CHAPTER 1
INTRODUCTION AND OBJECTIVES

1.1 Background

Wound healing is a complicated sequence of cellular and biochemical events proceeds through a series of different phases. Instant coverage of wound areas by wound dressing is necessary to complete the wound healing process. In general, the following properties are necessary for wound dressing. The dressing material must be capable of absorbing the exuded liquid from the wounded area. It should permit water evaporation at a certain rate and allow no microbial transport. A major drawback in conventional dressing material is the adherence between the dressing and the damaged tissues. If the separation between the dressing material and the tissue is difficult during dressing change a secondary damage to the wound will occur to prolong the wound healing time (1-3).

Wound dressing with an easily stripped off property is therefore highly desirable to help lightening the pain patients suffered during frequent dressing change. A method of preparing easily stripped off wound dressing has been developed by graft polymerization of N-isopropylacrylamide on polypropylene nonwoven fabric.

The two layered wound dressing materials have been made via graft copolymerization. In which base layer is made up of fabric such as cotton (34-38), chitosan (39-41), polypropylene (42-44), PET (44 and 45) and second layer made up of hydrogel such as NIPAM (34, 35, 40,and 44) , NIPAM/AAc (42, 45), AAc/ HEMA (39), PU/PNIPAM (41), PNIPAM/chitosan(37) methylmethacrylate (43) and acrylic acid(36).

The wound dressing material having control drug release properties is highly desirable for quick healing process .The advantages of addition of drug in wound dressing material to work at target affect cells.

Hydrogels are three dimensional cross-linked polymeric structures which are able to absorb and retain a large amount of water while remaining insoluble in aqueous solution. Recently a wide range of hydrophilic polymer have been examined as potential candidate for use as control drug release device due to its characteristics properties such as biocompatibility, swellability in water , higher water content and rubbery nature which is similar to natural tissue(6-9).

Hydrogels of copolymers of acrylic acid (AAc) with acrylamide (AAm) derivatives have been reported with adjustable swelling kinetics with application for various drug release such as, gentamicin sulfate (17), theophylline release(20), bovine serum albumin (BSA)(22), ascorbic acid(23), fluorescein isothiocyanate labelled bovine serum albumin(FITC-BSA)(24) and 5-fluorouracil (5-FU) (25), as the model drugs.

The hydrogel prepared in the above studies by free radical crosslinking copolymerization of AAm and AAC with a small amount of N, N'- methylene bisacrylamaide (MBAAm) as the crosslinker(6, 7, 9 and 10). The structural parameters and dynamic swelling behaviour of poly (AAm-co-AAc)hydrogel have investigated as a function of AAc concentration and crosslinker density at different pH conditions. Owing to the existence of hydrophilic –COOH and $–NH_2$ groups, the swelling behaviour of these hydrogels is highly dependent on pH of the surrounding medium. The development of drug delivery system requires the control of water content within the polymeric structure. Hydrogels based on poly (AAm) and poly (AAc) have the capacity to absorb a substantial amount of water which makes them potential candidates for drug delivery system.

In this study the attempt has been made to prepare hydrogel grafted cotton fabric wound dressing materials for drug release. Acrylamide/ acrylic acid hydrogel was grafted on cotton fabric by free radical graft polymerisation using APS as a chemical initiator and PEG as a crosslinker. The process parameters such as monomer, initiator and crosslinker concentration on

degree of polymerization of hydrogel on cotton fabric were optimized. The release kinetics of model BSA drug from fabric supported hydrogel was studied.

1.2 Objectives of the project

- Synthesis of hydrogel grafted fabric
- Optimization of grafting
- Characterisation of grafted fabric
- BSA drug release studies

CHAPTER 2

LITERATURE REVIEW

2.1 Composite dressing

A wound dressing includes a first layer located adjacent to wound and comprises a material which should be bioadsorbable, porous and adapted for serving as a scaffold for cell attachment; and a second layer which is in contact with first layer comprises an adsorbent, gel forming material adapted for serving as a barrier to cell adhesion and penetration. There are two kinds of dressing namely dry and wet (1,2).

Composite dressings are wound covers that combine physically distinct components into a single product to provide multiple functions, such as a bacterial barrier, absorption and adhesion. Usually, they are comprised of multiple layers and incorporate a semi- or non-adherent pad that covers the wound. Dressing namely dry and wet (1,2).

Composite dressings may also include an adhesive border of non-woven fabric tape or transparent film. They can function as either a primary or a secondary dressing on a wide variety of wounds and may be used with topical medications (1-3).

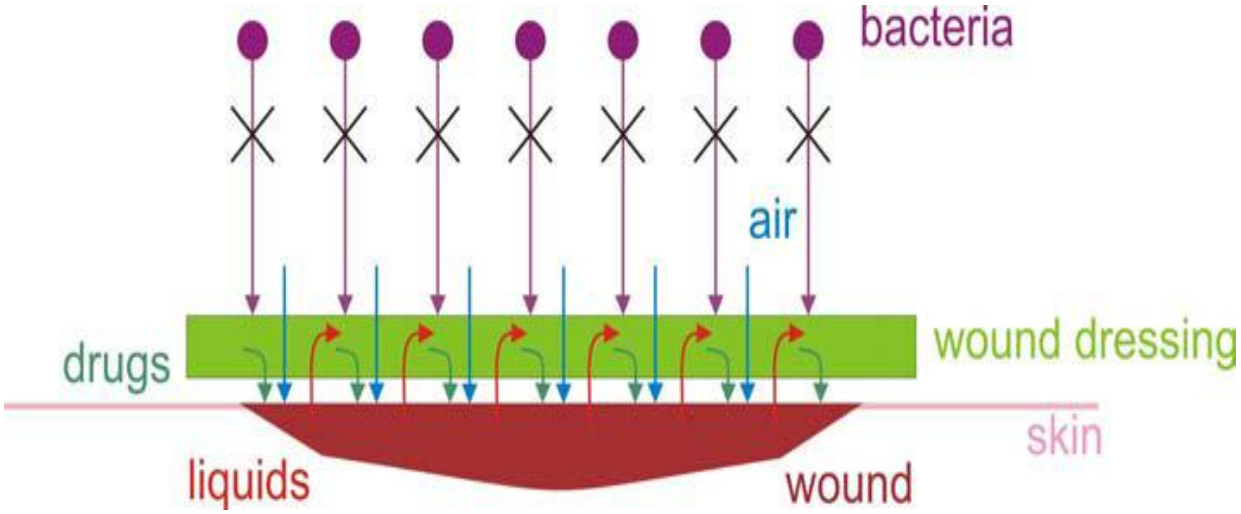


Figure 2-1 A wound dressing functionality

The basic function of the wound care materials is providing protection against an infection, blood and exudates absorption, to promote healing and possibly apply a medication to the wound. The today available materials range from simple cotton gauzes and lint to sophisticated multifunctional systems made from natural or synthetic materials(3).

Table 2-1 The categories of traditional and advanced wound dressings according to their design or a material.

Traditional dressing	**Advanced dressing**
Gauze	Alginates
Lint	Hydrogel
Wadding	Hydrocolloids
Plasters	Foam dressing
	Film dressing

Table 2-2 The functionality of traditional and advanced wound dressings.

Traditional dressing	**Advanced dressing**
Exudate absorption and drying of the wound	Keep a moist environment
Haemostatis	Remove exudates and necrotic tissue
Antisepsis	Keep temperature constant
Protection from infection	Oxygen permeable
Wound covering	Protection from exogeous infection
	Easy to handle
	Non-traumatic at the dressing change

Composite dressings are available in a wide variety of sizes, but the basic shape is usually square or rectangular. Composites are indicated for low-to-moderate exudate or, in cases where super-absorbers have been added for moderate to highly exuding wounds (e.g., Viasorb®).

The main benefits of composite dressings are their simplicity of use. Virtually everybody is familiar with the application of a Band-Aid, and by extension, the application of a composite dressing to cover a wound (5).

Basic composite dressings are readily available, relatively inexpensive, and versatile enough to find utility with many wound types. Though basic forms may not be seen to promote moist wound healing, they are quite adequate for most acute or surgical wounds and can function as inexpensive secondary dressings to hold advanced wound care products in place.

Non-woven composite dressings are extremely conformable and comfortable in use. The conformability insures they work well on a wide range of wound locations, adding to their versatility.

Newer composite dressing formats may switch out the basic fluff absorbent pad with foam or a hydrofiber pad, or basic or advanced pads with antimicrobial components (such as dressings with PHMB)(5).

The fibres, generally used in wound care grouped into natural and manmade categories. Most important natural fibres are cotton, silk and linen. Manmade synthetic polymer is polyesters, polyamide, polypropylene, polyurethane and polytetrafluroethylene etc. and fibre manufactured from naturally available polymer like alginates protein, polyglycolic acid, regenerated cellulose, chitin, chitosan hyaluronan etc. some non-fibres materials such as carbon and metal (silver) are also used(2).

Hydrogel wound dressings are three-dimensional polymeric networks and are available in sheet form or as a spreadable viscous gel. Hydrogel dressings are semipermeable to gases and

water vapour. The amorphous gel formed by hydrogel dressings maintains a moist and hydrated environment. Numerous materials have been developed for use as wound dressings, Based on the types of wounds and modes of healings (4).

2.2 Hydrogel

Hydrogels are hydrophilic three-dimensional (3D) networks that are chemically crosslinked or physically entangled with excellent water swelling capacity (6-9). The water holding capacity of the hydrogels arise mainly due to the presence of hydrophilic groups, viz. amino, carboxyl and hydroxyl groups, in the polymer chains. According to Hoffmann, the amount of water present in a hydrogel may vary from 10% to thousands of times of the weight of the xerogel (10). On a molecular level, water in a hydrogel is either bonding to polar hydrophilic groups as 'bond water' or is filling the space between the network chains, pores or voids as 'free water'(9). Hydrogels may exhibit drastic volume changes in response to specific external stimuli, such as the temperature, solvent quality, pH, electric field, etc.(11).

The water holding capacity and permeability are the most important characteristic features of a hydrogel (11). The equilibrium swelling degree and the elastic modulus of hydrogels depend on the cross-link and charge densities of the polymer network as well as on the cross-linked polymer concentration after the gel preparation (12). Another non-ideal feature of hydrogels is the so-called spatial gel inhomogeneity. In contrast to ideal gels with a homogeneous distribution of cross-links, hydrogels always exhibit an inhomogeneous cross-link density distribution, known as the spatial gel inhomogeneity (12).

Hydrogels are mainly classified as natural or synthetic according to their origin. Table 2-1 lists some of the natural polymers and synthetic monomers from which hydrogels can be prepared. Hydrogels from natural polymers have been widely used for tissue engineering applications, but limitations such as wet physical properties and batch to batch variations, have motivated

researchers to modify these polymers as well as to use synthetic polymers to prepare hydrogels, in the past couple of decades.

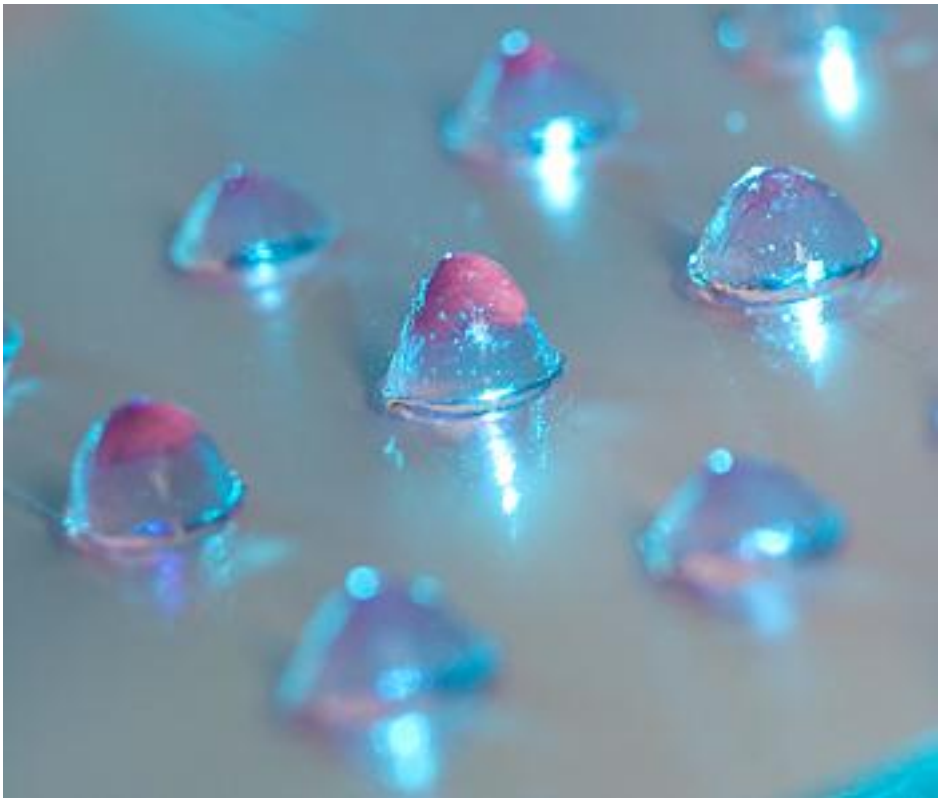


Figure 2-2 Hydrogel

Hydrogels can also be classified as physical or chemical gels based on their crosslinking (10). Chemical gels are usually covalently-crosslinked networks produced by crosslinking of water-soluble polymers or by conversion of hydrophobic polymers to hydrophilic polymers to form a network. These gels are permanent or thermoset, meaning the bonds do not break at elevated temperatures and hence do not reform at lower temperatures. The crosslinker used in chemically crosslinked gels is often toxic. This means the crosslinker needs to be removed prior to use in biological systems, which might alter the gel integrity. As a result, physically crosslinked gels are gaining much attention.

