and ceramics, as well as non-biodegradable materials like attractive nanoparticles, can both be utilized in sedate conveyance frameworks [33]. Certain physical characteristics of a hydrogel ought to be taken into thought some time recently utilizing it in sedate conveyance frameworks. Controlling the matrix's thickness of cross-links and fascination for water makes it basic to change the hydrogels' tall porosity. Since it empowers the stacking and consequent discharge of drugs, porosity plays a basic part in medicate conveyance. In lattice frameworks, the sedate is equally conveyed or broken down all through the hydrogel's three-dimensional structure [13].

Biomedical application of biosensors

We presently have better grasp of stimulus-sensitive hydrogels' potential for biological signal sensing in the medical and biomedical domains as a result of several research and advancements linked to their physical, chemical, mechanical, and biocompatibility qualities. Early ailment determination, treatment, and administration are made conceivable by the utilization of biosensors to track physiochemical changes within the human body. Regardless of certain precision restrictions, significant progressions have been accomplished within the creation of advanced biomaterials that empower an advanced era of biosensor plan and foundation, dispensing with blunder empowering response to physiological changes, for improving helpful effect. Besides, biosensing has ended up more progressed and engaging due to the viable combination of minor receptors with detecting components, an imperative step towards scaling back [34].

Wound dressing

Self-healing and wound dressing are two significant perspectives of hydrogel utilization. The advancement of innovation has made it conceivable for the mending preparation to be faster and more productive, for occurrence by utilizing hydrogel rather than normal hydrogels. Without a doubt, the skin isn't as it were a greatly vital organ for the human body but moreover a really common organ. The rheological behavior of hydrogels, in expansion to having a few unmistakable char characteristics like biocompatibility, natural neighborliness, and biodegradability, makes them perfect for utilization as wound dressings [35]. As already specified, the skin serves as the body's to begin with line of defense against pathogens and noteworthy water misfortune [36]. The utilize of wound-healing biosensors in restorative settings has too developed broad. It may be invaluable to utilize biosensors to identify diseases and wounds early on. It ought to be famous that amid the wound mending prepare, irritation and expansion deliver exudate that contains proteins, MMPs, and electrolytes, and changes in their concentration can increment or diminish the hazard of creating wound issues [37]. Investigate biosensors for wound dress checking has generally focused on physiological markers like temperature. Whereas uric corrosive in wound exudate contains a solid relationship with wound bacterial diseases, pH, and dampness. A comprehensive strategy of utilizing biosensors for wound exudates to degree pH, temperature, oxygen, and proteins has been inquired about [34]. Some traditional wound dressing is illustrated in Figure 3.

Figure 3. Traditional wound dressings which are divided into six forms are shown [38]

Tissue engineering

Due to the already specified characteristics of hydrogels in both physical highlights and mechanical behavior, tissue building is one of the foremost surprising applications of hydrogels. These biocompatible three-dimensional hydrogels have an uncommon quality that permits them to operate as platforms and mirror the characteristics of different body tissues. Hydrogels may be utilized within the body as tissue platforms because of their basic characteristics. Expanding the stream of cell metabolites into the cells and the expulsion of cell metabolites and squanders by means of their pores [39]. Hydrogels may be isolated into two categories: (a) physically and (b) chemically. Based on how they respond to extraordinary boosts, like temperature, pH, light, attractive and electric areas, ionic quality, or enzymatic environment, these hydrogels are alluded to be "savvy" or "cleverly" hydrogels [14]. The schematic of hydrogels in tissue building appears in **Figure 4**.

