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Review Article

A REVIEW ON INTERPENETRATING POLYMER NETWORK

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ABSTRACT

Natural polymers such as proteins and polysaccharides though very useful exhibit a limitation in their reactivity and process ability. These shortcomings were overcome by chemical and physical alteration of natural polymers. Among various investigations, the interpenetrating polymer networks (IPNs) for hydro gels have attracted much attention. It is a combination of at least two polymer chains each in network form, of which at least one is synthesized and/or cross linked in the immediate presence of the other without any covalent bonds between them. Water absorption and desorption properties of these IPN hydro gels were analyzed extensively. The water imbibing property of IPN is responsive not only to the chemical architecture of the macromolecular matrices, but also to the surrounding conditions such as pH, temperature, ionic strength, magnetic field, ultraviolet light, etc. These systems which are also termed as 'hungry networks' or 'intelligent polymers' are currently the focus of considerable scientific research due to their potential technological application in a large number of areas: medicine, industry, biology and environmental clean-up. Some of the significant applications of IPNs include artificial implants, dialysis membranes, drug-delivery systems, burn-dressings, etc. This review disserts about application and properties of IPN have enabled this polymer to become the choice of the pharmacologist as oral drug delivery matrices and other applications.

Keywords*:* Natural polymers, Interpenetrating polymer network, Water imbibing property, Biomedical applications, IPN

INTRODUCTION

Polymer mixtures or blends are widely used materials in modern industry. The chemical and physical combination methods and properties of multipolymers have of great practical and academic interest for the controlled release of drugs because they provide a convenient route for the modifications of properties to meet specific needs. They represent one of the most rapidly growing areas in polymer material science. This field got its intensive development during recent years and the literature on this topic is really immense.

An Interpenetrating polymer network (IPN) is a polymer comprising two or more networks which are at least partially interlaced on a polymer scale but not covalently bonded to each other. The network cannot be separated unless chemical bonds are broken. The two or more networks can be envisioned to be entangled in such a way that they are concatenated and cannot be pulled apart, but not bonded to each other by any chemical bond.

Classification of IPN [3]

Based on Chemical Bonding

Covalent cross linking leads to formation of hydro gels with a permanent network structure, since irreversible chemical links are formed. This type of linkage allows absorption of water and/or bioactive compounds without dissolution and permits drug release by diffusion

- **Covalent Semi IPN**- A covalent semi IPN contains two separate polymer systems that are cross linked to form a single polymer network.
- **Non Covalent Semi IPN**- A non covalent semi IPN is one in which only one of the polymer system is cross linked.
- **Non Covalent Full IPN**- A non covalent full IPN is a one in which the two separate polymers are independently cross linked.

Based on Arrangement Pattern

- Sequential IPN- In sequential IPN the second polymeric component network is polymerized following the completion of polymerization of the first component network.
- Novel IPN- Polymer comprising two or more polymer networks which are at least partially interlocked on a molecular scale but not covalently bonded to each other and cannot be separated unless chemical bonds are broken.
- Semi IPN- If only one component of the assembly is cross linked leaving the other in a linear form, the system is transferred as semi IPN.
- Simultaneously IPN- Simultaneously IPN is prepared by a process in which both component networks are polymerized concurrently, the IPN may be referred to as a simultaneously IPN.