Table 2-3 Natural and synthetic monomers that can be used for hydrogel preparation (13)

Natural Polymers	**Synthetic Monomers**
Chitosan	Hydroxyethylmethacrylate (HEMA)
Alginate	N-(2-Hydroxy propyl)methacrylate (HPMA)
Fibrin	N-Vinyl-2-pyrrolidone (NVP)
Collagen	N-isopropylacrylamide (NIPAMM)
Gelatin	Vinyl acetate (VAc)
Hyaluronic acid	Acryolic acid (AA)
Dextran	Methacrylic acid (MAA)
	Polyethylene glycol acrylate/methacrylate (IPEGA/PEGMA)
	Polyethylene glycol diacrylate/dimethacrylate (PEGDA/PEGDMA)

Table 2-4 Classification of Hydrogels

Classification	**Contents**
Source	Natural
	Synthetic
Component	Homopolymer
	Copolymer
	Multipolymer
Preparation method	Simultaneous polymerization
	Crosslink of polymer
Electric charge	Nonion
	Anion

	Cation Zwitter ion
Physical structure	Amorphous Crystaline Semicrystalline Hydrogen bonded
Crosslink	Covalent bond Intermolecular force
Functions	Biodegradable Stimuli responsive Superabsorbant
Physical appearance	Matrix Film Microsphere

2.2.1 Advantages

- Biocompatible
- Easy to modify
- Can be injected
- Timed release of growth factors and other nutrients to ensure proper tissue growth
- Entrapment of microbial cells within polyurethane hydrogel beads with the advantage of low toxicity
- Environmentally sensitive hydrogels have the ability to sense changes of pH, temperature or the concentration of metabolite and release their load as result of such a change.

- Natural hydrogel materials are being investigated for tissue engineering, which include agarose, methylcellulose, hylaronan, and other naturally derived polymers (14).

Biocompatibility of the hydrogels is generally associated with the hydrophilic nature of the same. The presence of water in the system makes it soft and rubbery. Contact angle testing method is used to measure the biocompatibility of the hydrogel. Materials producing small contact angles with blood are considered to be compatible with blood, while materials producing large contact angles have poor blood compatibility. Hydrophilicity has got an inverse relationship with the contact angle, i.e. lower contact angle indicates higher hydrophilicity of the material, and a proportional relationship with cell attachment, i.e. the higher the hydrophilicity, the greater is the cell attachment (10).

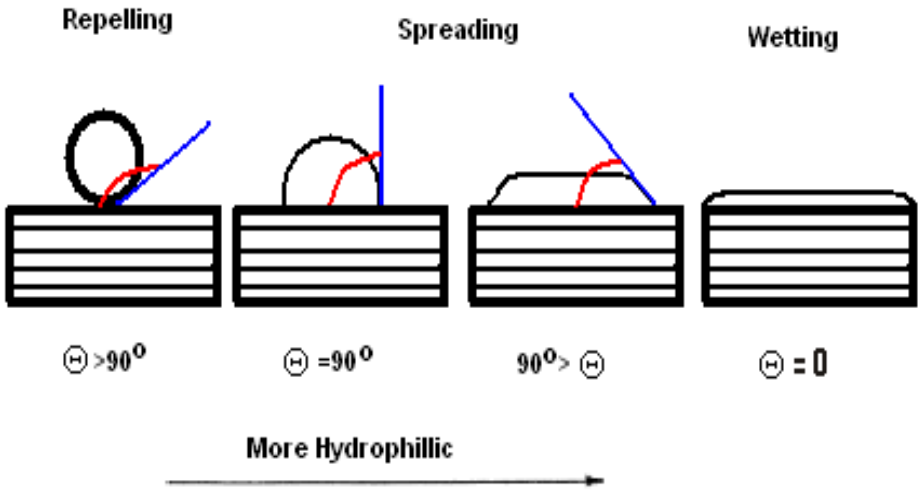


Figure 2-3 Effect of contact angle on the hydrophilicity of the solid surface.

2.2.2 Disadvantages

- High cost.
- Low mechanical strength
- Difficult to load
- Difficult to sterilize
- Nonadherent
- In contact lenses - lens deposition, hypoxia, dehydration and red eye reactions (14).

2.2.3 Applications

A. Applications of hydrogels in drug delivery

Hydrogels have been used for the development of controlled delivery systems for a long time. When the drug bearing hydrogel comes in contact with aqueous medium, water penetrates into the system and dissolves the drug. Diffusion is the main phenomena by which the dissolved drug diffuses out of the delivery systems to the surrounding aqueous medium (10).

The delivery systems employing hydrogels for controlled release can be categorized into reservoir and matrix devices (10,15).

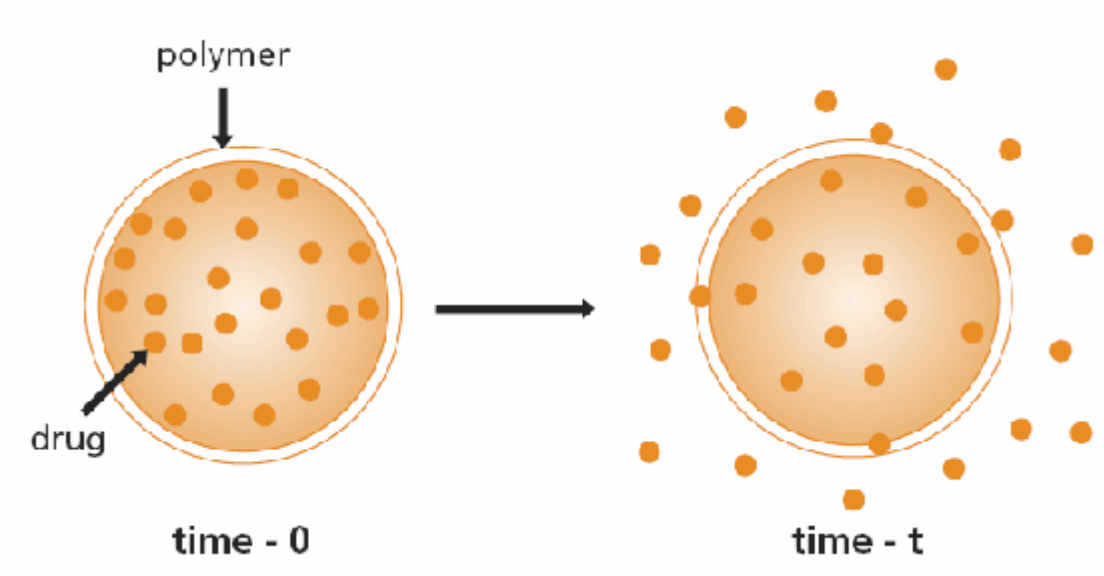


Figure 2-4 Drug delivery from typical reservoir device

In reservoir drug delivery system, a drug-enriched core (often termed as reservoir) is encapsulated within a uniform polymeric membrane of hydrogel which allows the diffusion of drug through it and in matrix type delivery system, the active agent is homogenously dispersed as a solid into a hydrogel matrix (10).

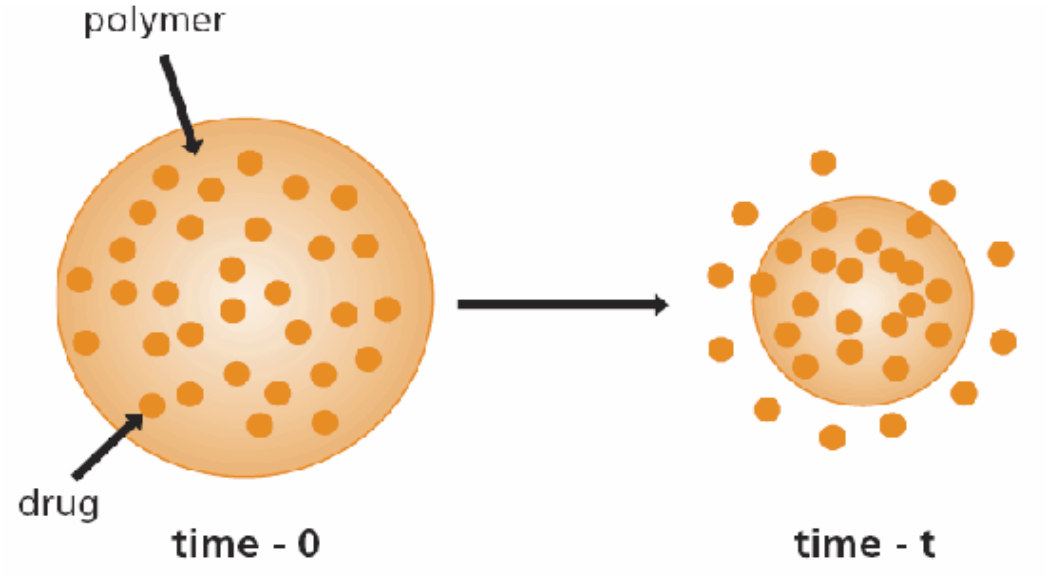


Figure 2-5 Drug delivery from a typical matrix drug delivery system.

As mentioned earlier, hydrogels are 3-dimensionally cross-linked polymer networks and hence act as a permeable matrix/membrane for the drug thereby governing the release rate of the drug. The diffusion of the drug through the hydrogels may be affected by the property (viz. pH sensitivity, light sensitivity, pressure sensitivity) of the hydrogel depending on the chemistry of the hydrogels and has been used successfully to design delivery systems which may release drug at a suitable environment(10).

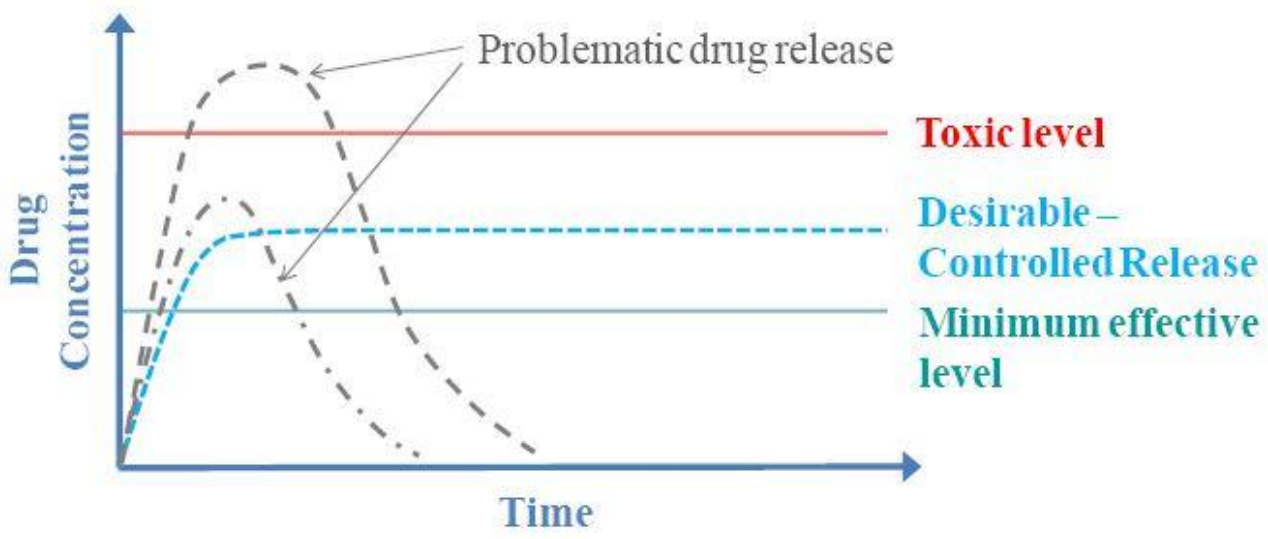


Figure 2-6 Released drug concentrations over time.

The lines that indicate the toxic and minimum effective levels of the drug are colored red and green, respectively. The desirable controlled drug release is colored blue while, shown in grey, two cases of problematic drug release indicate drug release ending too soon or, on some occasions, being below the minimum effective level or higher than the toxic level. Note that it is desirable, after a small initial amount of time, that the released drug concentration is constant and between the toxic and the minimum effective level (15).

B. Applications of hydrogels in wound healing

Hydrogels have played a significant role in wound care for over 20 years. The use of hydrogels in the healing of wounds dates back to late seventies or early eighties. As mentioned earlier, hydrogel is a crosslinked polymer matrix which has the ability to absorb and hold water in its network structure. Shultz et al (2003) suggested that hydrogels are the best choice for the treatment of dry wounds with necrotic eschar in situ. Most hydrogels have the ability to provide moisture to a dry environment and some can absorb limited amounts of exudate from a wound this can cause the gel to expand and fill a wound (Thomas, 1998). Hydrogels act as a moist wound dressing material and have the ability to absorb and retain the wound exudates along with the foreign bodies, such as bacteria, within its network structure (15). In addition to this, hydrogels have been found to promote fibroblast proliferation by reducing the fluid loss from the wound surface and protect the wound from external noxae necessary for rapid wound healing.

Since hydrogels help to keep the wound moist, keratinocytes can migrate on the surface. Hydrogels may be transparent, depending on the nature of the polymers, and provide cushioning and cooling/ soothing effects to the wound surface. The main advantage of the transparent hydrogels includes monitoring of the wound healing without removing the wound dressing. Hydrogel sheets are generally applied over the wound surface with backing of fabric or polymer film and are secured at the wound surface with adhesives or with bandages (15).

C. Applications of hydrogels in tissue engineering

Tissue engineering (TE) is a multidisciplinary approach and involves the expertise of materials science, medical science and biological science for the development of biological substitutes (tissue/ organ). It is emerging as an important field in regenerative medicine (15).