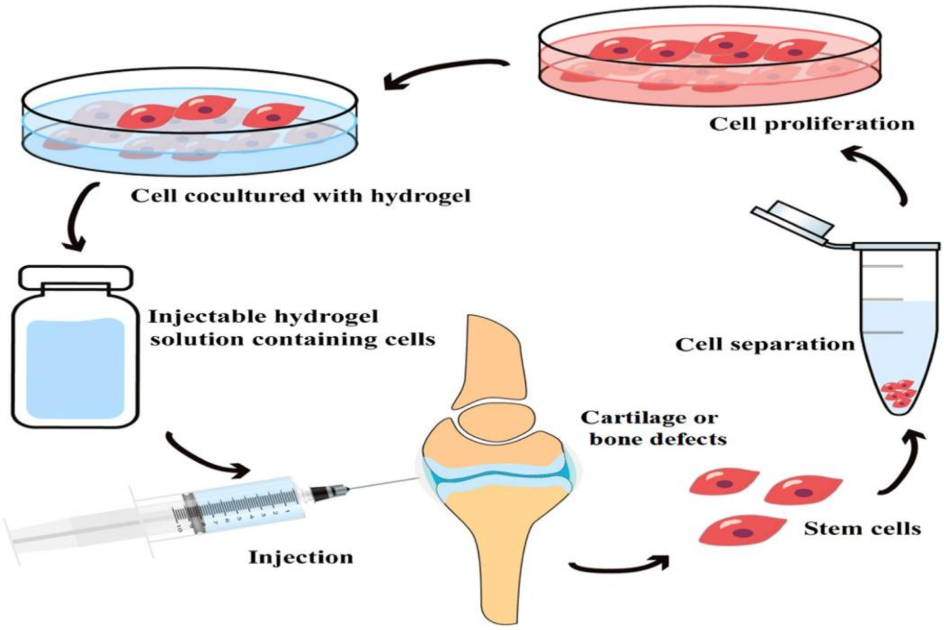

Figure 4. Application of injectable hydrogels for cartilage or bone [40]

Biologically active scaffolds in tissue engineering

Platforms are three-dimensional permeable strong biomaterials that will immobilize proteins, development variables, and other naturally dynamic biomaterials by giving a physical surface for dynamic biomolecules. These scaffolds/bioactive frameworks illustrate great bioactivity and specificity to framework structures in tissue building and regenerative medication [14]. It is significant to note that hydrogels are made to serve as a platform for the creation of tissues. Applications have to have recognizing characteristics like mechanical durability, surface characteristics, biodegradability, and electroactivity. However mechanical quality comes out best, especially when a hydrogel is utilized as an embed to supplant harmed tissue. Hydrogel platforms in tissue building are illustrated in **Figure 5**.

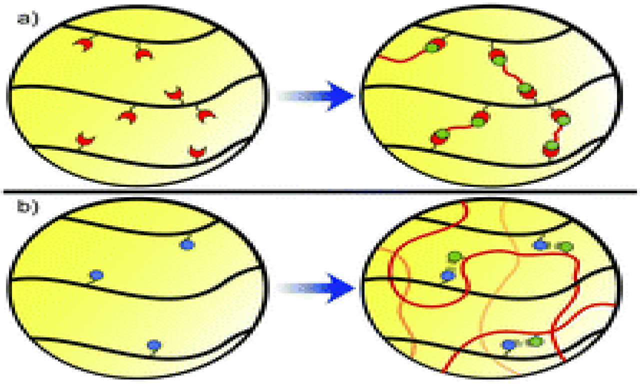

Figure 5. Hydrogel scaffolds in tissue engineering [41]

Type of hydrogels used for scaffolds

This sort is separated into two categories. In addition to this, they are regarded as stimuli-responsive hydrogels (shrewd hydrogels). a) Physical responsive hydrogels that have three sorts: Temperature-responsive hydrogels, Photo/light-responsive hydrogels, and Electro-and attractive responsive hydrogels. b) Chemical-responsive hydrogels are categorized into three sorts: pH-responsive hydrogels, Glucose-responsive hydrogels, and Biological/biochemical–responsive hydrogels [42]. Another point worth saying is that conventional hydrogels' constrained usefulness and moo mechanical quality have continuously been tricky issues. Be that as it may, the utilization of nanocomposite nowadays has encouraged the development of this division. The hydrogel has risen as an adaptable and cutting-edge innovation due to its tall mechanical properties, which incorporate electrical conductivity, antibacterial, antioxidation, and attractive properties. As an extraordinary fabric, it can open up modern conceivable outcomes for making them with extraordinary qualities. Shrewd hydrogels are in this manner completely essential in this field [43]. For a specific application, organically talking, the materials ought to at the same time increment wanted cellular capacities while dodging a solid and extended fiery response. In general, polymers utilized to form hydrogels are made to be safe to the tissue they are encompassing as well as the cells they are transporting. The typical ECM and tissue for the most part comprise of collagen and HA [44, 45].