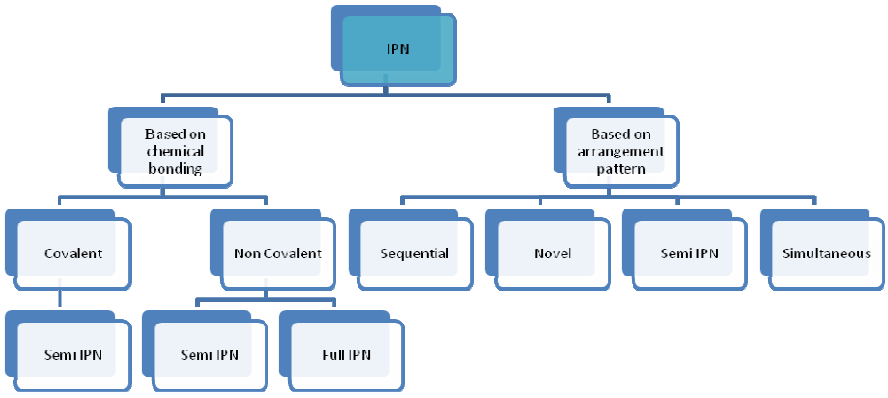

Fig. 1: Different forms of IPN

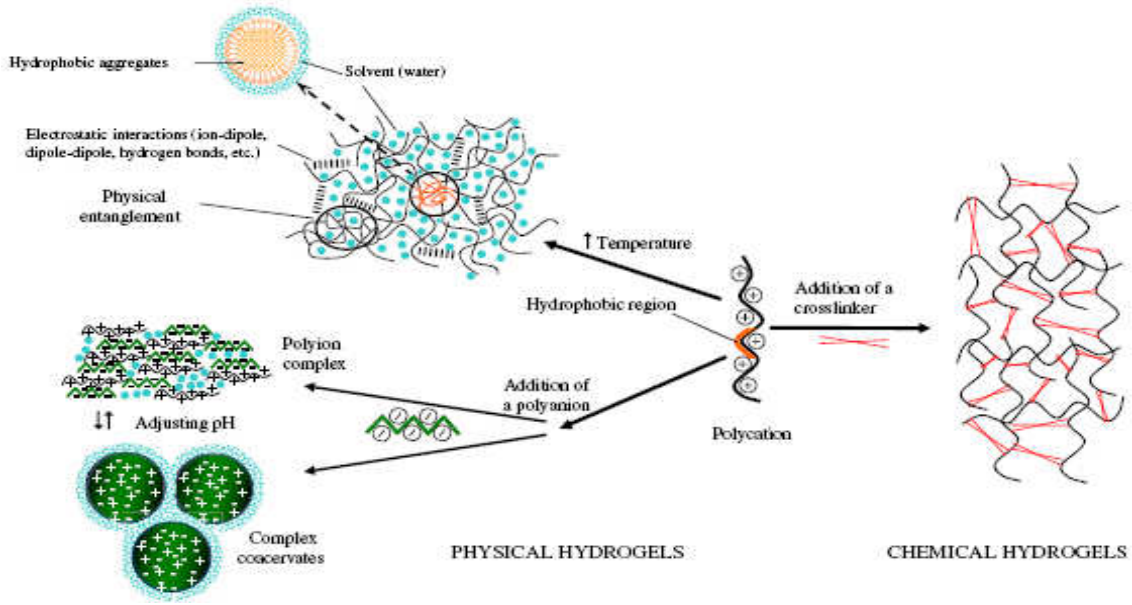

Fig. 2: (Source S. Farris et al), Overview of mechanisms for formation of physicalandchemicalhydrogels[16]

Properties of IPN

- A gel composed of two interpenetrating networks by cross linking a polymer (or polyelectrolyte) into a pre-existing highly cross linked network of a polymer (or polyelectrolyte) of a different kind have increased elastic and mechanical properties which was measured by the stress–strain behavior and comparing their elastic moduli and breaking points.
- According to US Patent data the calculated true stress per unit solid and strain shows that PGA/PAA IPNs are much stronger than either the individual polymer networks or copolymers. The effect of IPN formation on tensile strength is non linear, as the maximum strength is many times higher than that of PEG-PAA copolymer. The elastic moduli and tensile strength can be modified by changing the molecular weight.
- Oxygen permeability- IPN hydro gels composed of PEG as the first network and a second network of poly acrylic acid had oxygen permeability of 95.9±28.5 Barrers.
- Shape memory-Materials are said to show shape memory effect if they can be deformed and fixed into a temporary shape and recover their original permanent shape only on the exposure of external stimuli, like heat, light etc [4]
- Equilibrium water content- IPN can swell in solvent without dissolving. The water content of hydro gels was evaluated in terms of the swollen weight to dry weight ratio. The dry hydro gel was weighed and then immersed in water as well as phosphate buffered saline. At regular intervals the swollen gel was lifted, patted dried and weighed until the equilibrium was attained. The percentage of equilibrium water content(WC) was calculated from the swollen and dry weight of hydro gel:

$$WC = \frac{W_s - W_d}{W_s} \times 100$$

Where, W_s and W_d are weight of swollen and dry hydro gels respectively.[26-32]

- IPN systems are known to increase the phase stability of the final product.[5]
- Thermodynamic incompatibility can be overcome due to the permanent interlocking of the network segments
- High thermo stability
- Good dielectric properties
- Radar transparency
- Nutrient permeability
- Optical clarity- The percentage of light transmittance was found to be 90% and the refractive index was found to be 1.35

Synthesis of Some IPN

Synthesis of IPN based on the US Patent 2007/0179605 A1

The starting material to make the hydro gel was a solution of telechelic macro monomers (110) with functional end groups (112). They were polymerized to form a polymer network followed by the addition second polymer (140) of hydrophilic monomers (130) which were polymerized and cross linked in the presence of the first polymer(120). This resulted in the formation of IPN hydro gel (150). Polyethylene glycol (PEG) can also be used a first polymer as it is biocompatible, soluble in aqueous solution and gives wide range of molecular weights and chemical structures. IPN hydro gel was also prepared by UV initiated free radical polymerization. I t used the first network as PEG diacrylate (PEG-DA) or PEG dimethacrylate (PEG-DMA) dissolved in phosphate buffered saline (PBS). The following diagram shows steps in IPN preparation.[2]