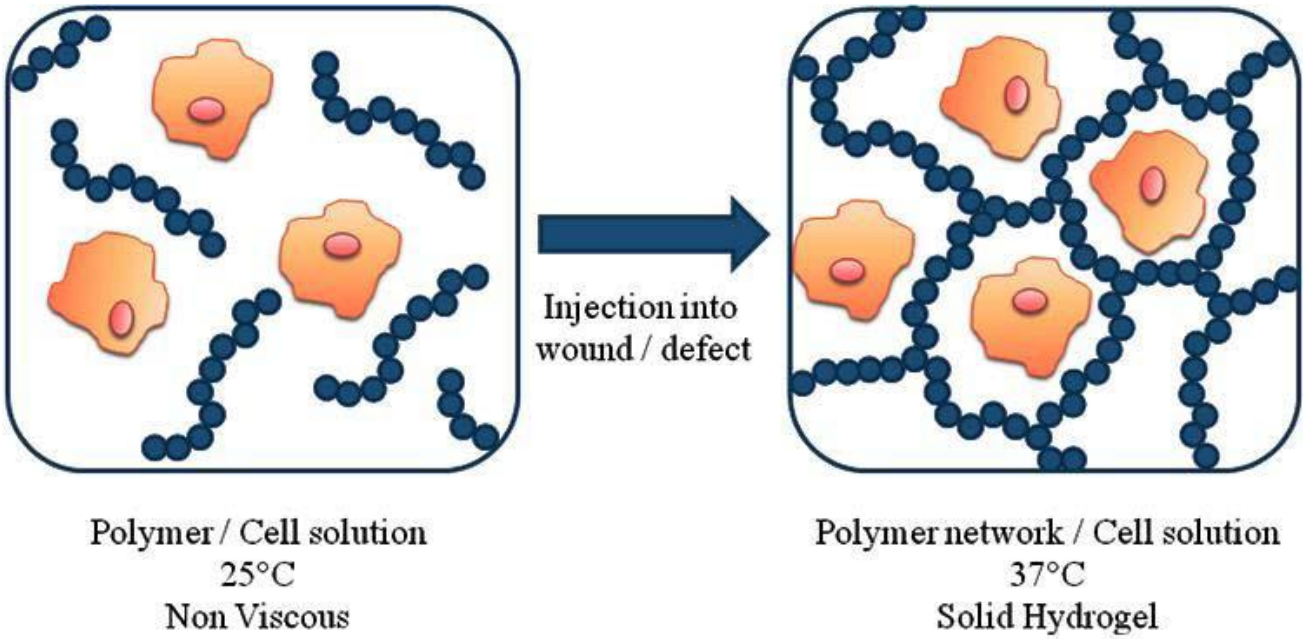


Figure 2-7 *In situ* formation of a scaffold in tissue engineering.

It aims to regenerate or replace biological damaged or diseased tissue or generate replacement organs for a wide range of medical conditions such as heart diseases, diabetes, cirrohosis, osteoarthritis, spinal cord injury and disfiguration. The tissue engineering involves the use of a scaffold/material within which cells will be seeded and consequently tissue will mature. This requires the use of a biocompatible material/scaffold, usually natural materials like proteins or synthetic polymers, with the appropriate 3D structure that will provide sufficient mechanical support and has the ability to convey both nutrients and growth factors to encapsulated cells (10). Recently the use of resorbable hydrogels in TE has gained much importance because (a) it is easy to process the polymers; (b) the properties of the hydrogels can be tailored very easily; and (c) resorbable polymers like polylactic acid (PLA), polyglycolic acid (PGA), and their co-

polymers (PLA-co-PGA; PLGA) are being used for biomedical application since long time. Thermoresponsive polymers in tissue engineering are commonly used.

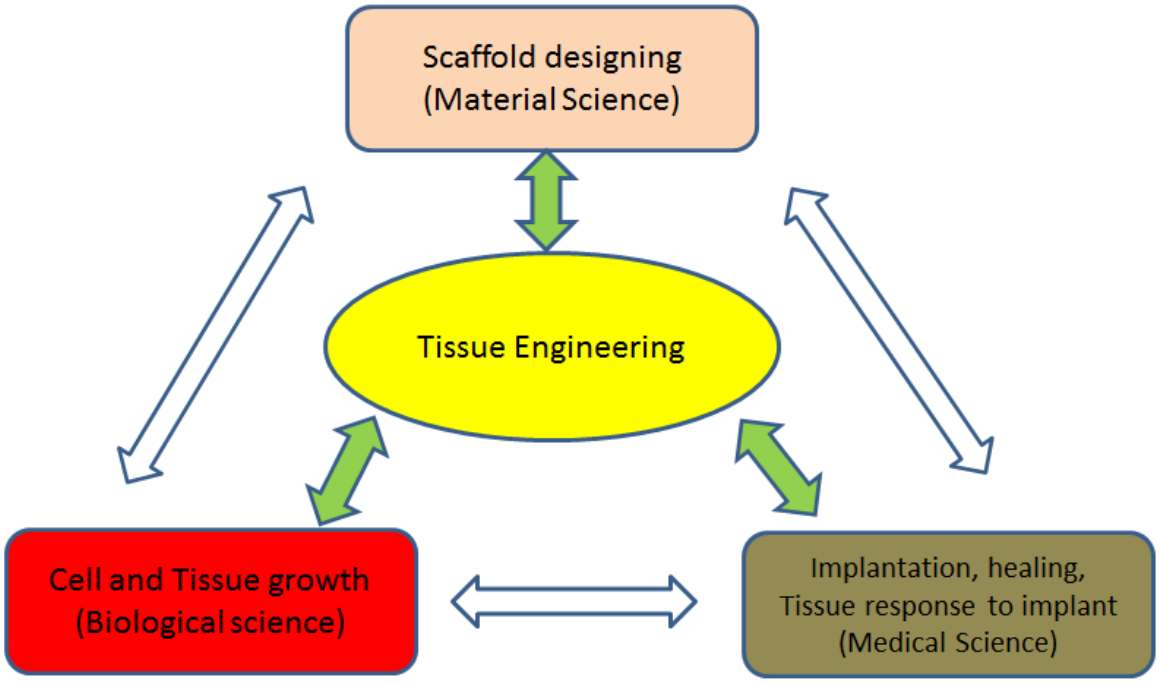


Figure 2-8 Schematic diagram showing multidisciplinary approach of tissue engineering

D. Application of hydrogels for gene delivery

Gene delivery is defined as the incorporation of foreign DNA particles into the host cells and can be mediated by viral and non-viral methods (15). However viruses have many disadvantages, the most severe of which is the immune response that they can cause and this is why non-viral carriers have been developed. The delivery of gene into the host cells by utilizing a virus uses the capability of a virus to incorporate its DNA into the host cells. For the purpose retroviruses and adenoviruses have been used.

Gene therapy aims at the treatment of many genetic diseases as it is a technique for correcting defective genes that are responsible for these genetic diseases. Specifically, the delivery of the appropriate, therapeutic gene (DNA) into the cells that will replace, repair or regulate the defective gene that causes the disease is a vital step for gene therapy (10). Of late researchers

have started the use of polymers, viz. poly-L-lysine (PLL), polyamidoamine dendrimer (PAMAM), polyethylenimmine (PEI), PGA, PLA and PLGA, for gene delivery (15).

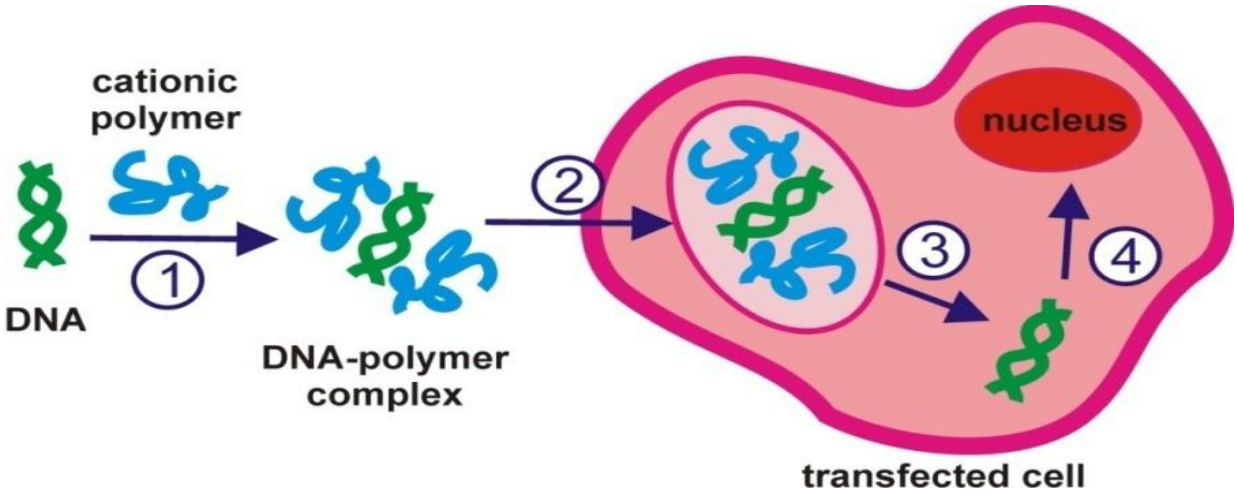


Figure 2-9 The main steps of gene delivery using a cationic polymer: (1) DNA complexation (2) complex traversing the cell membrane to the cytoplasm (3) DNA release into the cytoplasm and (4) DNA transfer into nucleus.

2.3 Hydrogel of poly (AAm-coAAc)

The water content of the hydrogels at equilibrium is one of their basic properties. A hydrogel with higher water content is generally more advantageous in increasing permeability and biocompatibility (16-21). Polyacrylamide hydrogels exhibit a very high capability to absorb water; they are permeable to oxygen and possess good biocompatibility (16, 20). Acrylic acid exhibits structural similarity with acrylamide and has a carboxylic group which makes it highly hydrophilic.

Hydrogels of copolymers of acrylic acid (AAc) with acrylamide (AAm) and its derivatives have been reported with adjustable swelling kinetics with applications for insulin release, to improve osteoblast adhesion and showing special properties such as super-absorbent hydrogels. Recently, the structural parameters and dynamic swelling behavior of poly(AAm-*co*-AAc) hydrogels have been investigated as a function of AAc concentration in hydrogels and crosslink density at different pH conditions(17). Owing to the existence of hydrophilic –COOH and –NH2

groups, the swelling behavior of these hydrogels is highly dependent on the pH of the surrounding medium.

Poly(acrylamide-co-acrylic acid) [P(AAm-co- AAc)] hydrogels are synthesized by the free-radical crosslinking copolymerization of acrylamide (AAm)and acrylic acid(16,17,19-21) by using MBAAm as a crosslinking agent. A polyacrylamide–polyacrylic acid copolymer hydrogel can be prepared by the controlled hydrolysis of polyacrylamide in an alkaline solution of 10% sodium hydroxide (18). In water, an increase of the AAc content further increased the response rate of the hydrogels because of simultaneous increase of both the porosity and hydrophilicity of the network (16). The crosslinking ratio and composition of the hydrogels affects the structural parameters and the swelling behaviour of the hydrogels (17).

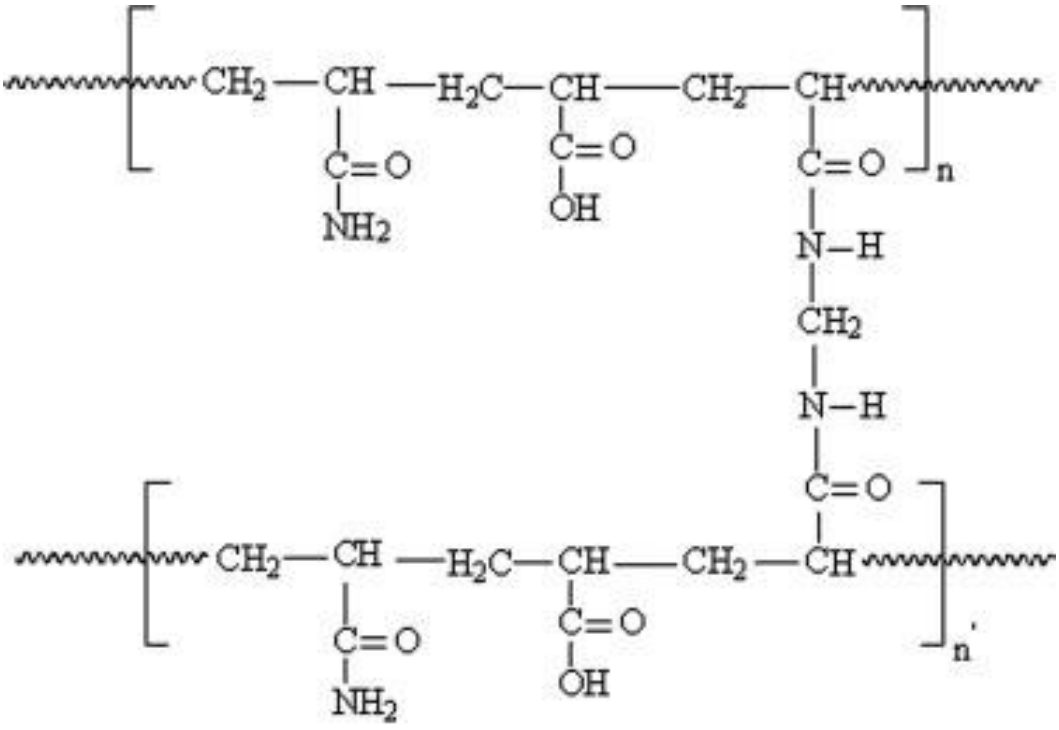


Figure 2-10 Poly (AAm-co-AAc) chain crosslinked by MBAAm

These copolymers have a capacity to bind various metals. The capacity of the copolymer hydrogel to bind various metal ions has been tested under a range of uptake conditions, with varying uptake time, pH and ionic strength. Ions such as Cu^{2+} (18, 21) and Cd^{2+}(18) were bound

more strongly to the copolymer hydrogel than the competing ions of Na^+ , K^+ , Ca^{2+} and Mg^{2+} , particularly at pH>5, largely due to the increased acidity of these transition metal ions(18).