Physically properties of scaffolds

Physical characteristics incorporate the energy and mechanics of gel arrangement, as well as mechanical and debasement behavior. These characteristics are decided by the most chain polymer's natural characteristics, the crosslinking characteristics (amount, sort, and covalent linkage atom), as well as natural components. Additionally, the energetic and instrument of gel arrangement clarify how chemicals and cells are included to frameworks and how those platforms are eventually dispersed. The denature of proteins may result in cell damage or passing amid common fabricating strategies and responses such as temperature rise, pH varieties, and the utilize of distinctive solvents [22, 44].

Injectable hydrogels for medical usages

Hydrogels ought to have certain mechanical and chemical qualities, especially when utilized for restorative mediations. Injectable hydrogels were made utilizing frameworks that may gel in situ, empowering the infusion of fluid polymer arrangements into the tissue where they from there on cemented [46]. It ought to be famous once more that common polymers like chitosan, alginate, hyaluronic corrosive, and gelatin, which are biodegradable and as often as possible come pre-functionalized with integrin official parts permitting for attachment and facilitated cellular reactions, have much higher mechanical properties, tailorable structures, and immunogenicities than manufactured polymers like PVA, PMMA, and PEG. To inspire craved reactions in vivo, be that as it may, amalgamation hydrogels need intrinsic bio-functionality and post-processing. To target understanding locales, they are connected in both wound dressing and medicate conveyance frameworks. It can be respected as a phenomenal methodology that required the sending of very intrusive surgical procedures. It is critical to consider hydrogels' degradability. Due to the momentous condensed structure and nanometer-sized pores of injectable hydrogels, multiplying cells at the micron scale are incapable to enter and break down the covalent bonds that hold them together. As a result, the upkeep of an exact adjustment between the rate of tissue integration and platform corruption is vital for the propagation of wound tissue. In terms of focused on sedate conveyance, hydrogels are utilized as retentive options or in numerous display strategies for localized discharge of helpful extreme. The dissemination rate and solvency of particles dispersed over the hydrogel lattice are essentially affected by pore measure, spine charge, and hydrophilic or cross-link thickness. In this way, these sorts of injectable hydrogel warehouses may work as areas for a wide range of restorative specialists. It ought to be famous once more that normal polymers like chitosan, alginate, hyaluronic corrosive, and gelatin, which are biodegradable and regularly come pre-functionalized with integrin official parts permitting for grip and facilitated cellular reactions, have much higher mechanical properties, tailorable structures, and immunogenicities than engineered polymers like PVA (Polyvinyl liquor), PMMA (Poly (methyl methacrylate)), and PEG (Polyethylene glycol). To inspire alluring responses in vivo, in any case, engineered hydrogels need inalienable bio-functionality and post-processing. To target persistent zones, they are utilized in both wound dressing and medication organization frameworks. It is respected as an incredible strategy that requires the utilization of amazingly obtrusive surgical procedures [47].

Hydrogel based on artificial muscles

Analysts have caught on to the noteworthiness of hydrogels in counterfeit muscle areas since 1989. It is vital that hydrogels may mirror the capacities of characteristic body components and carry on in a comparable way. For these sorts of applications, examinations on (PAAM) hydrogels incorporate those in [48]: Properties and materials exceptionally near to living tissue are Biocompatibility, Not biodegradable, Chemical control, Movable shape, Low-cost.

The significant viewpoint is that a hydrogel-based manufactured muscle framework must have two basic characteristics: It must, to begin with, and first, be a stimuli-responsive hydrogel; this survey article briefly depicts the numerous sorts of stimuli-responsive hydrogels. Moment, the hydrogel with anisotropic structure can camouflage isotropic compression and development of suited properties like bowing movement, directionally increased distortion, and compositive modified movement [22]. The foremost infinitesimal structures of hydrogels are isotropic since these sorts of hydrogels are ordinarily made through the polymerization of monomers that can be consistently scattered in a watery environment [49]. The lion's share of these characteristics is examined underneath as playing a significant part in a hydrogel-based fake muscle system: Bending Movement: For the most part, the foremost common frame of movement has a place to bowing movement, which produces noteworthy uprooting from diminutive withdrawals or expansions. For occasion, the biceps and triceps muscles within the arms are concentrated and the arms bend and fix. In addition, fake muscles may twist toward a layer that's generally diminishing and have various layers with changing degrees of reaction [49]. Directionally

Opened Up Misshaping: By way of intensifying the misshaping of manufactured muscle in a specific region, unidirectional compression and development of muscle fiber can be reestablished. It ought to be famous that making an anisotropic measurement or anisotropic firmness might involve directionally increased distortion. The firmness of hydrogels demonstrates their degree of resistance to misshapen, which anticipates the compression and development of stimuli-responsive hydrogels.