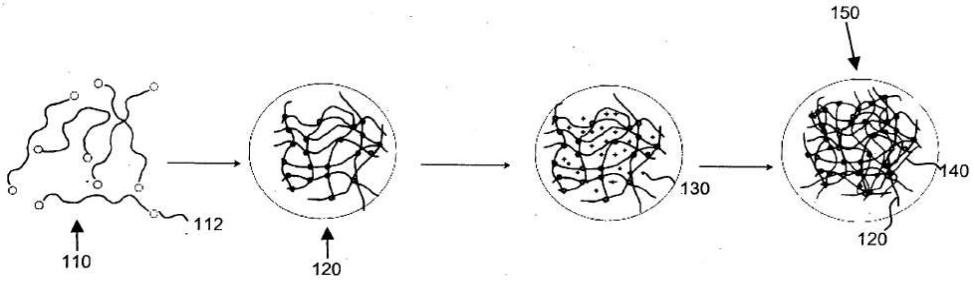

Fig. 3: (Source: David Myung et al, US 2007/0179605 A1) IPN hydro gels composed of poly (ethyleneglycol) macromere (PEGM) and chitosan[2]

There are two methods of preparation: sequential and simultaneous but here simultaneous method is used. PEGM was synthesized (Kim et al., 1995) and dissolved in 2 wt% acetic acid to give 10 wt% PEGM solutions. Chitosan was also dissolved in 2 wt% acetic acid and the solid content in solution was 1.5 wt%. A given amount of PEGM/chitosan mixed solution was obtained by mechanical stirring for 2 h. To this was added 2, 2-dimethoxy-2-phenyl acetophenone (0.45 wt% based on the weight of PEGM) and 5×10-5 mol of glutaraldehyde under agitation. The mixed solution was poured into a circular glass mould and was maintained at room temperature. Then, UV irradiation was performed to polymerize and crosslink PEGM within the cross linked chitosan network using a 450 W UV lamp (Ace Glass Co.) placed above the mould at a height of 20 cm for 1 h until gelation occurred. Finally, IPN samples obtained were washed with deionized water and dried under high vacuum for 2 days.[1, 31]

IPN hydro gels composed of PVA and chitosan

PVA was added to deionized water and heated at 80ºC for 1 h to make a solution containing 10 wt% PVA by weight. Acryloyl chloride (3 wt %) and 1 wt. % DMPAP in tetrahydrofuran (THF) were added to the PVA aqueous solution. Chitosan was dissolved in 4wt% acetic acid aqueous solution to prepare 3 wt. % chitosan solutions. The chitosan solution was then added to the PVA mixture. This mixture was mixed for 30 min. The mixed solution was poured into a Petri dish and stored in a box and exposed to a 450-W UV lamp (Ace Glass, USA) placed 20 cm above the mould for1 h under an N_2 atmosphere. The weights of the PVA-to-chitosan mixture were adjusted to 1:3, 1:1 and 3:1, respectively. The designation of each sample is listed in Table 1. The irradiated samples were dried in an oven at 50ºC for 12 h. The dry films were removed from the oven and washed with deionized water to remove any nonreactive materials that were not incorporated into the network.[6]

Table 1: Composition and designation of IPN hydro gels

Sample designation	PVA (wt %)	Chitosan
IPN1	75	25
IPN2	50	50
IPN3	25	75

Preparation of semi-IPN

The semi-IPNs were prepared by a free radical polymerization method. Prior to performing experiments, the reactants (Poly vinyl alcohol) PVA and *N*, *N9*-methylene bis-acrylamide (MBA) were degassed by purging dry N_2 for 30 min. Then, into a Petri dish (diam. 20, Corning) were added 0.75 g PVA, 14.0 mM AM, 17.3 mM ST, 0.12mM MBA, 0.073 mM KPS, and 1.4 M water. The dish was covered with the lid and reaction mixture homogenized by manual mixing. The Petri dish was then kept in an oven maintained at 80ºC for 3 h which was found to be a sufficient time for formation of the IPN. The IPN so formed was taken out and purified.[8, 35]

Synthesis of Poly (dimethylsiloxane) (PDMS) IPNs

Samples of the extracted and dried base networks (Base networks were formed by end-linking the long-chain PDMS with the tetra-functional cross linker tetrakis (dimethylsiloxy) silane in the presence of a platinum catalyst were swollen to various extents with short chains and proper amount of the catalyst cis-dichlorobis(diethyl sulfide) platinum(II)/toluene solution. The networks were put in an oven at 30 ºC to facilitate the swelling, and to evaporate the toluene present with the catalyst. For high concentration of absorbed short chains, more time was needed to swell the base networks with the short chain PDMS. After the networks were fully and uniformly swollen, a stoichiometric amount of cross-linker was incorporated with a small amount of toluene onto the inverse side of the network. The samples were put in a refrigerator overnight to allow the cross-linker to diffuse before extensive reaction takes place. After sufficient time had elapsed for homogeneity to be attained, the PDMS short chains were tetra-functionally cross-linked by heating the samples to 35 ºC for 2 days. Re-extractions and swelling gave soluble fractions from the second end-linking process and the equilibrium swelling ratios of the interpenetrated networks in toluene[9]