The use of these hydrogels for drug release have been investigated with gentamicin sulfate (17), theophylline release(20), bovine serum albumin (BSA)(22), ascorbic acid(23), fluorescein isothiocyanate labelled bovine serum albumin(FITC-BSA)(24) and 5-fluorouracil (5-FU) (25), as the model drugs.

2.4 Cotton fabric

Cotton is a natural fiber that comes from the seedpod of the cotton plant and is used to make many fabric types at every price point. The fiber is hollow in the center and, under the microscope, resembles a twisted ribbon (26). Cotton fiber differs markedly from other cellulose fibers in morphological traits. Due to many features, cotton even though it was discovered later than other fibres gained a superior position and stimulated immense development of textile industry.

The chemical composition of cotton fiber consists of ninety-five percent cellulose, one point three percent protein, one point two percent ash, point six percent wax, point three percent sugar, and .8 percent organic acids, and other chemical compounds that make up three point one percent (27-29). The non-cellulose chemicals of cotton are usually located in the cuticle of the fiber.

The chemical composition of cotton, when picked, is about 94 percent cellulose; in finished fabrics is it 99 percent cellulose (27). Cotton contains carbon, hydrogen, and oxygen with reactive hydroxyl groups. Glucose is the basic unit of the cellulose molecule. Cotton may have as many as 10,000 glucose monomers per molecule. Chemical structure of cotton is shown in figure 2-11.The molecular chains are arranged in long spiral linear chains within the fiber. The strength of a fiber is directly related to chain length.

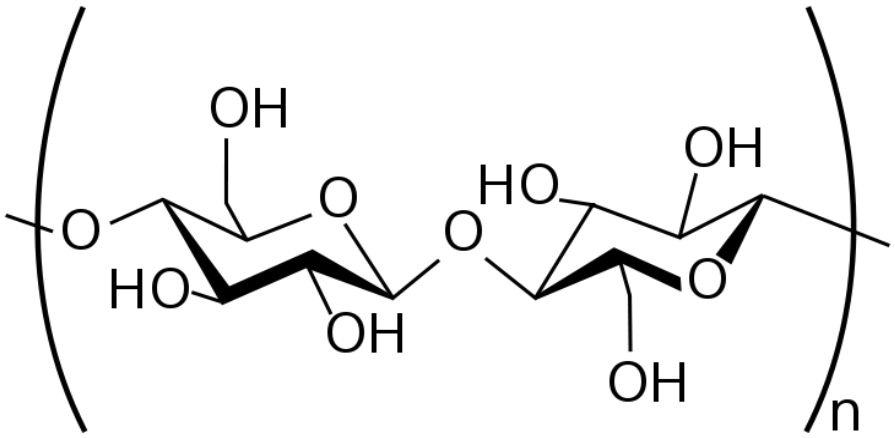


Figure 2-11 Chemical Structure of Cotton

Among the advantages of cotton fabric we can name the following:

1. Cotton fabrics show good durability and utility (but still cotton fabrics are inferior to synthetic fabrics in durability). Cotton is a chemically stable material; it stays undamaged even under the continuous exposure of weak acids and alkalis.

2. High water-absorbing capacity. In humid atmosphere cotton fabric can absorb 27% of water without getting damp.

3. Cotton fabric has very good breathable characteristics, it is hypoallergenic, agreeable to touch, and it is suits perfectly for people with skin hyper sensibility. It has low thermal-conductivity; therefore it is an ideal material for both summer and winter clothes: in summer it prevents your skin from heat, and in winter it preserves the warmth of your body.

4. Cotton fabrics are easy to dye.

5. Cotton fabrics have very low elasticity characteristics, so they almost don't stretch.

6. They are easy washable and can be ironed even at high temperature.

Cotton fabric is often used with WR (water resistance), OP (oil proof), flame retardant (FR) finishes; XM Textiles also provides cotton fabric with antistatic fibers. Cotton fabrics often find its application in producing work wear with high hygienic requirements and clothing for protection against low temperatures (26).

2.5 Grafting

'Grafting' is a method wherein monomers are covalently bonded (modified) onto the polymer chain (32). The polymer chains are activated by the action of chemical reagents, or high energy radiation treatment. The growth of functional monomers on activated macro radicals leads to branching and further to cross-linking. Grafting method is differing from blending and curing. In blending two polymers are mix together physically to obtain the requisite properties, whereas in curing, the polymerization of an oligomer mixture forms a coating which adheres to the substrate by physical forces. In principle, graft co-polymerization is an attractive method to impart a variety of functional groups to a polymer.

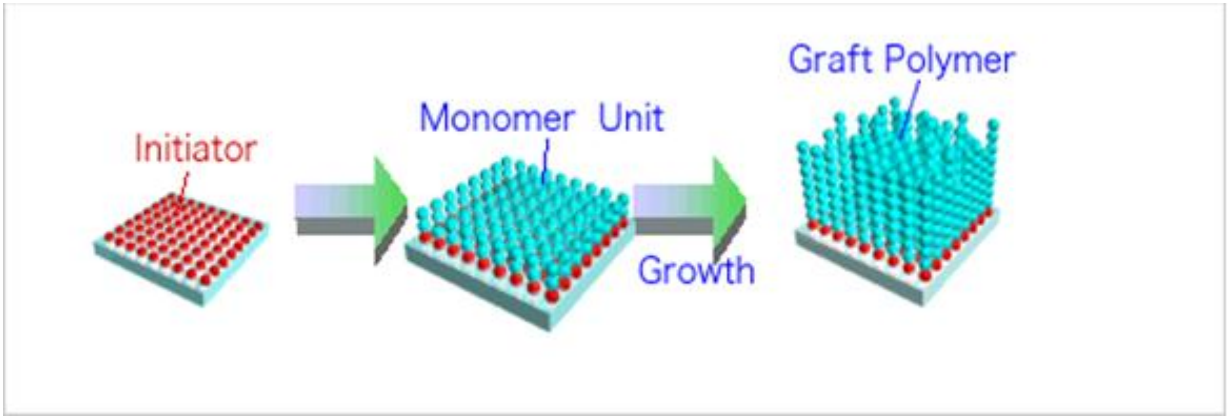


Figure 2-12 grafting copolymerization

Grafting can be accomplished by either " grafting to " or " grafting from " approaches. In " grafting to " approaches, functionalized monomers react with the backbone polymer to form the grafted one. On the other hand, " grafting from " is achieved by treating a substrate with some method to generate immobilized initiators followed by polymerization. High grafting density polymer also can be accomplished using this technique (33). The schematic presentation of all the processes is shown in Figure 2-13.

Graft co-polymerization initiated by chemical treatment, photo-irradiation, photochemical treatment, Plasma radiation induced treatment and enzymatic treatment.

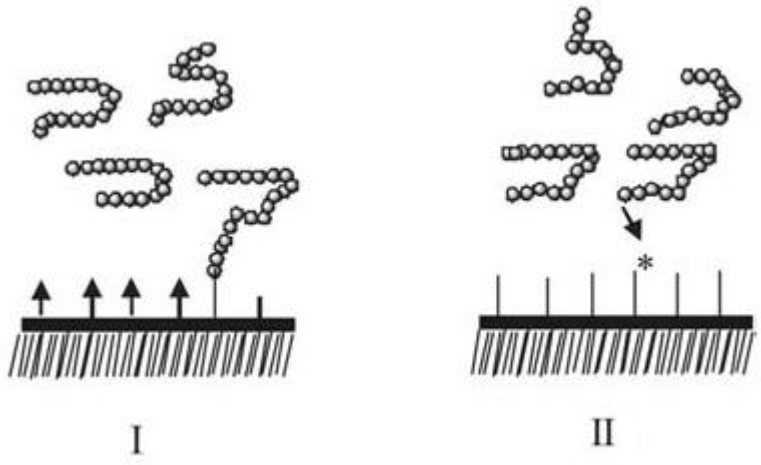


Figure 2-13 Schematic diagram of (I) grafting to, (II) grafting from.

2.6 Grafting of Hydrogel on Fabric

Graft copolymerization of cellulose is a process in which attempts have been made to combine synthetic polymers with cellulose, to produce material with the best properties of both. This process is known as grafting, usually done by modifying the cellulose molecules through creation of branches of synthetic monomers that confer certain desirable properties on the cellulose without destroying its intrinsic properties.

Depending on the chemical structure of the monomer grafted onto cellulose, graft copolymers gain new properties such as hydrophilic and hydrophobic character, improved elasticity, water absorption, ion-exchange capability and heat resistance. These copolymers are finding applications for water treatment for textile industry, for reclaiming ions of precious metals, and for personal care products such as diapers etc.

The two layered wound dressing materials have been made via graft copolymerization. In which base layer is made up of fabric such as cotton (34-38), chitosan (39-41), polypropylene (42-44), PET (44 and 45) and second layer made up of hydrogel such as NIPAM (34, 35, 40,and

44) , NIPAM/AAc (42, 45), AAc/ HEMA (39), PU/PNIPAM (41), PNIPAM/chitosan(37) methylmethacrylate (43) and acrylic acid(36).

Considerable work has been done on techniques of graft co-polymerization of different monomers (hydrogel) on polymeric (fabric) backbones. These techniques include chemical, radiation, photochemical, plasma-induced techniques and enzymatic grafting.

2.6.1 Grafting initiated by chemical means

Chemical means the grafting can proceed along two major paths, viz. free radical and ionic. In the chemical process, the role of initiator is very important as it determines the path of the grafting process. Apart from the general free-radical mechanism, grafting in the melt and atom transfer radicalpolymerization (ATRP) are also interesting techniques to carry out grafting.

In the chemical process, free radicals are produced from the initiators and transferred to the substrate to react with monomer to form the graft co-polymers. Acrylic acid (AcAc) and 2-hydroxyethyl methacrylate (HEMA) are graft copolymerized onto the chitosan backbone using radical initiation under different experimental conditions (4). Methacrylamide (MAam) as a reactive monomer was directly grafted onto cotton yarns using a $KMnO_4$ –HNO_3 redox system by chemical initiation technique (10). Graft copolymerization of acrylonitrile onto cellulosic material derived from bamboo (*Dendrocalamus strictus*) in heterogenous medium can be initiated effectively with ceric ammonium nitrate (46). Grafting of Industrial Cellulose Pulp with Vinyl acetate Monomer by Ceric Ion Redox System as Initiator (47)**.** Graft co-polymerization of acrylonitrile (AN) onto Saccharum cilliare fibre has been carried out in the presence of potassium persulphate and ferrous ammonium sulphate (FAS–KPS) as redox initiator (48). Methyl methacrylate (MMA) can be successfully grafted onto rubber-wood fiber in a free-radical solution polymerization initiated by ferrous ion and hydrogen peroxide (49). The graft copolymerization of cassava starch with acrylic acid was investigated using a free radical initiator system (Fe2+/H2O2 redox system) in water (50).

2.6.2 Grafting initiated by radiation technique

The irradiation of macromolecules can cause homolytic fission and thus forms free radicals on the polymer (34, 35, 41 -45). In the radiation technique, the presence of an initiator is not essential. The medium is important in this case, e.g. if irradiation is carried out in air, peroxides may be formed on the polymer. The lifetime of the free radical depends upon the nature of the backbone polymer. Grafting proceeds in three different ways: (a) pre-irradiation (b) peroxidation and (c) mutual irradiation technique. In the pre-irradiation technique (34), the polymer backbone is first irradiated in vacuum or in the presence of an inert gas to form free radicals. The irradiated polymer substrate is then treated with the monomer.

2.6.3 Photochemical grafting

Macromolecule containing chromophores absorbs light and goes to an excited state, which may dissociate into reactive free-radicals, whence the grafting process is initiated. If the absorption of light does not lead to the formation of free-radical sites through bond breaking, this process can be promoted by the addition of photosensitizers, e.g. benzoin ethyl ether, dyes, such as Na-2,7 anthraquinone sulphonate or acrylated azo dye, aromatic ketones (such as benzophenone, xanthone). That means the grafting process by photochemical technique can proceed in two ways: with or without a sensitizer.

2.6.4 Plasma radiation induced grafting

Plasma radiation induced grafting technique has received increasing interest. The main processes in plasmas are electron-induced excitation, ionization and dissociation. Thus, the accelerated electrons from the plasma have sufficient energy to induce cleavage of the chemical bonds in the polymeric structure, to form free radicals,which subsequently initiate graft co-polymerization.

Non-thermal plasma treatments using three different gases (air, nitrogen and argon) have been used to activate the cotton surface for subsequent poly(N-isopropylacrylamide)/chitosan microgel (PN/CS) incorporation(37).

Polypropylene (PP) non-woven fabric (NWF) was modified by direct current pulsed oxygen plasma-induced grafting polymerization of acrylic acid (AAc) ,chitosan and PNIPAAm to form a novel bigraft PP-g-chitosan-g-PNIPAAm wound dressing. AAc is used to improve hydrophilicity and to introduce carboxylic acid groups and PNIPAAm give temperature-responsive characteristics (40).

CHAPTER 3

EXPERIMENTAL

3.1 Materials

Reagent grade of Acrylamide (AAm) from Sisco Research laboratories (Mumbai, India), Acrylic acid (AAc) From Central drug house (Delhi, India), ammonium per sulphate (APS) from Central drug house (Delhi, India), ferrous ammonium Sulphate from Central drug house (Delhi, India), polyethylene glycol (PEG 6000) from LOBA CHEMI (Mumbai, India), Bovine Serum Albumin (BSA Or fraction-V**)** From HIMEDIA Laboratories Pvt(India). Ltd, cotton fabric (139 g/m^2) were used as received. All the experiments were carried out in distilled water. The chemical stricture of all the reagents used in this study is shown in Figure 3-1.