Living organisms move all of the parts of our bodies in a facilitated way by enacting the right muscles. Owing to this, it is vital to coordinate both basic and advanced misshapings, for instance, the previously mentioned bowing and directionally intensified movement. Designing methodologies, stimuli-responsive generation mateanisotropi anisotropic structures may all be utilized to make depend on, making them carefully composed with carefully arranged movement.

Implant

Due to the previously mentioned characteristics, hydrogels are utilized in a broad extend of embed applications, and their mechanical behavior may be made strides by including added substances like Ag, ZnO, or other nanoparticles. Moreover, are utilized not only as it were in clinical surgery but are too the center of consideration in dentistry. It is significant to note that inserts made of hydrogels have a critical part in plastic surgery [50]. For occasion, the female breast has as of late been expanded or revamped utilizing breast inserts. Three distinctive sorts of inserts are accessible: (a) inserts filled with silicon gels (SG), (b) inserts filled with silicon oil, and (c) inserts filled with monobloc hydrogel, an arrangement of saline and cellulose (MH). The utilization of SG inserts is commonly compared to that of saline inserts, which is unprecedented. These breast inserts are all made of silicon elastomer [51].

Hydrogels as Anti-Fouling Coating in Biomaterial Applications

The body's dismissal of the embed could be a major figure that diminishes the life expectancy and working of inserts, indeed in spite of the fact that visit contaminations are an extreme source of dismalness due to the implantation of restorative gear. The outside body response, a complicated arrangement of atomic activities that start with surface fouling and come full circle with the arrangement of a fibrotic capsule as the body endeavors to remove macroscopic outside components, is one of the foremost common ways the body rejects an implant. The improvement of hydrogels as an antifouling fabric could be a coordinated result of the hydrogel coating's relative dependence on biofilm development. To be more exact, antifouling materials work to halt the nonspecific atom connection that happens when materials are exposed to complex liquids on the surface of apparatuses [50]. The most grounded associations between materials and water molecules to form a defensive layer of water that sterically avoids getting to basic materials are likely the most excellent strategy for making antifouling materials [52].

Hydrogel-based material for hygiene product

More than 30 years ago, superabsorbent polymers were created for the agricultural and diaper industries. Since then, their use has grown due to their exceptional water retention. Water retention is regarded as a crucial diaper characteristic. As a result, feminine napkins have been made using superabsorbent polymers. Super-porous hydrogels were eventually introduced. In contrast to superabsorbent polymers, super-porous hydrogels (SPH) display outstanding size-independent rapid swelling kinetics. SPH is made of covalently bonded hydrophobic polymers. Sulfopropyl acrylate, salts of acrylic acid, and very hydrophilic acrylamide were used to create 1st generation of super-porous hydrogels. By adding a "hybrid agent," hybrid super-porous hydrogel, the next generation of SPHs, is created. In order to absorb liquids, superabsorbent hydrogels, particularly those made of acrylate polymers, are often utilized in hygiene products. They may retain fluids on their structure and keep them away from the skin. Another quality worth noting is that they pose no risk to the skin, making them pleasant for both children and adults to wear[53].

