A REVIEW ON: SUPER POROUS HYDROGELS IN DRUG DELIVERY SYSTEM

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ABSTRACT

Super porous hydro gels are originally developed as novel drug delivery system to retain drugs in the gastric medium. these are swell in the stomach and maintain their integrity in the harsh stomach environment these review discuss the classification of hydro gel products based on Generation and polymeric composition, SHP(super porous hydro gels) environment conditions, technical features, process design implementation, preparation of SHP(super porous hydrogels), evaluation, their pharmaceutical applications. These structures allow dried SPHs to swell very fast to a very large size on contact with water. Because of these unique properties, SPHs were initially used to develop gastric retention device that increases the gastric very residence time of drugs to get long-term, oral controlled drug delivery.

Key words: SHP (Super porous hydro gels), SRT (Short residence time), GET (Gastric emptying time), hydrogels, swelling.

INTRODUCTION

Hydro gels are hydrophilic cross-linked polymers able to absorb large amounts of water and they are water insoluble.^{1,2,3} The swelling properties of hydro gels are mainly related to the network elasticity, the presence of hydrophilic functional groups, the cross-link density, and porosity. A variety of stimuli sensitive hydro gels have been studied, but in many cases, slow response to environmental stimuli limited their effective uses.⁴ Although such slow swelling is beneficial for many applications, there are many situations where a fast swelling polymer is more desirable. Therefore, a new generation of hydro gels, which swell and absorb water very rapidly, has been developed. Examples of this new generation are super porous hydro gels (SPHs), which swell to an equilibrium size in a short period of time.⁵

SPH, A new generation of hydro gel is the three-dimensional network of hydrophilic polymer with numerous pores larger than 100 μm to 1mm connected together to form open channel structures. SPHs, which absorb water very rapidly and swells to equilibrium size in a short period due to the presence of interconnected microscopic pores.⁶ The first approach for SPH synthesis involves cross-linking of co-monomers using multifunctional co-monomer, which acts as cross-linking agent. Polymerization reaction and Gas blowing techniques are mainly used to synthesize SPHs. Inorganic carbonates such as sodium bicarbonates are the commonly used foaming agents, which have been safely applied in drug delivery systems. The second method involves copolymerization of linear polymers by irradiation or by chemical compounds.⁷ Several important characteristic of SPHs includes their fast swelling, higher swelling ratio, and surface slipperiness, which make them an excellent candidate material to develop gastric retention devices.⁸

GENERATIONS OF SUPERPOROUS HYDROGELS

Super porous hydro gels are porous hydrophilic crosslinked structures with the capability of absorbing aqueous fluids up to a few hundred times their own weight. Highest swelling is

generally reached in a fraction of a minute with having average pores of 200 nm in size. There are three generations of super porous hydro gels were developed:

- First generation SPHs- Conventional SPHs
- Second generation SPHs- SPHs composite.
- Third generation of SPHs- SPH hybrid.

FIRST GENERATION SPHs (CSPHs)-

These first generation SPHs are prepared by SPHs with fast swelling kinetics and superabsorbent properties. These are polymerized and cross linked with different vinyl monomers and they require a foaming agent, foam stabilizer and a foaming aid, along with these different wetting agents are also added to increase the water absorption rate to less than a minute. Highly hydrophilic acryl amide, salts of acrylic acid, and sulfopropyl acryl ate are mostly used for preparation of CSPHs. Generally dried SPHs are brittle and hard in nature, but when they are dissolved in aqueous fluids, the moisture-induced plasticization of these polymers results into soft and flexible structures. When these polymers are in dry state, handling is very difficult, because during drying process the porous structure becomes collapsed due to the surface tension of water, which pulls the polymer chains together. This problem can be overcome by replacing the water with alcohol, since it has low surface tension, which prevents the porous structure from collapsing during drying

SECOND-GENERATION SPHs - SPH

In second generation SPHs are developed to overcome the lack of desirable mechanical properties in CSPHs, by modifying the conventional SPHs with the addition of superdisintegrants into the formulation. In SPH composites, composite is a matrix, which contains both dispersed phase and continuous phase. The preparation of SPH composites also includes the same monomer, cross linker, and initiating system in CSPHs, but along with these we also use swell able filler, i.e. composite agent (which is cross-linked water absorbent hydrophilic polymer). While this filler dispersed into the reacting mixture, it would swells and absorbs a mixed solution of monomer, cross linker, initiator and the water-soluble foaming additives. Upon polymerization, at the same time the pH of the solution rises (B). polymer chains are formed, since the filler serves as the local point of physical cross-linking. Each composite agent or swollen filler serves as an isolated individual reactor, throughout the polymerization process, in which cross-linking polymerization occurs. As the cross-linking polymerization precedes entire the solution, individual composite agent particles are connected together by connecting the polymer chains.