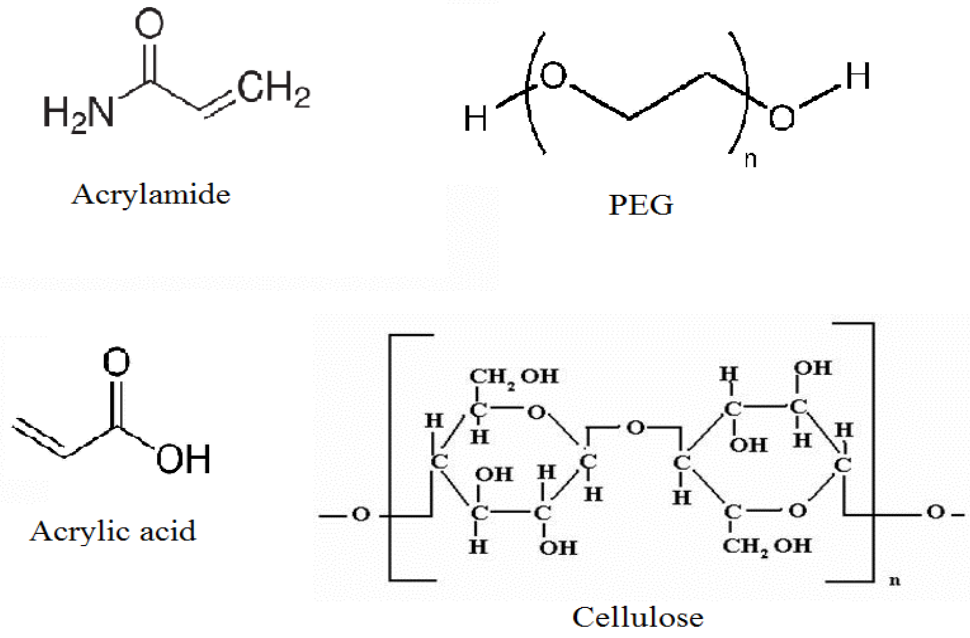


Figure 3-1 Chemical structure of used chemicals

3.2 Methods

3.2.1 Preparation of fabric supported hydrogel wound dressing material

3.2.1.1 Treatment of cotton fabric with ammonium per sulphate (APS)

Woven cotton fabric with the thickness of (0.22) mm were cut into pieces (3.5 ×3.5 cm^2) and immersed in solution of different concentration of APS ranging from 1% to 5% for 24 h. The sample was thoroughly washed with distilled water several times and squeezed between two filter papers to remove excess solution.

3.2.1.2 Graft polymerization

APS treated fabric first grafted with different concentration of acrylamide and acrylic acid monomers ranging from 5 to 15%. The grafting reaction was carried out in three neck flask under nitrogen atmosphere for 15 to 45 min at varied temperature range from 30 to 60 ˚C. After grafting of acrylamide/ acrylic acid on cotton fabric PEG as crosslinking agent was added. The time of PEG addition was varied from 15 to 45 min.

3.3 Characterization

3.3.1 Grafting yield (%)

The grafting yield was determined as the ratio of the dry weight of AAm-co-AAc hydrogel to the dry weight of the cellulose fabric as shown below:

Grafting yield (%) = Wg –Wd/Wd×100% (1)

Where Wg is the total weight of the hydrogel grafted cotton fabric and Wd is the dry Weight of the cellulose fabric.

3.3.2 Fourier Transform Infrared (FTIR)

FTIR analysis of hydrogel grafted cotton fabric was investigated using transmittance mode on Thermo Scientific Nicolet 380 spectrophotometer (Nicolet) (U.S.A). Scanning was carried out using KBr pellet method in frequency range of 500 cm^{-1} to 4000 cm^{-1}. For this, fabric was cut into a fine powder form and mixed with KBr. Pellet was prepared by 1 part of sample with 20 part of KBr and base line was made automatically by instrument.

3.3.3 X-ray Diffraction

X-ray diffraction intensity curves were obtained at a λ=1.5Å for 2θ from 0 to 40 with a Bruker D8 advanced X-ray diffractrometer (Germany) using CuKα radiation.

3.3.4 Thermogravimetric Analysis (TGA)

Thermal degradation behaviour of hydrogels was studied by thermo gravimetric analysis (TGA) technique. Thermal gravimetric analysis was performed using a TGAQ50 V20.10 Build 36 (TA instruments) (U.S). TGA thermo grams were recorded in the temperature range of 0 to 700°C and at a heating rate of 10°C min^{-1}, under N_2 atmosphere (40 mL min^{-1}),and evaluated using STARe Software DB V9.00.

3.3.5 Scanning Electron Microscopy (SEM)

The morphology of hydrogel grafted on cotton fabric was examined by SEM (model no. S-3700N, Hitachi) (Germany). Samples were gold-sputter coated to render them electrically conductive and fixed by adhesive tape in the sample stage.

3.3.6 Swelling Properties:

The weight of each dried hydrogel grafted cotton fabric was measured before the swelling experiment. These samples were then soaked in buffer solutions with pH range of 5.5–8.5 at room temperature. At periodic intervals the sample was taken out from the beaker, the surface moisture was removed by blotting and weighed in a calibrated analytical balance. The swelling ratio was determined by normalizing the water uptake with respect to the mass of the dried gel.

$$\text{Swelling Ratio} = (Ms-Md) \times 100 / Md \qquad (2)$$

Where Ms, Md indicate the mass of swollen and dry hydrogel grafted cotton fabric respectively.

3.3.7 Mechanical Proprties

The mechanical properties such as tensile strength, modulus and percentage strain at break were measured using an Instron 3369 at an extension rate of 5 mm/min. The force and elongation were measured when equal size 10 mm width and 40 mm length rectangular size dressing material broke off.

3.3.7.1 Tensile Strength

Tensile Strength (N/mm^2) = Breaking Force (N)/Cross-sectional Area of Sample (mm^2)

3.3.7.2 Modulus

Modulus is the measurement of material's stiffness

Modulus = Difference in stress/difference in corresponding strain

3.3.7.3 Elongation at Break

$$\text{Elongation at Break (\%)} = \frac{\text{Increase in Length at Breaking Point (mm)}}{\text{Initial Length (mm)}} \times 100$$

3.3.8 BSA Release Studies

. The drug release study of hydrogel grafted cotton fabric was examined by Cary 300 UV-Visible spectrophotometer (Agilents Technologies).

3.3.8.1 BSA drug loading

Dried sample discs weighing 30 mg were placed in test tubes containing 10 mL of aqueous solutions of BSA (1%). Then test tubes were placed, in absence of light at room temperature for 3 days. After 3 days, hydrogels were separated from the solutions and dried.

3.3.8.2 *In Vitro* BSA drug Release Study

Release of BSA was carried out at different pH 5.5 (acidic), pH 7(neutral) and pH 8.5(basic) by using buffer solutions. Experiments were performed by placing the dried sample containing the drug in test tube. The volume of water in the vessel was 10 ml. The amount of drug released at each time point was determined spectrophotometrically at 280 nm using Cary 300 UV-VIS

spectrophotometer. The distribution of the drug molecules in the hydrogel was assumed to be homogeneous.

The buffer solution of pH 5.5 was prepared18 by mixing 100 mL of 1M Potassium dihydrogen orthophosphate and small amount of Di-pottasium hydrogen orthophosphate and the buffer solution of pH 8.5 was prepared by mixing 100 ml of 1M of Di-pottasium hydrogen orthophosphate and small amount of Potassium dihydrogen orthophosphate.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Preparation of fabric supported hydrogel wound dressing material

For the development of fabric supported hydrogel wound dressing material, the fabric was first treated with initiator solution. APS was used as an initiator to create the activate site on fabric. The initiator treated fabric was graft polymerised with acrylic acid and acrylamide. After graft polymerization, crosslinking agent was added for the formation of hydrogel on cotton fabric. The mechanism of initiation on cotton fabric, graft polymerisation of monomers and crosslinked hydrogel formation is shown in Figure 4-1.

Chemically, fabric supported hydrogel wound dressing material was synthesized by free radical co-polymerization. Chemical reactions involved in polymerization are shown in Figure 4-2.

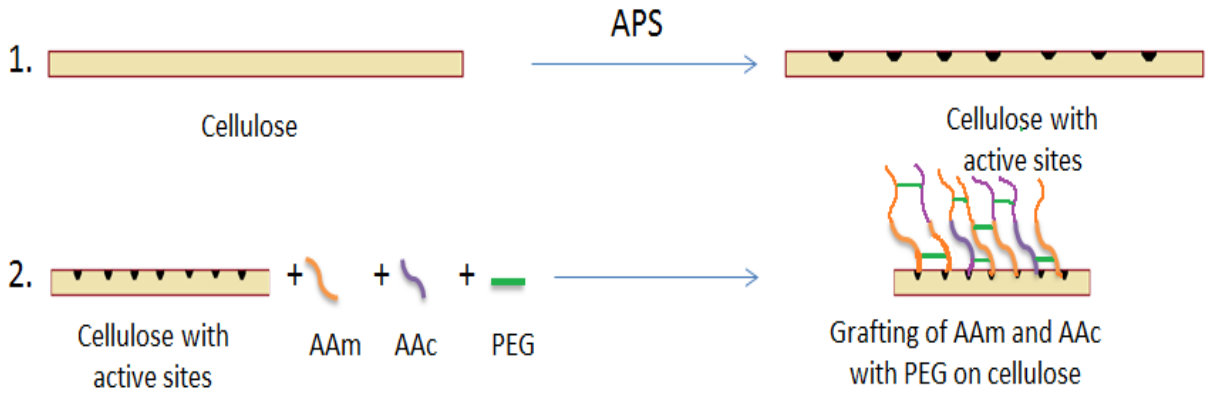


Figure 4-1 (1) Creation of active site on cellulose and (2) Grafting of AAm and AAc with PEG

4.2 Mechanism of grafting

APS produce cellulose macroradicals via direct abstraction of hydrogen atom from cellulose molecules. This reaction is represented in figure 4-2 (1). Where, Cell-OH represents the cotton cellulose molecule. In the presence of a vinyl monomer the cellulose is added to the double bond of the vinyl monomer, resulting in a covalent bond between monomer and cellulose with

creation of free radical on the monomer i.e. a chain is initiated. Subsequent addition of monomer molecules to the initiated chain propagates the grafting reaction onto cellulose. Termination of the growing grafted chain may occur via reaction with the initiator, coupling or combination and disproportionation.

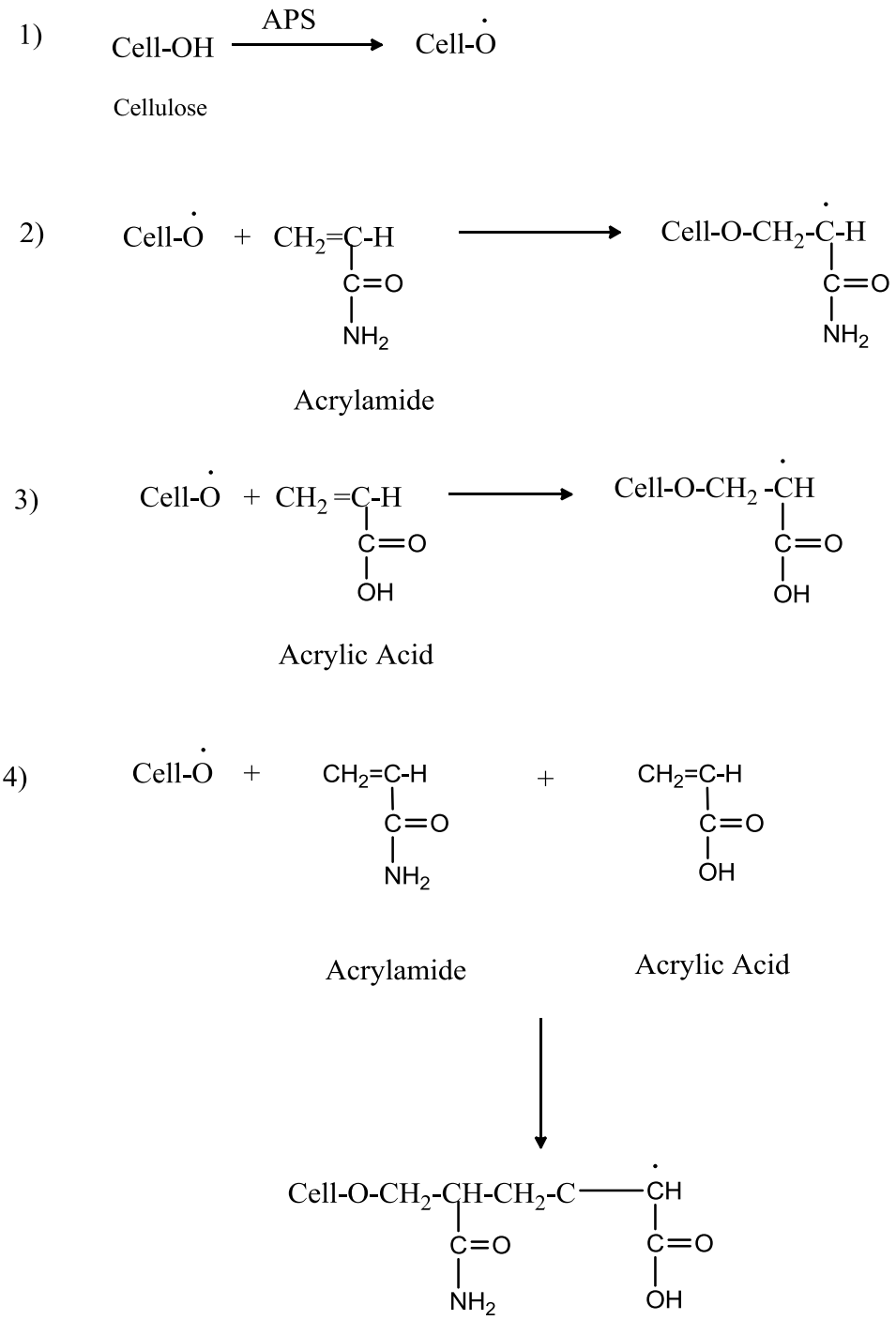


Figure 4-2 Chemical reactions involve in graft polymerization

4.3 Grafting yield (%)

The effect of monomer concentration, initiator concentration, time of reaction, temperature of reaction and PEG addition time were optimized with maximum grafting yield.