Cosmetic industry

Hydrogels are used in multifarious fields for a variety of purposes due to their flexibility and adaptability. Biomedical, dye removal, heavy metal ion removal, agriculture, sanitary napkins, pH-sensors, biosensors, and supercapacitors make up the majority of applications for hydrogels [54]. The priority of the skin is to shield the body from harmful environmental elements like UV rays and microorganisms. Additionally, it helps keep the body fluids and temperature stable. The maintenance of the skin's appearance and texture depends on proper hydration. Along with climatic factors and pollution exposure, photoaging from cumulative exposure and natural aging from genetic factors are the main causes of skin damage. Cosmetics are used to improve the texture and appearance of the skin. Body care products like moisturizers, body lotions, and skin cleaners are examples of cosmetics. Due to their qualities, including biocompatibility, elasticity, softness, and high water content, hydrogels have drawn a lot of attention. The hydrogels can be used to treat aging, cellulite, wrinkles, pigmentation, and other skin-related problems. Bioadhesive hydrogel that contains caffeine is used for cosmetic applications, particularly for cellulitis or gynoid lip dystrophy. possessing properties of hydrogel for bioadhesive. It aids in the gradual absorption of caffeine into the skin, improving the look and texture of the skin. People can purchase hydrogels in the market in a variety of forms, including face masks, lip masks, and under-eye pads. Additionally, there are some collagen hydrogels that help the skin regenerate and restore its softness, elasticity, and hydration [25].

Industrial applications

Because of their capacity to store a lot of water without dissolving and their remarkable volume changes in reaction to even tiny environmental changes, hydrogels are applied in plentiful industrial applications.

Hydrogels as sensors

Radiative radical polymerization that is triggered by UV or heat is used to create hydrogels in aqueous solutions. These approaches may be used in a variety of more specialized procedures for the development of unusual hydrogel structures that are helpful for manufacturing sensors, in addition to reactions, self-assembly, or recognition patterns like coiled coils, peptides, hydrogen bridges, or DNA. To be more precise, hydrogels may be created by creating vapor phases with arrays of hydrogel microworms that are well-ordered, cylindrical, and have a high surface-to-volume ratio. These hydrogels can then be employed for various sensing applications [55].

Hydrogels for biosensors

The extracellular matrix's void-filling component and hydrogel share a strong water affinity and hydrophilic character. A mammalian cell's natural environment makes it inherently biocompatible. As a result, these hydrogels are used in several applications, including controlled medication delivery systems and contact lenses. In reality, owing to its open pore porous structure and hydrophilic environment, hydrogel biosensors are utilized to shield and cover sensor components to keep away undesired contact with biological molecules or cells. This allows analytes to diffuse through the hydrogel matrix. A higher cross-linking density, however, limits and sometimes even prevents the diffusion of bigger molecules like proteins, and cells often cannot penetrate gel structures unless they are biodegradable [56].

Hydrogel as stimulus-responsive sensors

Hydrogel that responds to stimulation might serve as an active sensing component. Certain gels respond to physical stimuli including temperature, light pressure, and electric field, and are sensitive to even little environmental changes. Chemical stimuli (pH, ions), magnetic field, biological stimuli, and ionic strength. Via volume changes, enzymes, and antigens [56]. By using specific techniques, we may reduce or increase the shape and size. The reaction rate relies on the hydrogel composition, shape, and size [57].

Application of pH-responsive hydrogels

Due to the fact that the pH in various bodily parts varies, the drug delivery industry is without a doubt the most essential application for pH-responsive hydrogels. For instance, the pH in the stomach is (<3), which is substantially different from the neutral pH in the intestine [58]. To control the release of the medicine, pH-responsive hydrogels were inserted inside either capsules or silicon matrices [59]. PH-responsive hydrogels are also used as biosensors and permeation barriers [60]. Mostly, they include enzymes that alter the pH of the local microenvironment within the hydrogel [20]. Moreover, pH-responsive hydrogels have been used in the creation of permeation switches and biosensors [61]. The pH-responsive hydrogels are primarily stocked with enzymes for such applications, which alter the pH of the local microenvironment within the hydrogels. One of the most popular enzymes utilized in pH-responsive hydrogels is glucose oxides. The conversion of glucose to gluconic acid by glucose oxides decreases the local pH, which has an impact on the swelling of pH-responsive hydrogels. These hydrogels may also be used as separating membranes. Hydrogels that respond to pH block the passage of certain ions and serve as filters. Another use for this class of hydrogels is surface modification, such as altering surface wettability [62].