Semi IPNs

A polymer comprising one or more networks or one or more linear or branched polymer(s) characterized my penetration on a molecular scale of at least one of the networks by at least some of the linear or branched macromolecules. Semi IPNs is distinguished from IPNs because the constituent linear or branched polymers can, in principle be separated from the constituent polymer network(s) without breaking chemical bonds; they are polymer blends.

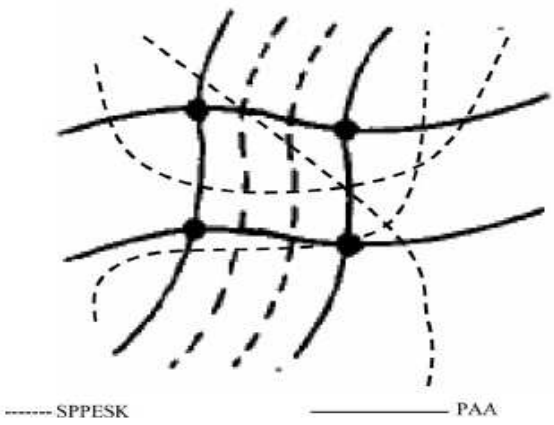

Fig. 4: (Source, X. Wu et al) sIPN structure[18]

Drug molecules which are hydrophobic and small in size (low molecular weight), diffuse through the wall of silicone tubing at a controlled rate, polymers have occupied a central status in drug release control as well as in the fabrication of drug delivery systems. [(25)] In comparison with other classes of materials, polymeric materials, including natural, semi natural, and synthetic polymers, present countless opportunities to modulate the properties of drug delivery systems other than to meet several criteria such as biodegradability, biocompatibility, and reproducibility because of their diversity in chemistry, topology, and dimension. Novel acrylic-based polymers are used as mucoadhesive delivery systems because they are very beneficial to overcome the shortcomings of oral drug administration and they exhibit very high adhesive bond strength in contact with tissues. Thus, they allow the localization of the drug at the site of absorption increasing its residence time at the absorbing tissue and increasing drug bioavailability. Currently several approaches are being pursued for improved delivery of therapeutic products like sheets, films, hydro gels, calcifiable matrix, sponges, tablets, capsules, transdermal patches, microspheres, nanoparticles etc.[10, 11, 12, 13, 27]

Drugs Administered

Gentamycin sulphate and Vancomycin hydrochloride

Conventional drug delivery methods have uncertain period of antibiotic delivery as the drug carrier is non-degradable and causes induction of the foreign body reaction. Polymer loaded drugs optimize the dose of antibiotics (gentamycin sulphate (GS) and vancomycin hydrochloride (VCl)) -loaded interpenetrating network hydro gel based on poly(acrylic acid (AA)) and gelatin for at least 6 weeks in vivo release of drug at the site of infection without systemic toxicity. The performance of the implant was evaluated by gross examination, histological, microbiological evaluation, radiography and scanning electron microscopy (SEM). GS or VCl was loaded onto the devices by swelling phenomenon. The devices were IPN devices based on poly (AA) and gelatin, which are cross linked selectively using 0.3 mol % of N, N0-methylene bisacrylamide and 1 wt% of glutaraldehyde, respectively.[13]

Stomach-specific drug delivery of clarithromycin

Interpenetrating polymeric network (IPN) hydro gels were prepared by varying the concentration of cross linking agent (glutaraldehyde). The amount of chitosan, poly (acrylic acid), poly (vinyl pyrrolidone) and *N*, *N'*-methylenebisacrylamide were kept constant in all formulations. The entrapment efficiency of clarithromycin in

different formulation of IPN hydro gel was found to be 94.2±2.4%, 95±2.1%, 95.4±2.7% and 96.8±1.9% for FC1, FC2, FC3 and FC4 respectively.[28]

Release of chlorphenramine maleate

Spherical, semi-interpenetrating polymer network beads of chitosan and glycine, cross linked with different concentrations of glutaraldehyde were prepared for controlled release of drugs. The structural and morphological studies of the beads were carried out with FTIR and SEM techniques. The swelling behavior of the beads at different time intervals was monitored in solutions of different pH. Structural changes of the beads in response to solution pH were put forward using the data obtained from IR/UV spectral analysis. The release experiments were performed in solutions of pH 2.0 and pH 7.4 at 37°C, using chlorphenramine maleate as a model drug. The results indicate that, chitosan might be useful as a vehicle for controlled release of drugs.