4.3.1 Effect of ammonium per sulphate concentration

The effect of APS concentration on degree of grafting of hydrogel was studied and the results are shown in Figure 4-3.

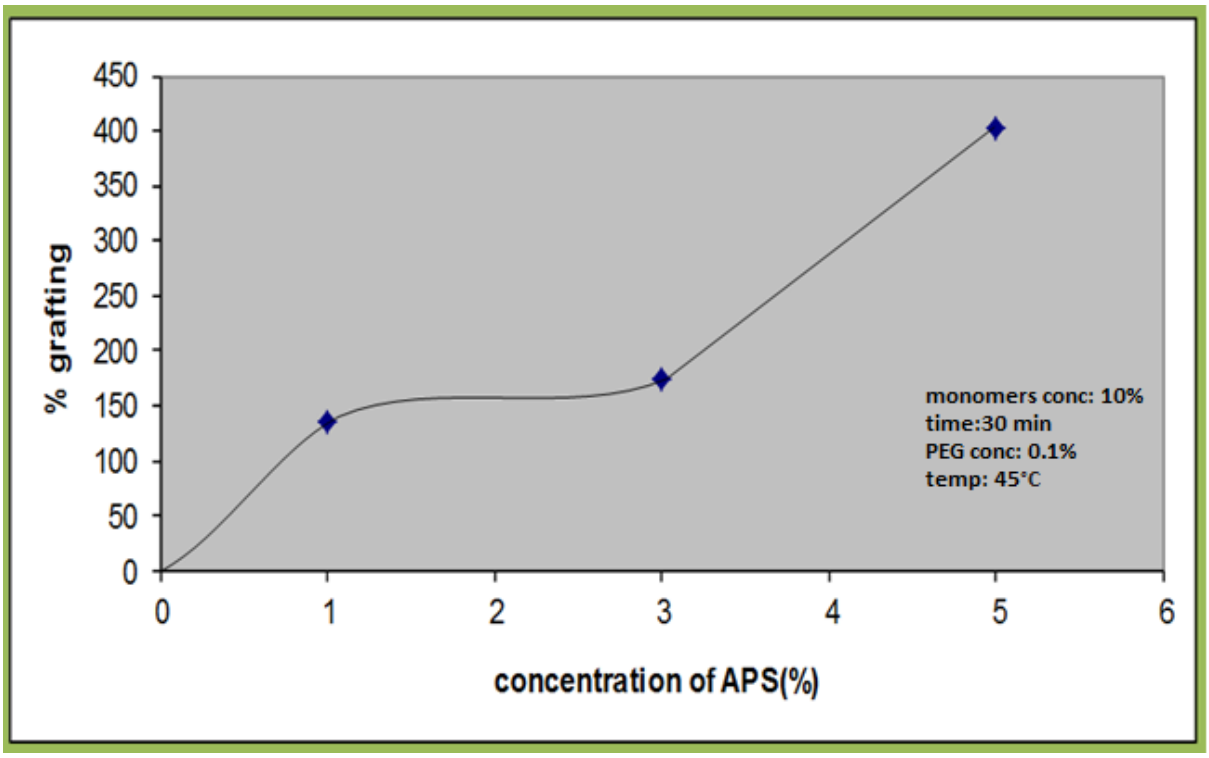


Figure 4-3 Effect of APS concentration on % grafting

APS concentration was increased from 1 % to 5 %. At 5 % of APS concentration, the degree of grafting of hydrogel was found 402%. These increasing trends of the grafting parameters indicated that APS exclusively participate in the formation of active sites on the surface of cotton fabric to this concentration of APS. For further studies the initiator concentration 5% was taken as it is gives sufficient grafting of hydrogel on cotton fabric.

Similar results have been given by *R. Khullar*1, *et. al* and others, according to which % grafting increases with the increase initiator concentration and reaches maximum value of %

grafting at a particular concentration of initiator, beyond which it decreases. Concentration of initiator depends on its chemical nature.

4.3.2 Effect of monomer concentration

Two different monomers acrylamide and acrylic acid were grafted on cotton fabric. The ratio of acrylamide/acrylic acid was taken 1:1 in this study. The effect of monomer concentration was

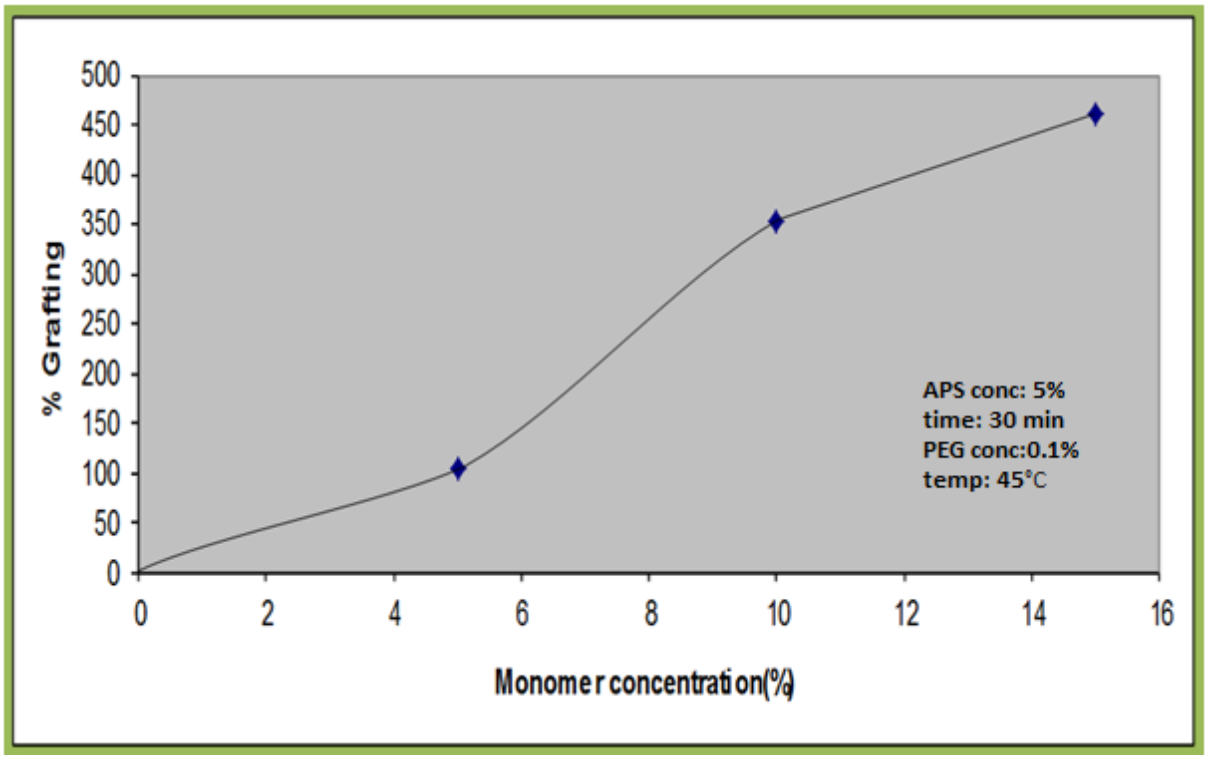


Figure4-4 Effect of monomers concentration on % grafting

studied and the results are shown in Figure 4-4. The results show that as the monomer concentration increases from 5 %to 15 %, there is an increase in % grafting, the degree of grafting of hydrogel was found 460% at 15% .This is due to more accessibility of monomers for grafting.

Similar effect of monomer concentration have been observed by A S Singha in Pressure induced graft-co-polymerization of acrylonitrile onto Saccharum cilliare fibre and evaluation of some properties of grafted fibre.

4.3.3 Effect of temperature

The grafting reactions were carried out at different temperatures (30-60°C) keeping the other variables constant. The effect of temperature on % grafting is shown in Figure 4-5. Results show that maximum % grafting (352%) is obtained at 45°C and decreases with further increase in temperature. The dependence of % grafting on temperature can be ascribed to higher rate of dissociation of initiator as well as the diffusion and mobility of monomer from the aqueous phase to fabric phase, resulting in considerable improvement in the grafting yield.

Similar result of temperature on % grafting have been given by Faraj A. Abu-Ilaiwi et al" in Graft Copolymerization of Methyl Methacrylate onto Rubber-Wood Fiber Using H_2O_2 and Fe^{+2} as an Initiator System".

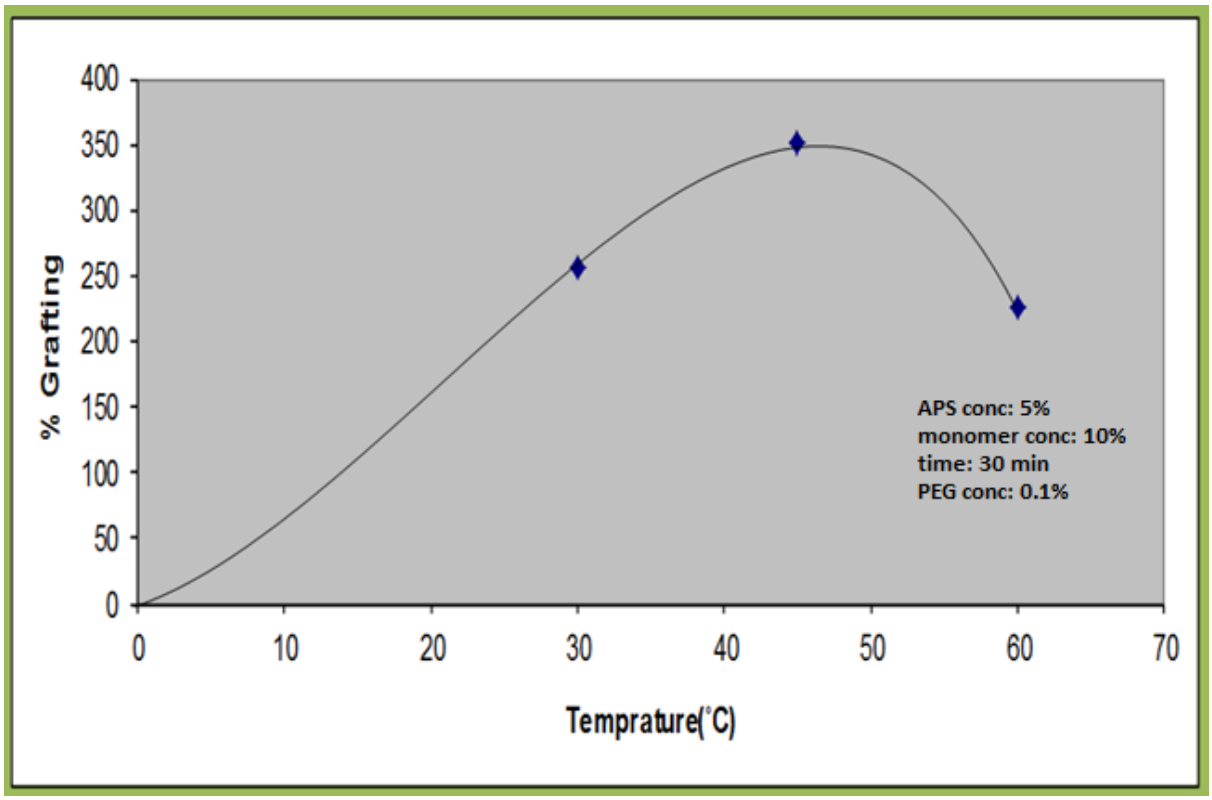


Figure 4-5 Effect of temperature on % grafting

4.3.4 Effect of duration of polymerization

The effect of polymerization time on % grafting was studied and the results are shown in Figure 4-6. It can be seen from the figure that the % grafting increases rapidly with increase in time up to 45 min, reaching a value 436%. The increase in % grafting is accounted for by the Increase in number of grafting sites in the initial stages of reaction due to high rate of APS participation in the formation of reactive sites at the fabric backbone.

Similar results have been found in "Grafting of Industrial Cellulose Pulp with Vinyl acetate Monomer by Ceric Ion Redox System as Initiator" by Éva Borbély, József Erdélyi.