Application of temperature-responsive hydrogels

Due to the bioactive agent's controlled release and sensitivity to temperature change, thermo-sensitive hydrogels have been extensively produced [63]. Hydrogels that respond to temperature are classified as either negatively or positively thermos-sensitive and are thermally reversible. A stepwise temperature shift was employed to generate an on-off drug release profile using thermo-sensitive monolithic hydrogels, which are negatively thermos-sensitive for drug delivery systems [64]. Some hydrogels generated by IPNs display positive thermos-sensitive, swelling at high temperatures, and shrinking at low temperatures, making them suitable for drug release systems. Positive temperature dependency of swelling is seen in IPNs of poly (acrylic acid) and polyacrylamide (PAAm) or p(AAm-co-MMA) [65]. The transition temperature was changed to a higher temperature by increasing the BMA concentration. Moreover, such hydrogels' swelling was reversible and in response to gradual temperature changes. the model medication ketoprofen's rate of release from a monolithic device had reversible alterations as a consequence [19]. The thermos-reversible gel; part of it has received FDA and EPA approval for use as agricultural goods, food additives, and medicinal substances [20].

Application of light-sensitive hydrogels

In addition to having advantages over other sensitive hydrogels, light-sensitive hydrogels have the ability for used in optical switches and display devices. For instance, thermal diffusion can limit the sensitivity of pH-sensitive hydrogels while hydrogen ion diffusion can limit the sensitivity of temperature-sensitive hydrogels. Both the engineering and the biochemical fields require the development of light-sensitive hydrogels [66]. To be more precise, this kind of hydrogel can alter physical and chemical properties such as viscosity, conductivity, wettability, solubility, mechanical properties, polymer morphology, etc. in response to light signals. The induction of the chromophore in the photoreceptor causes the chromophore to go through isomerization, cracking, or dimerization in response to the light stimulus. As a result, the light signal can be converted into a chemical signal, which then influences or modifies the composition and functionality of this particular hydrogel [67]. The evolution of photoresponsive artificial muscles, switches, and memory devices can make use of light-sensitive hydrogels. They are used specifically in medical applications like drug delivery systems because cross-linked hyaluronic acid hydrogels respond by degrading in a photosensitized manner when exposed to methylene blue [68].

Application of electro-responsive hydrogels

The area of drug delivery systems uses electro-responsive hydrogels more than other environmentally-responsive hydrogels. Edrophonium chloride and hydrocortisone may be released pulsatile employing electric current in hydrogels composed of poly (2-acryamidi-2-

methylpropane sulfonic acid-co-n-butylmethacrylate) [20, 69]. One of the greatest benefits of electro-responsive hydrogels is that the drug release may be readily regulated by adjusting the electric field, as should be emphasized [20].

Hydrogels in separation technology

The main causes of water source pollution are heavy metal ions (Cd+2, Pb+2, Cu+2, Mg+2, etc.) and organic pollutants in industrial effluents (like dyes) or other materials like paper or plastic. Most of the time, these pollutants are poisonous to both people and aquatic life. Therefore, prior to disposal, these pollutants must be eliminated [70]. Heavy materials can be treated using a variety of thermal, physical, chemical, electrical, and biological techniques because they are completely toxic, non-biodegradable, and carcinogenic. Because they have -OH, -NH2, -CONH3, -COOH, and -SO3 groups in their structure, superabsorbent hydrogels can be activated and modified to change their properties and be used for the removal and separation of toxic heavy metals. For instance, a hydrogel made of polyacrylamide, gum ghatti, and polyaniline exhibits ideal material characteristics for the removal of malachite green dye from contaminated water [71]. There are several purification techniques that have been reported to address this problem, including oxidation, membrane filtering, surface absorption, and coagulation and flocculation. Some of these approaches have efficiency, viability, and cost constraints. All types of organic and inorganic pollutants (dyes) are suggested to be removed from water using the surface absorption method because it is both efficient and affordable [72]. Recently, a novel hydrogel method has been used to separate oil from water. Diverse materials have been investigated in terms of surface, morphology, nanostructure, and chemical composition. Oil/water separation is becoming more and more significant to ecology. For instance, due to their interfacial characteristics (superhydrophobicity and underwater superoleophobicity), hydrogels stand out as a possible choice among them. Hydrogel-coated materials have highly effective hydrogel-coated material separation. It has been investigated how to use hydrogel as an absorbent to remove toxic elements, heavy metals, and dyes from a variety of effluents. Metal ion adsorption is favored by absorbents with carboxyl, sulfonic, phosphonic, and nitrogen groups on their surface [73].