Release of theophylline

An IPN composed of polyvinyl alcohol and poly acrylic acid was used to release theophylline in controlled manner.

❖ Polymeric material comprising an IPN network of a polyol(allyl carbonate)

Eg. Nouryset®200

❖ IPN formation of graft copolymer of guar gum with modified poly(acryl amide) to form hydro gel microspheres. The microspheres loaded with two antihypertensive drugs, verapamil hydrochloride and nifedipine. IPN based microspherical formulation was also used for the prolonged delivery of anti-cancer drug such as capecitabine.

Applications

Corneal Transplantation

Over 10 million people worldwide are blind due to corneal disease. Corneal transplantation is highly effective at treating this condition. Artificial corneas offer an alternative treatment that has potential for widespread, cost-effective distribution to patients. These devices come in two general categories: tissue-engineered corneas and synthetic corneal prostheses (keratoprostheses). While tissue-engineered constructs containing functional corneal cells are extremely promising, they are still in preclinical development. A number of keratoprostheses are now available to restore sight to individuals with severe blindness refractory to standard transplantation. However, these devices are still only reserved for cases in which human donor transplants fail. PEG/PAA interpenetrating networks were synthesized by a two-step sequential network formation technique based on UV-initiated free radical polymerization. A precursor solution for the first network was composed of 50% w/w purified PEG-diacrylate (PEG-DA) dissolved in deionized water along with 2-hydroxy-2-methyl propiophenone, a UV-sensitive free-radical initiator, at a concentration of 1% with respect to the PEG-DA. The solution was cast into a glass/Teflon mold, covered with a glass plate, and reacted under a UV light source at room temperature. The mold consisted of Teflon spacers placed between glass plates. Upon UV exposure, the precursor solution underwent free-radical induced gelation and became insoluble in water. The resulting transparent PEG hydro gel was gently peeled off the glass with a metal spatula and had a smooth, homogeneous surface. To incorporate the second network, the hydro gel was removed from the mold and immersed in a 50% v/v acrylic acid solution with 1% v/v (with respect to the monomer) 2- hydroxyl-2-methyl propiophenone as the photo initiator, and 1% v/v (with respect to the monomer) triethylene glycol dimethacrylate as the cross linking agent for 24 h at room temperature. The swollen gel was then placed back between glass plates along with Teflon spacers and exposed to the UV source. In this way, the acrylic acid monomers were polymerized within the polyethylene glycol network to form an interpenetrating polymer network structure. Following synthesis, the PEG/PAA hydro gels were washed extensively in Dulbecco's phosphate buffered saline (DPBS) with repeated solvent exchanges at 37 ºC for 5 days to remove any unreacted components and to facilitate equilibrium swelling. The water content of the hydro gels increased from 80% to about 90% after equilibration in DPBS.[30]

Scafffolds

Scaffolds used in tissue engineering applications, particularly for articular cartilage repair should demonstrate compatible biological and physical properties which match the physiological conditions in vitro and in vivo. The major function of the scaffolds is to provide a temporary support to body structures to allow the stress transfer over-time to injured sites, and facilitate tissue regeneration on the scaffolds. Hydro gels are ideally used as inject able scaffolds due to their mass is composed of water primarily, they can be used to fill irregularly shaped defects, allow minimally invasive surgical procedures and act as facilitator to incorporate with cells and bioactive agents. In cartilage engineering, hydro gels are being used to encapsulate cells and growth factors in a polymer network, which immobilizes the cells and allows differentiation in chondrocytes more effectively by forcing them to retain in a rounded shape.[14, 19, 37]

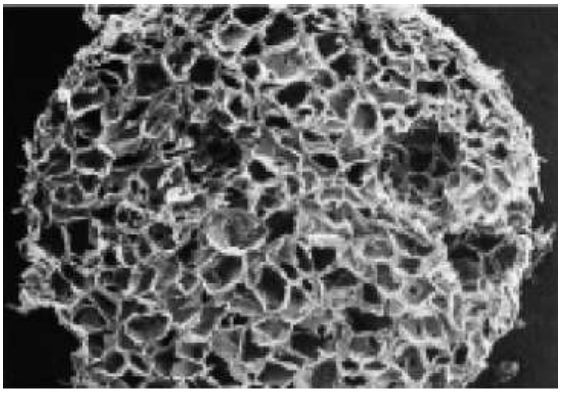

Fig. 5: A synthetic polymer scaffold synthesized from D, D-L, L poly lactic acid[35]