THIRD-GENERATION SPHs

SPH Hybrids The third generation of SPHs is improved versions of the second generation, and developed based on SPH hybrids for synthesizing SPHs which are having high mechanical and elastic properties. In second generation SPHs, pre-crosslinked matrix-swelling additive is added, where as SPH hybrids are prepared by adding a hybrid agent that can be cross-linked after SPH is formed. The hybrid agent is a water-soluble or water-dispersible polymer that can form crosslinked structure (in a manner similar to forming interpenetrating network) through chemical or physical cross-linking. Examples of hybrid agents are polysaccharides including sodium alginate, pectin, chitosan or synthetic water-soluble hydrophilic polymers such as poly (vinyl alcohol). Once the second network is formed, the whole system becomes similar to interpenetrating polymer networks.⁹

Classification according to polymeric composition:

The method of preparation leads to formations of some important classes of hydro gels. These can be exemplified by the following:

Homopolymeric hydro gels are referred to polymer network derived from a single species of monomer, which is a basic structural unit comprising of any polymer network .¹⁰

(a). **Homopolymers** may have cross-linked skeletal structure depending on the nature of the monomer and polymerization technique.

(b) **Co polymeric hydro gels** are comprised of two or more different monomer species with at least one hydrophilic component, arranged in a random, block or alternating configuration along the chain of the polymer network. ¹¹

(c) **Multi polymer interpenetrating polymeric hydro gel (IPN)** an important class of hydro gels, is made of two independent cross-linked synthetic and/or natural polymer component, contained in a network form. In semi IPN hydro gel, one component is a cross-linked polymer and other component is a non-cross-linked polymer .^{12,13}

Classification based on configuration

The classification of hydro gels depends on their physical structure and chemical composition can be classified as follows:

(A) Amorphous (non-crystalline).

(B) Semi crystalline: A complex mixture of amorphous and crystalline phases.

(C) Crystalline.

Classification based on type of cross-linking

Hydro gels can be divided into two categories based on the chemical or physical nature of the cross-link junctions. Chemically cross-linked networks have permanent junctions, while physical networks have transient junctions that arise from either polymer chain entanglements or physical interactions such as ionic interactions, hydrogen bonds, or hydrophobic interactions ¹⁴.

Classification based on physical appearance

Hydro gels appearance as matrix, film, or microsphere depends on the technique of polymerization involved in the preparation process.

Classification according to network electrical charge

Hydro gels may be categorized into four groups on the basis of presence or absence of electrical charge located on the cross linked chains:

(A) Nonionic (neutral).

(B) Ionic (including anionic or cationic).

(C) Amphoteric electrolyte (impolitic) containing both acidic and basic groups.

(D) Zwitterionic (polybetaines) containing both anionic and cationic groups in each structural repeating unit.

Hydro gel-forming natural polymers include proteins such as collagen and gelatin and polysaccharides such as starch, alginate, and agarose. Synthetic polymers that form hydro gels are traditionally prepared using chemical polymerization methods.

Hydro gel product sensitive to environmental conditions:

As mentioned above, hydro gels as three-dimensional cross linked hydrophilic polymer networks are capable of swelling or de-swelling reversibly in water and retaining large volume of liquid in swollen state.

Hydro gels can be designed with controllable responses as to shrink or expand with changes in external environmental conditions.

They may perform dramatic volume transition in response to a variety of physical and chemical stimuli, where the physical stimuli include temperature, electric or magnetic field, light, pressure, and sound, while the chemical stimuli include pH, solvent composition, ionic strength, and molecular species

The extent of swelling or de-swelling in response to the changes in the external environment of the hydro gel could be so drastic that the phenomenon is referred to as volume collapse or phase transition ¹⁵.

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Stimuli respond swelling hydro gel (Fig-1)

The extent of swelling or de-swelling in response to the changes in the external environment of the hydro gel could be so drastic that the phenomenon is referred to as volume collapse or phase transition ^[10]. Synthetic hydro gels have been a field of extensive research for the past four decades, and it still remains a very active area of research today.