Food industry

A few analysts have conducted as of late on the basic work that hydrogels, especially those made of characteristic biopolymers, play within the nourishment segment and its bundling.

Proteins, polysaccharides, and lipids found in biomass as well as polyhydroxyalkanoates delivered by microorganisms are promptly changed over into biopolymers [74]. Biopolymer-based hydrogels have obviously gathered a part of intrigued in this trade as eco-friendly materials as a result of natural concerns. As a result, makers may create an item that's cheap, biocompatible, biodegradable, and has wanted qualities by utilizing biopolymers such as proteins and polysaccharides in different applications [75]. In arrange to form up to the miniature structures for the update of nourishment pressing utilizations, biopolymers that are specifically extricated from biomass (proteins, polysaccharides, lipids) or from microorganisms (polyhydroxy-alkanoates) as well as a few delivered by ordinary chemical amalgamation (polylactic corrosive) have been utilized. Besides, the improvement of viable biopolymer pressing materials with craved qualities may benefit from the utilization of hydrogel. When combined with proteins, stiff and unbending direct polysaccharides like pectin and xanthan gum tend to form complexes that are perfect for making gels within the shape of sheets, films, and coatings. Acacia gum, which is globular and adaptable, makes round structures (miniaturized scale- and nano-capsules) that will encase dynamic substances and be embedded within the film. For the era of protein-polysaccharide couples, huge atomic weight-flexible proteins are best due to their capacity to persevere changes within the biopolymer adaptation brought on by various forms of associations (electrostatic, hydrophobic, physical traps). Boosted bundling (gas and dampness boundaries), antibacterial pressing, item condition Nano-additives, expanded self-life, assurance from oxidation, and work veiling are among the promising employments of hydrogels within the nourishment commerce, especially in the nourishment industry [76].

Proteins

Other than being a source of bioactive peptides and amino acids, proteins incorporate certain useful bunches that connect with other particles to encourage their embodiment. They are frequently utilized to supply vitamins, minerals, probiotics, cancer prevention agents, and dietary-added substances due to their typifying capacities and dietary esteem as a dependable and secure status. Protein-based hydrogels are essentially created through noncovalent intelligence, such as hydrogen bonds and hydrophobic or electrostatic intelligence, between the proteins themselves. They are, in any case, rarely made by covalent bonds, such as disulfide bonds [77].

Polysaccharides

The presentation of polysaccharides as a supportive component for nourishment commerce features an assortment of legitimizations. Since they incorporate hydroxyl and other utilitarian bunches, polysaccharides are non-toxic, secure, hypoallergenic, biocompatible, and biodegradable polymers that empower chemical and/or physical intuition. For the creation of bio-compatible hydrogels, polysaccharides such as pectin, cashew gums, gum Arabic, starch, chitosan, chitin, hyaluronic corrosive, and cellulose subsidiaries have been utilized [78]. It is vital to note that when combined with proteins, hardened and inflexible linear polysaccharides like pectin and xanthan gum tend to make complexes that are useful for gels in an assortment of geometries, counting sheets, layers, and coatings. Acacia gum, which is globular and adaptable, makes round structures (smaller scale- and nanocapsules) that will encase dynamic substances and be consolidated in movies. For the union of protein-polysaccharide pairings, tall atomic weight-flexible proteins are an alluring choice due to their compatibility with withstanding changes within the biopolymers compliance included within the diverse sorts of associations [79]. The quality and security of nourishment amid bundling have also recently been tended to by utilizing brilliantly hydrogels. Dynamic and cleverly pressing materials may be made utilizing stimulus-responsive hydrogels that respond to an alteration in pH employing a colorimetric pointer. They are frequently made utilizing common fixings (food-grade proteins, polysaccharides, and lipids) to supply amazing supportability, small hurt to the environment, and negligible poisonous quality [80]. For this case, Lu et al. arranged nanocellulose hydrogels with a pH-responsive color, which gave a color, alter in reaction to changes within the quality of chicken breast amid capacity [81]. A few pH-sensitive colors have been detailed in stimulus-responsive hydrogels as markers of nourishment freshness in cleverly bundling.