Control Neural Stem Cell Behaviour

Highly-regulated signals surrounding stem cells, such as growth factors at specific concentrations and matrix mechanical stiffness, have been implicated in modulating stem cell proliferation and maturation. However, tight control of proliferation and lineage commitment signals is rarely achieved during growth outside the body, since the spectrum of biochemical and mechanical signals that govern stem cell renewal and maturation are not fully understood. Therefore, stem cell control can potentially be enhanced through the development of material platforms that more precisely orchestrate signal presentation to stem cells. Using a biomimetic interfacial interpenetrating polymer network (IPN), we define a robust synthetic and highly-defined platform for the culture of adult neural stem cells. IPNs modified with two cell-binding ligands, CGGNGEPRGDTYRAY from bone sialoprotein [bsp-RGD (15)] and CSRARKQAASIKVAVSADR from laminin [lam-IKVAV (19)], were assayed for their ability to regulate self-renewal and differentiation in a dose-dependent manner. IPNs with >5.3 pmol/cm2 bsp-RGD(15) supported both self-renewal and differentiation, whereas IPNs with lam-IKVAV(19) failed to support stem cell adhesion and did not influence differentiation. The IPN platform is highly tunable to probe stem cell signal transduction mechanisms and to control stem cell behavior in vitro.[15, 34]

Polymer for Food Packaging

For more than fifty years, plastic polymers have been the most practical and economical solution for packaging applications due to their low cost; ready availability; excellent optical, mechanical, and barrier properties; heat stability; and resistance against water and grease. Despite these advantages, environmentalists have urged replacement of plastics with materials from renewable resources, because plastic films are neither totally recyclable nor biodegradable and may cause serious environmental and waste disposal problems. Although high development costs and lack of

available alternate products limited progress in this direction, recent explosions in prices of petroleum products have brought this problem to the forefront again, emphasizing the limited nature of the crude oil resources and providing compelling economic incentive for the exploration of renewable alternatives based on biomaterials. Indeed, these changes in the competition scene make it both imperative and profitable to focus research on renewable bio-materials, addressing development of new techniques and methods that take specific advantage of unique and individual features of readily-available biopolymers. [16]

Nanocomposite Polymer Hydrogels

The technological need for new and better soft materials as well as the drive for new knowledge and fundamental understanding has led to significant advances in the field of nanocomposite gels. A variety of complex gel structures with unique chemical, physical, and biological properties have been engineered or discovered at the nanoscale. The possibility to form self-assembled and supramolecular morphologies makes organic polymers and inorganic nanoparticles desirable building blocks for the design of water based gels. In general, nanocomposite polymer hydro gels may be defined as cross-linked polymer networks swollen with water in the presence of nanoparticles or nanostructures. The polymer is cross-linked to form a network via chemical or physical interactions. The chemical cross-linking is permanent due to covalent bonds. The physical interactions are non-covalent in nature and often a result of hydrogen bonding, hydrophobic, and ionic interactions. Nanoparticles add unique physical properties to polymer hydro gels such as responsiveness to mechanical, optical, thermal, barrier, sound, magnetic, electric stimulation, etc. These unique properties lead to applications in the electronics, optics, sensors, actuators and micro fluidics sectors, as well as catalysis, separation devices, drug delivery, and many other biotechnological areas. The combination and formulation of synthetic and natural polymers with nanoparticles and biomolecules synergistically allows combining advantageous chemical, physical, and biological properties to produce nanocomposite hydro gels that support the repair and regeneration of human tissues and body functions. Various nanocomposite hydro gels are listed below:

- Polymer/silicate-based nanocomposite gels
- Poly(ethylene oxide)–silicate nanocomposites
- Poly(acryl amide)– and poly(vinyl alcohol)–silicate nanocomposites
- Polymer–metal nanoparticle hydro gels
- Polymer–magnetic nanoparticle hydro gels

Applications of nanocomposite hydro gels for tissue engineering usually depend on the combination of functional properties that are engineered into the nanocomposite hydro gels to make these materials more versatile. Creative approaches incorporate biomolecules into magnetic nanoparticle (5–10 nm) gels for chemotherapeutic loading and for tumor-associated bimolecular binding nanocomposite polymer hydro gels with bentonite have shown promising potential in drug delivery applications.[17, 25]