Hydro gel technical features

The functional features of an ideal hydro gel material can be listed as follows ¹⁶

- The highest absorption capacity (maximum equilibrium swelling) in saline.
- Desired rate of absorption (preferred particle size and porosity) depending on the application requirement.
- The highest absorbency under load (AUL).
- The lowest soluble content and residual monomer.
- The lowest price
- . The highest durability and stability in the swelling environment and during the storage.
- The highest biodegradability without formation of toxic species following the degradation.
- PH-neutrality after swelling in water.
- Colorlessness, odorless, non toxic,
- Photo stability.
- Re-wetting capability (if required) the hydro gel has to be able to give back the imbibed solution or to maintain it; depending on the application requirement (e.g., in agricultural or hygienic applications).

Obviously, it is impossible that a hydro gel sample would simultaneously fulfill all the above mentioned required features. In fact, the synthetic components for achieving the maximum level of some of these features will lead to inefficiency of the rest. Therefore, in practice, the production reaction variables must be optimized such that an appropriate balance between the properties is achieved. For example, a hygienic products of hydro gels must possess the highest absorption rate, the lowest re-wetting, and the lowest residual monomer, and the hydro gels used in drug delivery must be porous and response to either pH or temperature.

Process design implications

The production of polymeric hydro gels is typically accomplished by one of two well-established schemes: (a) polymerization of hydrophilic monomers and (b) modification or fictionalization of existing polymers (natural or artificial). Hydro gel: Preparation, characterization, and applications 109 The technology of hydro gel production will be discussed in the following sections with an emphasis on recent methods and techniques.

The original sources of hydro gels are often divided into two main classes; i.e., artificial (petrochemical-based) and natural. The latter can be divided into two main groups, i.e., the hydro gels based on polysaccharides and others based on polypeptides (proteins).

The natural-based hydro gels are usually prepared through addition of some synthetic parts onto the natural substrates, e.g., graft copolymerization of vinyl monomers on polysaccharides. It should be pointed out when the term “hydro gel” is used without specifying its type; it actually implies the most conventional type of hydro gels, i.e., the anionic acrylic that comprises a co polymeric network based on the partially neutralized acrylic acid (AA) or acryl amide (AM) ^[13].

The greatest volume of hydro gels comprises full artificial or of petrochemical origin. They are produced from the acrylic monomers. Acrylic acid (AA) and its sodium or potassium salts, and acryl amide (AM) are most frequently used in the hydro gel industrial production.

The two general pathways to prepare acrylic hydro gel networks are simultaneous polymerization and cross-linking by a polyvinyl cross-linker and cross linking of a water-soluble prepolymer by a polyfunctional cross-linker.

The most common and most versatile technique for the production of synthetic hydro gels is the free-radical multifunctional vinyl monomers. Each of these monomers contains a carbon double bond through which an active center may propagate to produce polymer chains.

The method for generating active centers depends on the particular monomers, solvents, and the reaction conditions to be employed, but may be based on heat (thermal initiators), light (photo initiators), γ -radiation, or electron beams.¹⁷

PREPARATION OF SPHs:-

Synthesis of Super porous Hydro gels:

Synthesis of super porous hydro gels is same to the synthesis of ordinary hydro gels but the only difference is that a foaming agent is added to prepare super porous hydro gels. The timing of the polymerization has to be matched with the timing of foam formation. If the kinetics of the two processes are not matched, then super porous hydro gels with interconnected pores will not be formed. The important step of this process is to use acid to control the polymerization kinetics. Addition of NaHCO_3 leads to foam formation as well as rise in pH, which accelerates the polymerization process. After the addition of NaHCO_3 , polymerization becomes complete within a few minutes. The pH of the monomer mixture is low because of the addition of acid, and this makes polymerization very slow. The addition of NaHCO_3 results in foaming and The pH increase accelerates the polymerization process, which is completed before the foam subsides. This results in formation of super porous hydro gel.

Super porous Hydro gels for Gastric retention:

Any vinyl monomer can be used to prepare super porous hydro gels using the process

The type of monomer included in the super porous hydro gel Preparation significantly affects the overall properties of the super porous hydro gels. Mechanical property is the important property of SPHs. The super porous hydro gels have neither large swelling volume nor good mechanical strength, when acryl amide (AM) is used as the only monomer. When sulfopropylacrylamide potassium salt (SPAK) is used alone, the super porous hydro gels swells to a large size in the simulated gastric fluid (SGF) but are not strong. When AM and SPAK are Copolymerized, however, super porous hydro gels shows good swelling as well as Good mechanical properties.