Enhanced oil recovery

The utilization of superabsorbent hydrogel is the center of dialog for the oil segment. As a result, the utilization of hydrogels in improved oil recuperation (EOR) has developed recently. There's a deficiency of accessible oil assets, and finding unused oil sources is challenging. Concurring to think about, when a modern oil store is burrowed, as it were generally 20–40% of its potential oil can be extricated, taking off 60–80% of the reservoir's unique oil undiscovered. Oil from the supply may be expelled utilizing hydrogel in this strategy [82]. Long-term flooding causes abundant water generation, which causes erosion to develop and at last, causes early sur-in of the wells that still contain significant amounts of hydrocarbons. Usually a common issue in developing supplies. The hydrogels utilized in this segment are able to work at high temperatures and have a tall assimilation rate [74]. In Figure 6, the utilization of hydrogels in this industry is outlined.

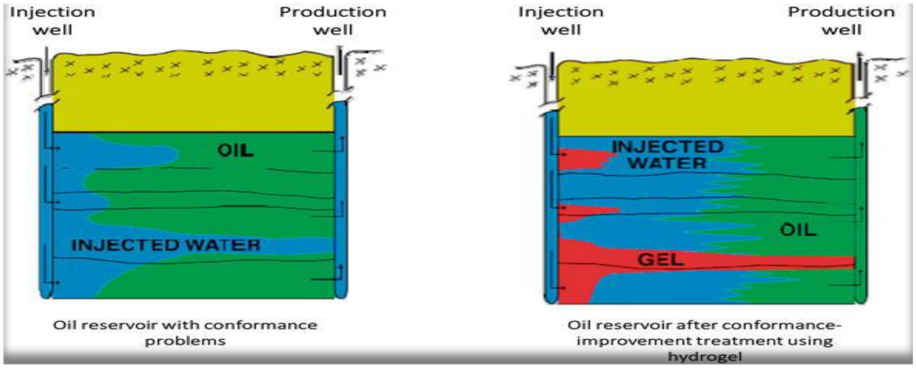

Figure 6. Schematic of Enhanced in the oil industry in order to improve treatment after applying hydrogel [83]

Agriculture industry

There is no sense in disputing the fact that one of the most alluring applications for hydrogels is in the agricultural sector due to their capacity to regulate the flow of nutrients from hydrogels laden with fertilizer into crops. With very porous soil, a significant amount of the fertilizer provided to the soil is lost by leaching. In order to employ this method, a hydrogel is made using a variety of polysaccharides, including chitosan, pectin, and carboxymethyl cellulose, which is then utilized to entice the soil with fertilizer [10]. Moreover, hydrogels made of super absorbent polymers (SAPs) have the capacity to expand and absorb large amounts of water or aqueous solutions, making them advantageous for enhancing soil water retention and plant water delivery. It will thus preserve soil moisture and improve the soil's capacity to store water. SAP hydrogels may have an impact on the soil's permeability, density structure, texture, and rates of water evaporation and infiltration. The positive effects of applying super-absorbent hydrogels are briefly mentioned [84]. The schematic of swelling of hydrogels in soil for plants is shown in Figure 7.

Figure 7. Hydrogels for plants to keep moisture soil [85]

- enhancing the water preserve capacity of soil over several years, irrigation frequency can be decreased by 50%.
- Decreased loss of water and nutrients due to leaching.
- Decreasing the evaporation of water from the soil.
- Improving the physical properties of dense soils by increasing aeration.
- Increase plant growth. Water and fertilizers are constantly accessible in the root zone for optimal absorption by plants.
- Protecting nature from drought and pollutants in groundwater[86].

Conclusions

This review article aimed to offer an extensive range of applications for smart hydrogels, because of their distinctive properties especially, stimuli- response type. Owing to their rate of swelling, indissolubility characteristics, and size of holes that are connected to monomers, and type of stimuli-response hydrogels are preferred for usage in certain applications. Moreover, the type of smart hydrogels are applied for certain applications: therefore, it causes them to be considered as an advanced material because their response to the environment will be different in various situations. The highlight point is that smart hydrogels have different types their application will be different based on their type. There is no sense in disputing the fact that the science of hydrogels is always evolving and is used in a variety of applications today in both business and medicine. There is no sense in arguing that hydrogel's applications will expand in the future owing to their biodegradability and biocompatibility. It is no exaggeration to say that hydrogel science is an endless subject in the world. therefore, human will witness developing hydrogels in different from with different applications in the future.

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