Use in Fuel Cells

The special structure and variety of components of IPNs make it possible to tailor the properties of IPN membranes, so as to improve the dimensional stability, thermal and mechanical properties as well as reduce the phase separation of the membranes. A novel interpenetrating polymer network PEM was prepared by in situ polymerization of acrylic acid (AA) in the presence of sulfonated poly (phthalazinone ether sulfone ketone) (SPPESK) in a *N*-methyl-2-pyrrolidone (NMP) solvent, using methylene-bis-acrylamide (MBA) as cross-linker of AA. Properties of water uptake, proton conductivity and thermal stability were examined. Due to the numerous carboxyl group introduced by acrylic acid the IPN membranes exhibit high water uptake. Permanent entanglements of the cross-linked PAA and SPPESK chains in the IPN membranes endow the membranes with good dimensional stability, as well as high water uptake. Proton conductivity of the IPN membranes can be adjusted by changing the ratios of MBA/AA and SPPESK/AA with a given initial DS of SPPESK. Proton conductivity of the DS0.71-2%-0.25 IPN membranes reached a high value of 1.882×10−2 S/cm, nearly 3.9 times and 1.2 times as that of the corresponding SPPESK and Nafion 112 membranes under the same testing condition, respectively. TGA analysis indicates that the present interpenetrating method does not decrease the thermal stability of the proton exchange membranes. One single *T*g and dense morphology of the SPPESK/PAA IPN membranes provide evidence for the miscibility of the two components of the IPN. Sulfonated aromatic hydrocarbon polymers therefore become one of the promising materials for PEMs, due to their high water uptake and low price. While further modifications are still needed for these sulfonated polymers because it is difficult to have a balance of their proton conductivity and mechanical stability in hydrated state.[18]

Future Aspects

Solar cells

Its contains thin film of polymers alternative to silicon based solar cells. Novel semiconducting polymers based on alternating ester substituted thieno [3, 4 b]thiophene and benzodithiophene units. These polymers exhibit a synergistic combination of properties that lead to an excellent photovoltaic effect. The stabilization of quinoidal structure from thieno-[3, 4-b]thiophene results in a low band gap of the polymer of about 1.6 eV, showing efficient absorption around the region with the highest photon flux of the solar spectrum (about 700 nm). The introduction of fluorine into the thieno [3, 4-b] thiophene provides the polymer with a relatively low-lying highest occupied molecular orbital (HOMO) energy level, which offers enhanced Voc. The rigid backbone results in a good hole mobility of the polymer, and the side chains on the ester and benzodithiophene enable good solubility in organic solution and suitable miscibility with the fulleride acceptor. All these advantages of thieno [3, 4-b]thiophene and benzodithiophene polymers (PTBs) helps in achieving power concersion efficiency (PCE) up to 6.1%. [20]

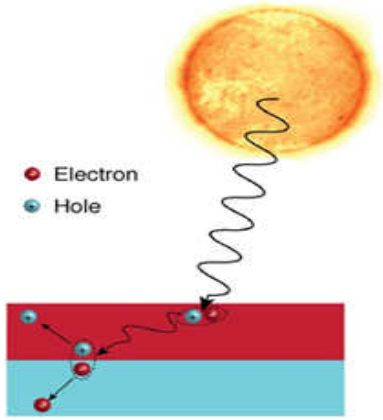

Fig. 6: (Source: Yongye Liang et al) Two polymer layer solar cell: Incoming photon from sun creates exciton (electron hole pair) that travel to interface where charge separation occurs producing useful voltage[20]

Drug delivery

IPN hydro gels based on polyvinyl alcohol (PVA) networking with polyacrylic acid (PAA), generated insitu, were prepared by without any added cross linker, using benzoyl peroxide an initiator and sodium chloride (NaCl) as additive. The response of the hydro gels with and without NaCl was observed by studying their swelling behavior, biodegradability and thermal stability. Scanning electron microscopic study revealed that the pores of the prepared IPN were mostly open in presence of NaCl, thus making the hydro gel macro porous. (PVA-co-PAA)/NaCl was found to be more biodegradable than without NaCl. The IPN hydrogel showed comparatively higher swelling at intestinal pH than that of gastric medium and presence of NaCl in the IPN increases the swelling properties in both media.

Thermal stability of IPN was affected by copolymerization, due to increasing porosity of the IPN. The prepared nontoxic, hydrophilic IPN hydro gel system holds good for further drug delivery studies in connection to its super swelling and biodegradability.[21, 38]

Tissue engineering (TE)

To effectively repair or replace damaged tissues, it is necessary to design scaffolds with tunable structural and biomechanical properties that closely mimic the host tissue. IPN hydro gel based on gelatin methacrylate (GelMA) and silk fibroin (SF) formed by sequential polymerization, which possesses tunable, structural and biological properties. Experimental results revealed that IPNs, where both the GelMA and SF were independently cross linked in interpenetrating networks, demonstrated a lower swelling ratio, higher compressive modulus and lower degradation rate compared to the GelMA and semi-IPN hydro gels, where only GelMA was cross linked. In addition, photolithography combined with lyophilization techniques was used to fabricate three-dimensional micro patterned and porous micro scaffolds from GelMA–SF IPN hydro gels, furthering their versatility for use in various micro scale tissue engineering applications. Overall, this study introduces a class of photocrosslinkable, mechanically robust and tunable IPN hydro gels that could be useful for various tissue engineering and regenerative medicine applications.[22]