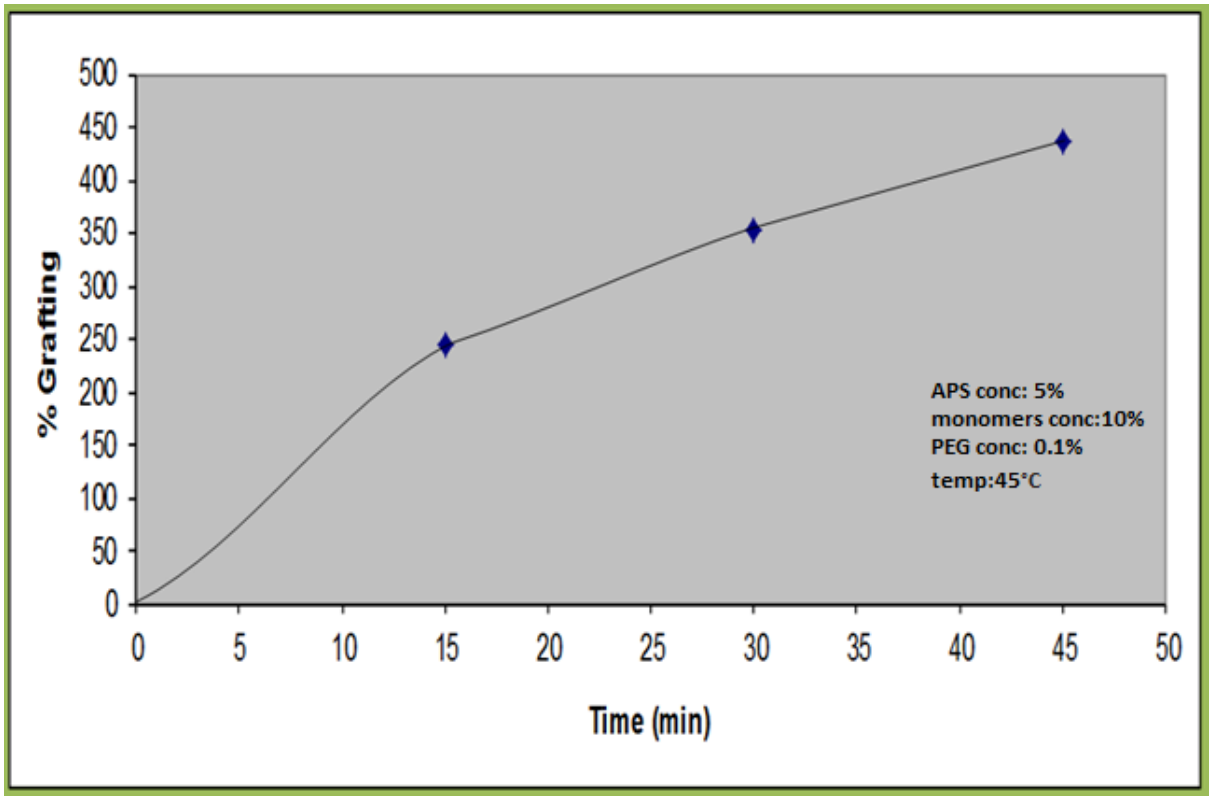
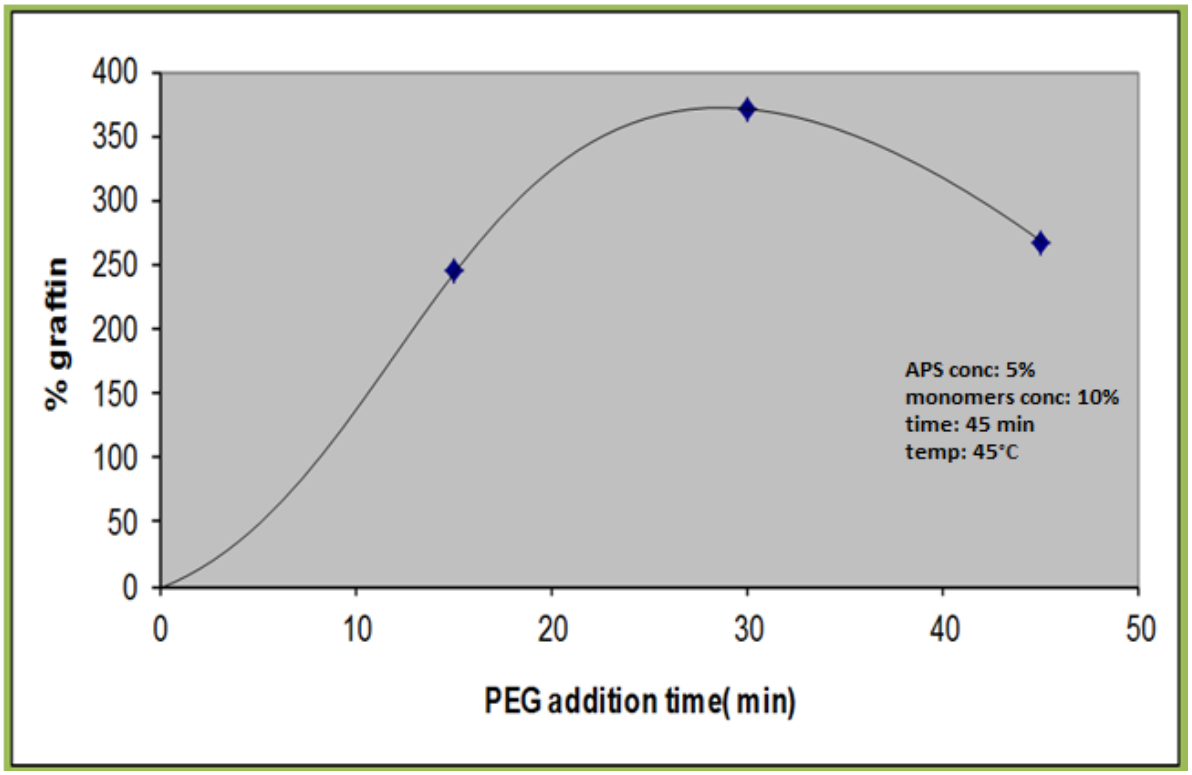


Figure 4-6 Effect of duration of polymerization on % grafting

4.3.5 Effect of the PEG addition time

The effect of PEG addition time was studied and the results are shown in Figure 4-7. PEG Addition time was increased from 15-45 min. It is evident that the grafting parameters, % grafting increases with an increase in the PEG addition time, but reaches maximum value of 372

% when PEG addition was taken place after 30 minutes at 45 °C Further increase in PEG addition time is accompanied by a decrease in the %G.



. **Figure 4-7** Effect of the PEG addition time on % grafting

4.4 FTIR

FTIR Spectroscopy was performed on to determine the structure of the organic compounds and to identify the presence of specific functional groups within a sample.

FT-IR spectra of ungrafted cotton (Fig. 4-8) shows characteristic cellulose peaks around 1000–1200 cm^{-1}.Other characteristic bands related to the chemical structure of cellulose were the hydrogen-bonded OH stretching at 3445.4 cm^{-1}, the CH stretching at 29102.4 cm^{-1} , the asymmetrical COO^- stretching at 1642.5 cm^{-1} , and the CH wagging at 1372.2 cm^{-1} and the C-O stretching at 1058.6 cm^{-1}.

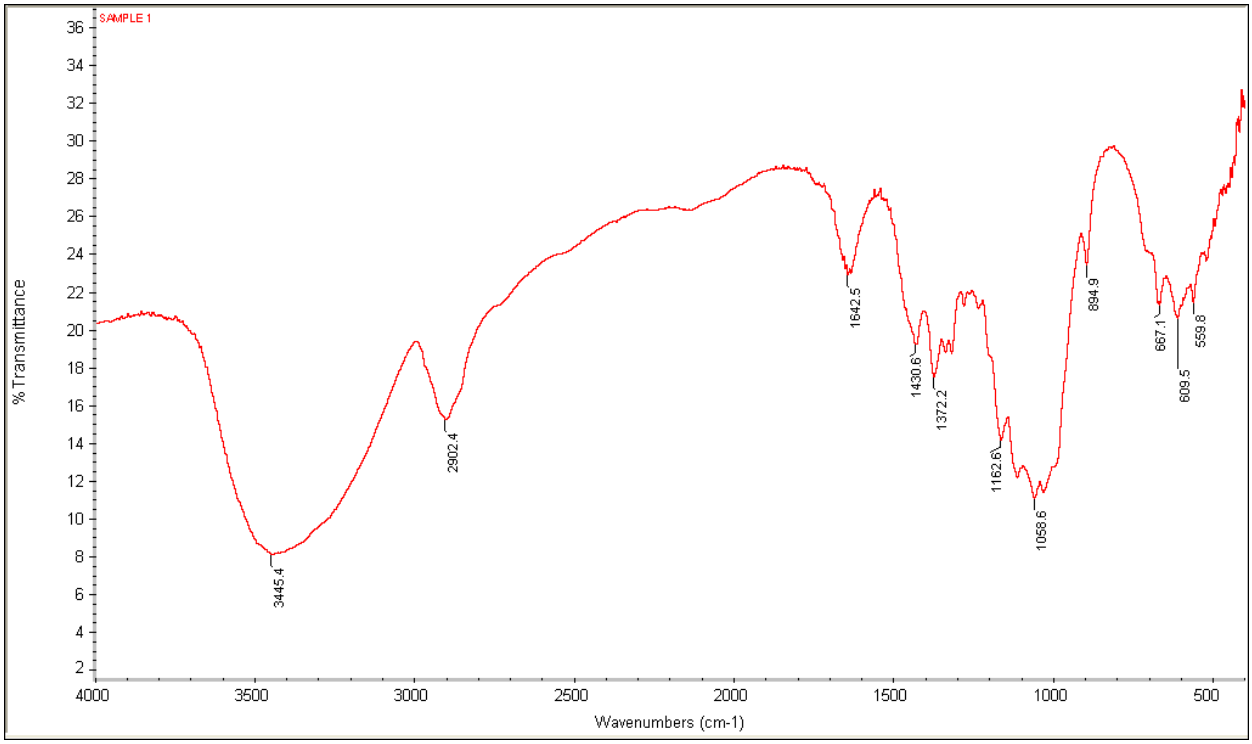


Figure 4-8 FTIR spectra of cotton fabric

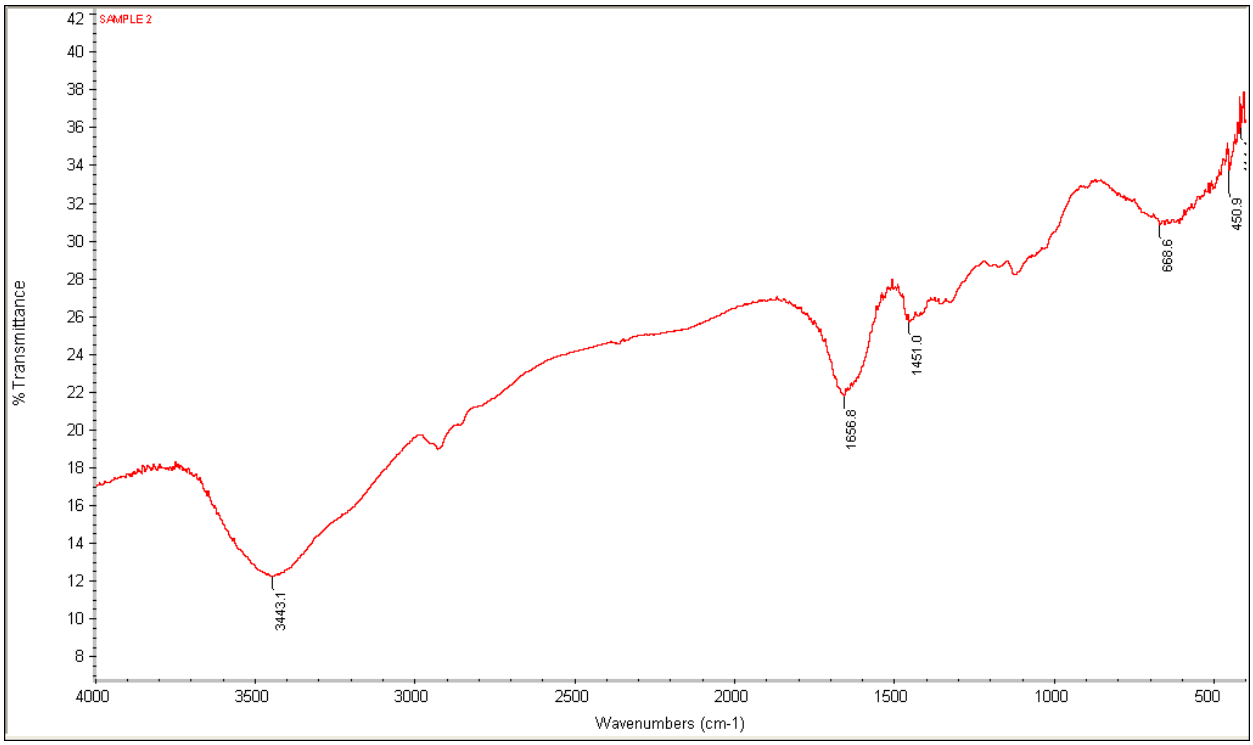


Figure 4-9 FTIR spectra of PAAm-g-cotton

FTIR spectra of polyacrylamide grafted cotton fabric (Figure 4-9) shows the characteristic peaks of polyacrylamide. N-H stretching at 3453.1 cm^{-1},C=O (C=O of amide group) stretching at 1656.8 cm^{-1}.