Super porous Hydro gel Composites:-

The mechanical strength of super porous hydro gels can be improved greatly by incorporating a composite material. Among the many composite materials, Ac-Di-Sol is superior to others in improving the mechanical strength of super porous hydro gels. Ac-Di-Sol can be added to the monomer solution before polymerization and foaming. Addition of Ac-Di-Sol increases structural integrity by increasing the (physical) cross linking density of the super porous hydro gel. If Ac-Di-Sol is incorporated in very large proportion however, a good mixing of all the ingredients becomes difficult because of increase in the viscosity of the solution.

Acidification of the SPAK Super porous hydro gels: -

Pretreatment of SPHs by acidification increase the mechanical strength of the super porous hydro gels. The ultimate compression pressure (UCP) is used to measure the mechanical strength of super porous hydro gels. UCP value is determined by applying increasing amounts of weights until a point when the super porous hydro gel started cracking. The pressure at this point is defined as penetration pressure (PP) and calculated by the following equation:

PP = Fu/S

are commonly used to evaluate SPH mechanical Where Fu is the ultimate compressive force at complete breakage of polymer and S is the contact area of the lower touch.¹⁸

EVALUTION TESTS FOR SUPPER POROUS HYDROGLS**1. Measurement of gelation kinetics**

As the polymerization reaction proceeded, the viscosity continuously increased until the full network structure (gel structure) was formed. The gelation time was defined as a period of time for gel formation following addition of glyoxal and measured by a simple tilting method after adjustment of pH to 5.0 with acetic acid. It was determined by the duration of time taken by the reactant mixture to become viscous and the viscous solution no longer descended in the tilted tube position.¹⁹

2. Drug loading

The method of soaking or equilibration was employed for drug loading. In this method the amount of buffer necessary for complete swelling of super porous hydro gel was determined. Thereafter the drug solution in the determined amount of buffer which was required for complete swelling was prepared. Subsequently, super porous hydro gel was placed in the drug solution and left until all the drug solution was sucked up. Then the completely swollen super porous hydro gel loaded with the drug was placed in an oven at 30°C for drying overnight.²⁰

3. Swelling studies

A completely dry, pre-weighed, disc-shaped super porous hydro gel was weighed and then immersed in excess of swelling medium. At various time intervals, the hydro gel was removed from the solution and weighed after excessive solution on the surface was blotted. Data presented in this experiment were the mean values of triplicate measurements. Results were calculated according to the following equation.²¹

$$Q = (M_s - M_d)/M_d$$

Where Q is the swelling ratio

Ms the mass in the swollen state

M_d the mass in the dried state.

4. Porosity measurement

For porosity measurement, the solvent replacement method was used. Dried hydro gels were immersed overnight in absolute ethanol and weighed after excess ethanol on the surface was blotted. The porosity was calculated from the following equation:

$$\text{Porosity} = (M_2 - M_1/\rho V)$$

Where

M₁ and M₂ are the mass of the hydro gel before and after immersion in absolute ethanol,

ρ is the density of absolute ethanol

V is the volume of the hydro gel²²

5. Determination of void fraction

The void fraction was calculated by the following equation:

$$\text{Void Fraction} = \text{Dimensional volume of the hydro gel} / \text{Total volume of pores}$$

The void fraction inside super porous hydro gels was determined by immersing the hydro gels in HCl solution (pH 1.2) up to equilibrium swelling. The dimensions of the swollen

hydro gels were measured and by using these data, sample volumes were determined as the dimensional volume. In the meantime, the amount of absorbed buffer into the hydro gels was determined by subtracting the weight of dried hydro gel from the weight of swollen hydro gel and the resulting values were assigned as the total volume of pores in the hydro gels.²³

6. Water retention

The following equation was used to determine the water retention capacity (WR_t) as a function of time:

$$WR_t = (W_p - W_d)/(W_s - W_d)$$

Where W_d is the weight of the dried hydro gel, W_s is the weight of the fully swollen hydrogel, and W is the weight of the hydro gel at various exposure times. For determination of the water-retention capacity of the hydro gels as a function of the time of exposure at 37°C, the water loss of the fully swollen polymer at timed intervals was determined by gravimetric.²⁴

7. Mechanical Properties

The compressive strengths of various super porous hydro gel formulations were determined using a bench comparator. Briefly, after the fully swollen hydro gel was put longitudinally under the lower touch of a bench comparator, different scale loads were successively applied on the upper touch until the point where the hydro gel could not support any more weight and completely fractured. The pressure at this point was defined as penetration pressure (PP) and calculated by the following equation:

$$PP = F_u/S$$

Where F_u is the ultimate compressive force at complete breakage of polymer
 S is the contact area of the lower touch.²⁵

8. Determination content of drug

A weight of super porous hydro gel containing 4 mg of drug in 100 ml volumetric flask was treated with about 10 ml hydrochloric acid solution of pH 1.2 mixed well and made up to volume. The mixture was filtered and drug content was determined using UV-Vis spectrophotometer at 228 nm.