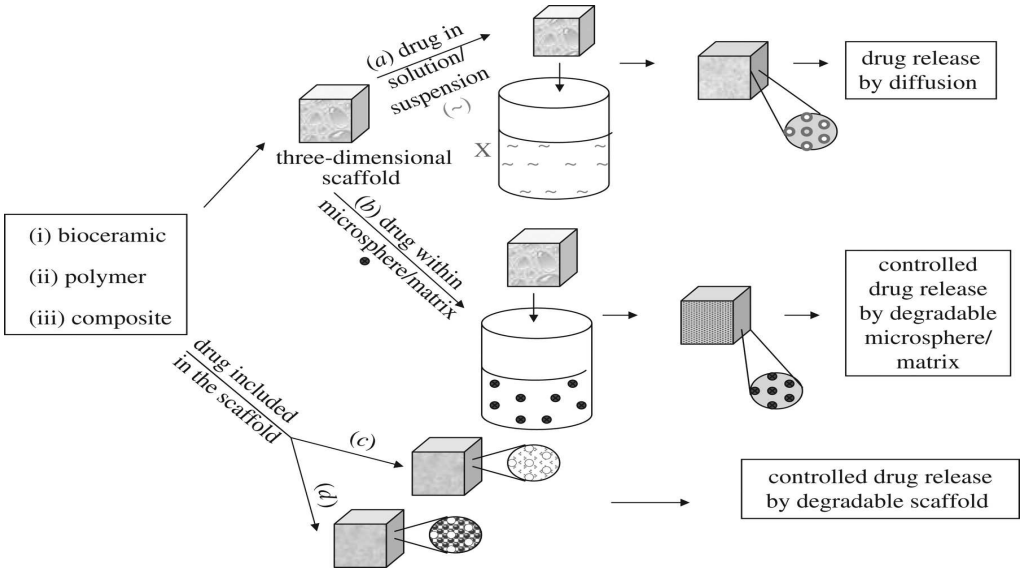

Fig. 7: (Source Viviana et al) Schematic representation of the most common strategies to deliver drugs from 3D scaffolds in bone TE[36]

Cartilage TE

A new method for encapsulating cells in IPN hydro gels of superior mechanical integrity was developed. In this study, two biocompatible materials—agarose and poly(ethylene glycol) (PEG) diacrylate—were combined to create a new IPN hydro gel with greatly enhanced mechanical performance. Similar mechanical property improvements were seen when IPNs-encapsulated chondrocytes, and LIVE/DEAD cell viability assays demonstrated that cells survived the IPN encapsulation process. The majority of IPN-encapsulated chondrocytes remained viable 1 week post encapsulation, and chondrocytes exhibited glycosaminoglycan synthesis comparable to that of agarose-encapsulated chondrocytes at 3 weeks post encapsulation. The introduction of a new method for encapsulating cells in a hydro gel with enhanced mechanical performance is a promising step toward cartilage defect repair. This method can be applied to fabricate a broad variety of cell-based IPNs by varying monomers and polymers in type and concentration and by adding functional groups such as degradable sequences or cell adhesion groups. Further, this technology may be applicable in other cell-based applications where mechanical integrity of cell-containing hydro gels is of great importance.[23]

Polymers as uteral stents

Stents are commonly used during surgery for uteral stones. The main advantages of stent placement are facilitation of stone fragment passage, prevention of uteral obstruction and prevention of delayed formation of uteral stricture. The majority of people with indwelling uteral stents are at an increased risk of urinary tract infection. Stent encrustations and its associated complications lead to significant morbidity. Various polymers find their application as uteral stents with regards to various issues such as encrustation, bacterial colonization, urinary tract infections and related clinical issues.[24]

Fig. 8: (Source: Nandakumar Venkatesan et al) Uteral stents[24]

CONCLUSION

IPN has found immense use in various biomedical applications. Its unique properties of swelling capacity, specificity, mechanical strength, nutrient and oxygen permeability, durability in the body and sensitivity can be identified. Nanocomposite polymer hydro gels are new generation materials useful for a wide variety of applications. From stimuli-responsive sensors and actuators to micro fluidics, pharmaceutical, and biomedical devices the potential impact for nanocomposite hydro gels to influence the lives of the general public continues to grow. Although a substantial number of technical hurdles still need to be overcome, the rapid progress that has been made by investigators since the advent of the pioneering AlphaCor hydro gel keratoprosthesis serves as strong evidence that a biointegrable synthetic donor cornea capable of surface epithelialization may become a clinical reality in the years to come. Despite many advances, numerous challenges and opportunities remain for making an impact in the field of smart polymers. While new responsive polymer compositions are continually being developed and the ability to prepare macromolecules with topological complexity is expanding, many underutilized stimuli will take on greater roles in the next generation of smart materials. IPN has not only use as biomaterial in tissue engineering and drug delivery but also in other fields of science like use as fuel cells, solar

cells, food packaging etc. Thus IPN holds many advancements and future applications that will be of immense help to mankind.

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