9. FT-IR spectroscopy

FT-IR spectroscopy was employed to ascertain the compatibility between the drug and the polymers. It was also used to investigate the chemical structure of the synthesized hydro gels. The FTIR spectrum was recorded over the range of 400–4000 cm^{-1} using KBr pellet method by Fourier-Transform Infrared (FT-IR) spectrophotometer, (Shimadzu, FT- IR 8400S, Japan).

10. Scanning electron microscopy

The dried super porous hydro gels were used for scanning electron microscopy (SEM) studies to determine the morphology of the dried samples. Scanning electron microscope was used after coating the samples with gold using a Hummer Sputter Coater. Images were captured using a digital capture card and Digital Scan Generator.

11. In vitro release studies

In vitro drug release of rosiglitazone male ate from the super porous hydro gels was evaluated in triplicates at using a United States Pharmacopoeia (USP) Dissolution Test Apparatus Type 2 .(paddle method) . At regular time intervals, 10 ml of the dissolution medium were withdrawn, replaced with an equivalent volume of fresh dissolution fluid and analyzed for the drug using a UV-Vis spectrophotometer. ²⁵

The obtained data were fitted into various release models. To determine release mechanism, the parameters n and k of the Korsmeyer-Peppas equation were computed

12. Structure and size of pores

The scanning electron microscopic photograph of super porous hydro gel clearly shows the presence of pores on the surface. The super porous hydro gel has high porosity and is responsible for faster swelling of super porous hydro gels when compared to conventional hydro gels.

13. In vitro release studies

The release of the drug was found to be dependent to the amount of chitosan and cross linker and as the amount of chitosan increased, the release was faster since chitosan is a pH sensitive monomer. Drug release was found to be inversely related to the amount of cross linking agent and at higher crosslink density where the openings are less release is also low. The best fit model was found to be Korsmeyer-peppas model and since the value of n , the time exponent, calculated from this equation was found to be greater than 1 in all the drug release profiles, the release mechanism is assumed to be super case-II transport, wherein multiple release mechanisms exist. ²⁶

PHARMACEUTICAL APPLICATIONS OF SPHs:

1. Development of Gastric Retention Devices Gastric retention devices: are mostly useful in delivery of many drugs. From the last 2 decades using well-established principles to prevent the dosage form from exiting the pylorus during gastric emptying. The main aim to develop gastric retention devices is to make an oral formulation, which doesn't pass through the pylorus by fast swelling to a large size. They are most beneficial in the delivery of drugs, which acts locally in stomach (e.g., antacids and antibiotics for bacteria-based ulcers etc), or primarily absorbed in the stomach. These gastric retention devices are also useful for drugs which are or degraded in the colon (eg: Metaprolol) and which are poorly soluble in alkaline pH medium. However prolonged gastric retention devices are not necessary in cases like, the drugs which are primarily absorbed in the colon (since it sustain the blood levels up to 24hours), and also for drugs which are unstable in the presence of acidic pH. This gastric retention is also not desirable for drugs like aspirin, and non-steroidal anti inflammatory drugs. ²⁷

2. Development of Fast-Dissolving Tablets

The major benefit of the fast-dissolving tablet technologies is that the dosage forms can be administered easily in the absence of water and without the need of swallowing. This feature is especially useful to children and the elderly. There are basically three different technologies were developed from the initial success of first fast-dissolving tablets: They are freeze-drying, sublimation or heat molding, and direct compression. By using freeze-drying technology the tablets which are dissolved within 5 seconds can be prepared, whereas by using sublimation or molding technology, tablets which are dissolved within 15 seconds can be prepared. But these two methods are having the disadvantage that they are expensive and the produced tablets are mechanically weak. Therefore direct compression technology was developed, which is less expensive and prepared tablets are having good physical resistance. By this method the prepared tablets are disintegrate within 10 seconds due to the fast uptake of water into the core of tablet. This direct compression method involves the addition of fine particles of super porous Hydro gels to the drug and other excipient.

3. Development of Diet Aid: Diet soft drinks, meal replacement shakes, diet biomedical device for treating aneurysms. The SPHs can theoretically occupy a significant portion of the stomach space due to their rapid and extensive swelling, leaving less space for food, and thereby suppressing appetite. This type of system can help to lose weight in obese people. Maintaining the integrity and volume of the swollen SPH for a substantial period of time is the major challenge in the use of SPHs as a weight loss aid. Developing new drug delivery technologies and utilizing them in product development is critical for pharmaceutical companies to survive. Super porous hydro gels are a new class of hydro gel materials that, regardless of their original size, rapidly swell to a large size. Different generations of SPHs evolved to address the needs for certain pharmaceutical applications, including gastric retention. Studies have shown that some SPH formulations are potentially exploitable for heavy duty applications in which superb swelling and mechanical properties are required in harsh swelling media. The feasibility of using these SPHs in oral solid and semi-solid dose formulations have also been studied. Preliminary safety and efficacy of certain SPH formulations have been evaluated in-vivo, paving the way for further development of these materials for pharmaceutical, food and biomedical applications. Super porous hydro gels can be made elastic, and this property can minimize their rupture. Various pharmaceutical and biomedical applications of super porous hydro gels have been made, and several products are under development. The unique properties of super porous hydro gels can also be used for no pharmaceutical and non-biomedical application²⁸

4. Development of Occlusion Devices for Treatment of Chemoembolization

Chemoembolization is a combined method of embolization and chemotherapy. Embolization has been used for cancer treatment by restricting the oxygen supply to the growing tumours. This method could be combined with chemotherapeutic agents to achieve local delivery and low systemic toxicity. A chemotherapeutic agent and an anti-angiogenic agent could be loaded into SPHs for chemoembolization therapy. The property of fast swelling to a large size of super porous hydro gels has been useful in the development of a new the size and shape of an aneurysm site is predetermined by a non-invasive imaging method, a super porous hydro gel of the same shape (but smaller size) can be made. When a super porous hydro gel is deployed at the aneurysm site, it swells quickly to occupy the space and make the blood clot. Deposition of super porous hydro gels resulted in up to 95% aneurysm occlusion without any evidence of parent artery compromise and inflammatory response. A new occlusion device made of a combination of super porous hydro gel and

platinum coils, known as Hydro coil, is currently under development. A bioactive can be released from the super porous hydro gels either to enhance or to delay blood clotting

5. Biomedical applications- In the biomedical area, SPHs and SPH composites can be used to make various biomedical devices, such as artificial pancreas, artificial cornea, and artificial skin, articular cartilage, soft tissue substitutes, cell growth substrates in tissue engineering, burn dressings, surgical augmentation of the female breast, or hem perfusion in blood detoxification and in the treatment of uremia. Vascular in growth into super porous hydro gels are useful for cell transplantation, tissue engineering and in combination with cell therapies. Hydroxyapatite containing super porous hydro gel composites³⁵ and novel scaffolds of poly (2-hydroxyethyl methacrylate) super porous hydro gels are useful for bone tissue engineering²⁹

ADVANTAGES OF SPHs –

Super porous hydro gels have three unique properties that conventional hydro gels do not have. The swelling rate is very fast.

1. The Super porous hydro gels swell completely within a minute regardless of the size of the dried super porous hydro gel.

2. Super porous hydro gels swell to such an extent that the weight of fully swollen super porous hydro gel is higher than the weights of dried super porous hydro gels.

3. Though the super porous hydro gels contain small percentage of solid content of the total weight, it can exert significant expansion force during swelling.

4. Super porous hydro gels can also be made elastic, which minimizes their rupture.

5. The unique properties of super porous hydro gels can also be used for non pharmaceutical and non-biomedical applications.³⁰

Conclusion:

Super porous hydro gels are a new class of hydro gel materials that, regardless of their original size, rapidly swells to a large size. Different generations of SPHs evolved to address the needs for certain pharmaceutical applications, including gastric retention. It also involved technologies adopted for hydro gel production together with process design implications, preparation process. An innovated category of recent generations of hydro gel materials was also presented in some details. Super-porous hydro gels are new materials that, regardless of their original size, rapidly swell to a large size. Different generations of SPHs evolved to address the needs for certain applications.

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