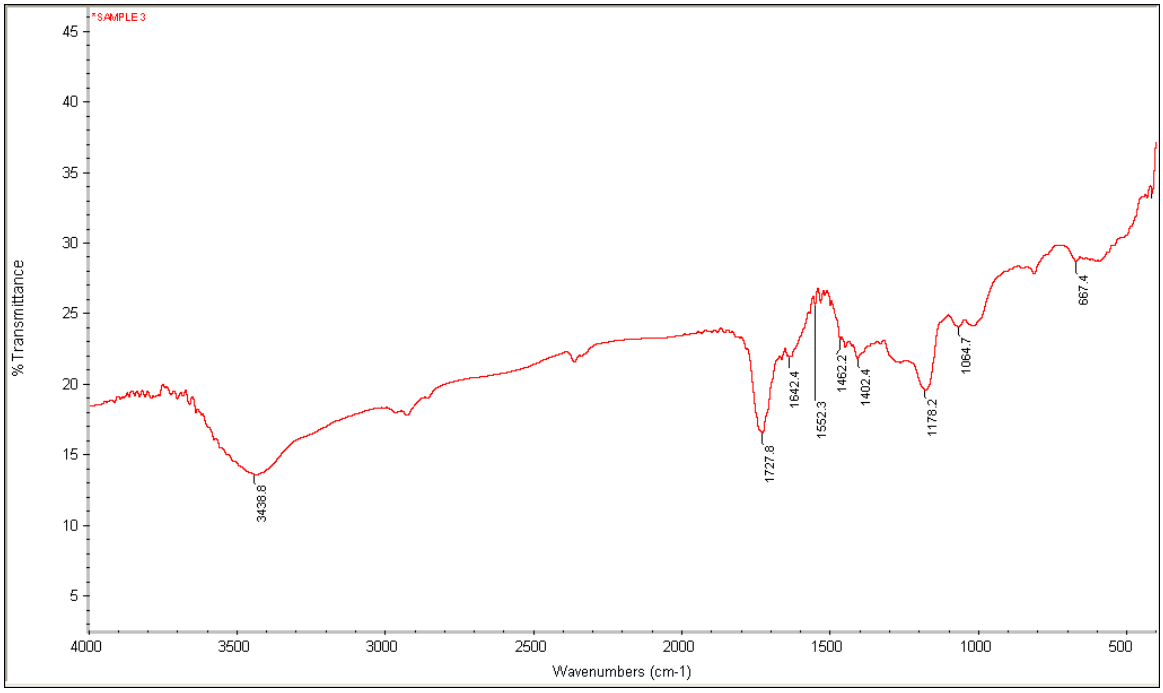


Figure 4-10 FTIR spectra of poly AAc-g-cotton

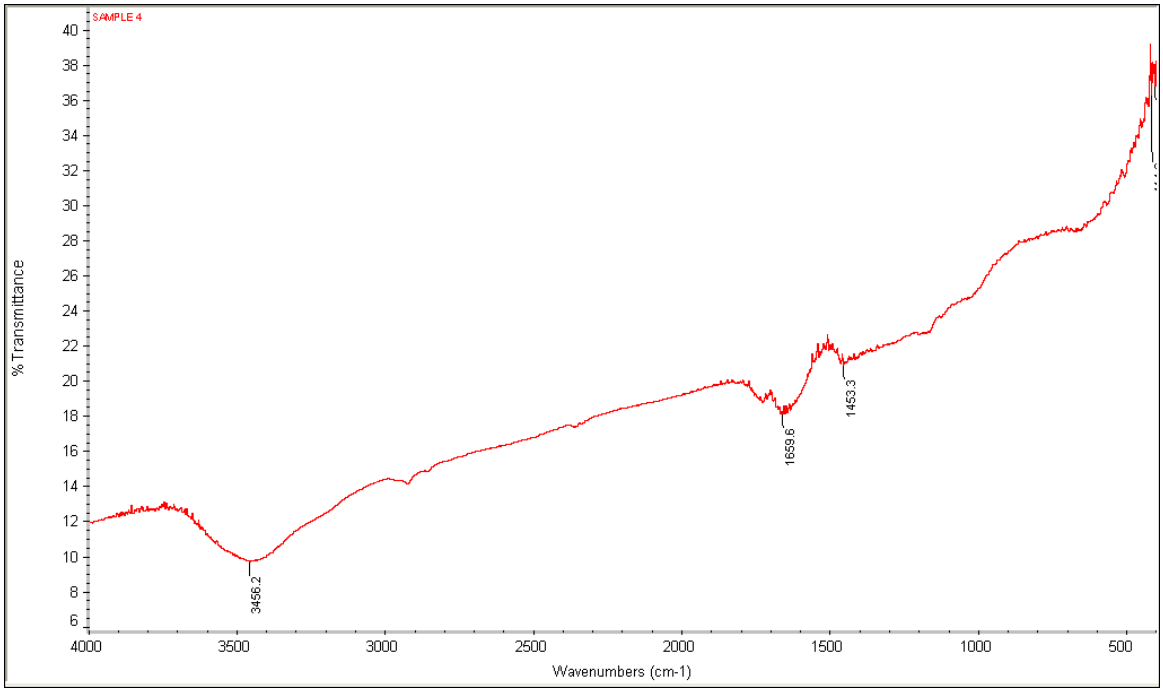


Figure 4-11 FTIR spectra of poly (AAm-co-AAc) grafted cotton fabric

FTIR spectra of polyacrylic acid grafted cotton fabric (Figure 4-10) shows the characteristic peaks of polyacrylic acid . O-H stretching at 3438.8cm^{-1},C=O (C=O of acidic group) stretching at 1727.8 cm^{-1}.

FTIR spectra of poly (AAm-co-AAc) grafted cotton fabric (Figure 4-11) shows the characteristic peaks of polyacrylic acid and acrylamide. N-H stretching at 3456.2 cm^{-1}, C=O (C=O of acidic group) stretching at 1727.8 cm^{-1}. C=O (C=O of acrylamide group) stretching at 1659.6 cm^{-1}.

FTIR spectra of poly (AAm-co-AAc-co-PEG) grafted cotton fabric (Figure 4-12) shows the characteristic peaks of polyacrylic acid, acrylamide and PEG. N-H stretching at 3442.5.2 cm^{-1}, C=O (C=O of acidic group) stretching at 1727.8 cm^{-1}. C=O (C=O of acrylamide group) stretching at 1658.4cm^{-1}.The main characteristic peak of C-O-C stretching at 1167.3 cm^{-1}is found which shows the presence of PEG crosslinking in hydrogel.

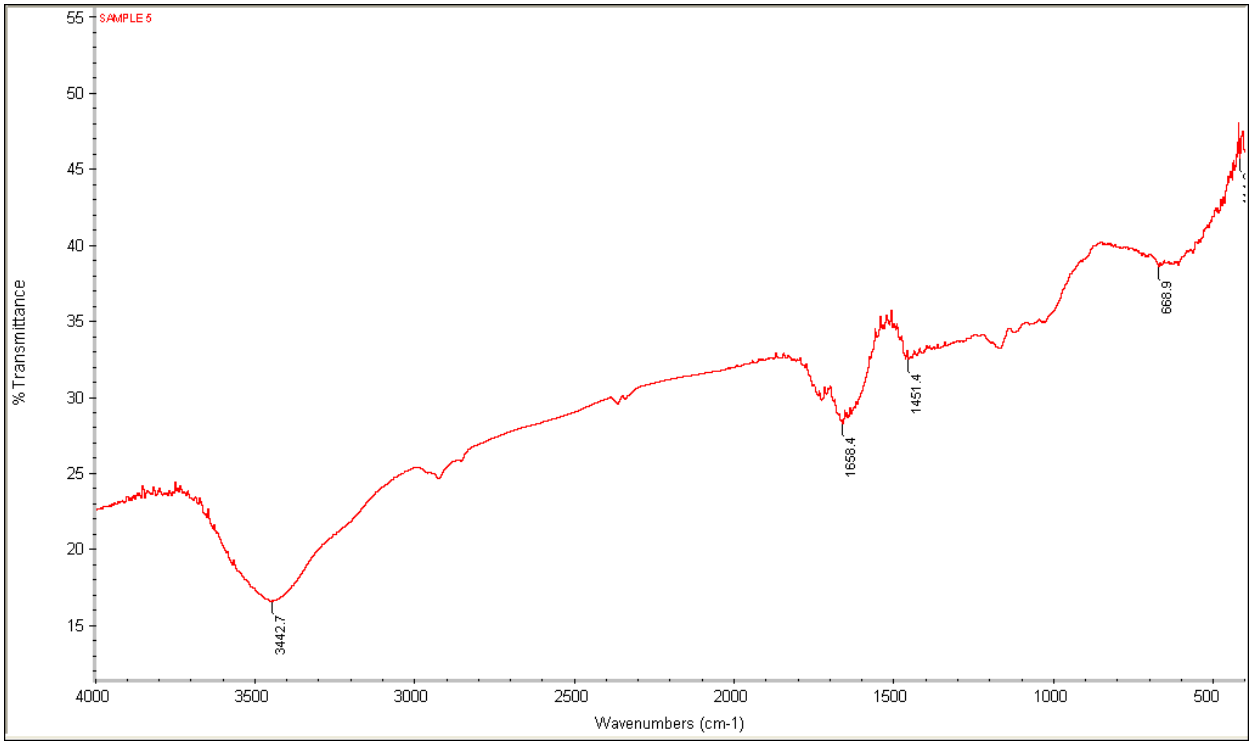


Figure 4-12 FTIR spectra of poly (AAm-co-AAc-co-PEG) grafted cotton fabric

4.5 X-Ray Diffraction (XRD)

XRD curve of ungrafted cotton fabric and grafted cotton fabric are shown in figure 4-13 and Figure 4-14 respectively. Since cellulosic materials generally contain both crystalline and amorphous regions so it is evident that X-ray diffraction patterns of such materials will show both the region in the form of sharp peaks and diffused patterns (Singha et al 2006).

As evident from the XRD curve the degree of crystallinity decreases with on grafting. This change in diffraction pattern occurs due to the creation of disorder in the crystalline pattern of the main polymeric backbone by the grafted units of the poly(AAm –co-AAc) chains. Results show the pure cotton gives characteristic peaks at 2θ value of 16.5^{o}, 22.8^{o} and a broad hump (weak) at 2θ= 34.2^{o} which represents the characteristic signature of cellulosic structure and match with its standard XRD pattern. Therefore, diffraction pattern of grafted cotton shows peak at 2θ values of 16.5^{o}, 22.8^{o} and 34.2^{o} due to cotton substrate. Some extra peaks due to grafting of hydrogel were observed in addition to all the characteristic peaks of cotton.

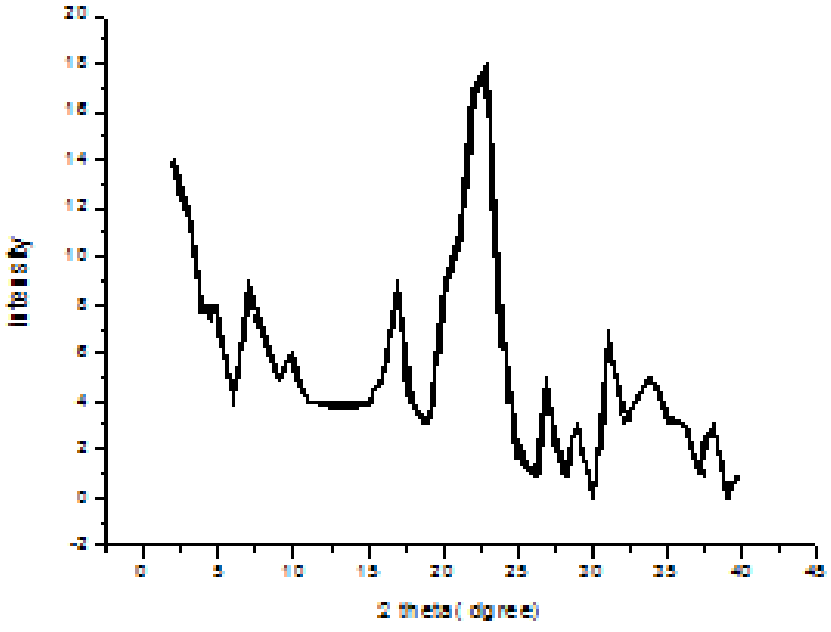


Figure 4-13 XRD pattern of ungrafted cotton fabric

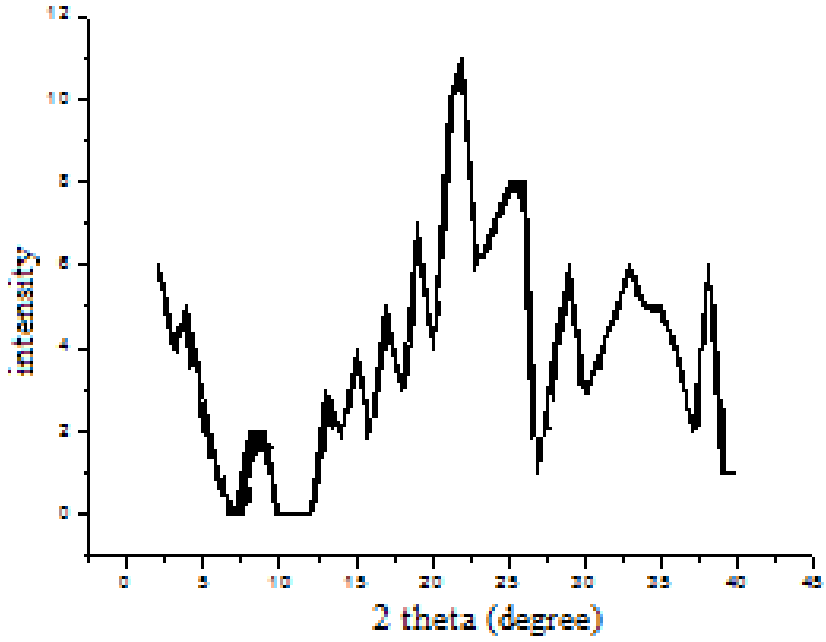


Figure 4-14 XRD pattern of hydrogel grafted cotton fabric

4.6 Thermogravimetric analysis TGA

Thermogravimetric analysis technique was used to study the effect of increasing temperature on ungrafted cotton fabric and hydrogel grafted fabrics. TGA provides quantitative information on weight change during heating process (H. S. Sharma, 1988). Thermogravimetric (TG) curves of ungrafted cotton fabric (CF) and its grafted sample were obtained by plotting the weight loss of samples at every 2 °C/min rise in temperature.

Fig 4-15 shows the TGA scan of ungrafted cotton fabric. TG curve of ungrafted Cotton fabric shows two stages of thermal degradation. A mass loss of about 2 % up to 250 °C occurs before the start of first stage of thermal degradation, which is due to the loss of water molecules from the CF. First stage occurs between 250 °C – 380 °C with mass loss of about 77%. The observed decrease in the weight may be attributed to dehydration of the cotton cellulose and oxidative thermal degradation, where large amount of flammable volatile compound are formed (Kaur et.al., 1986).

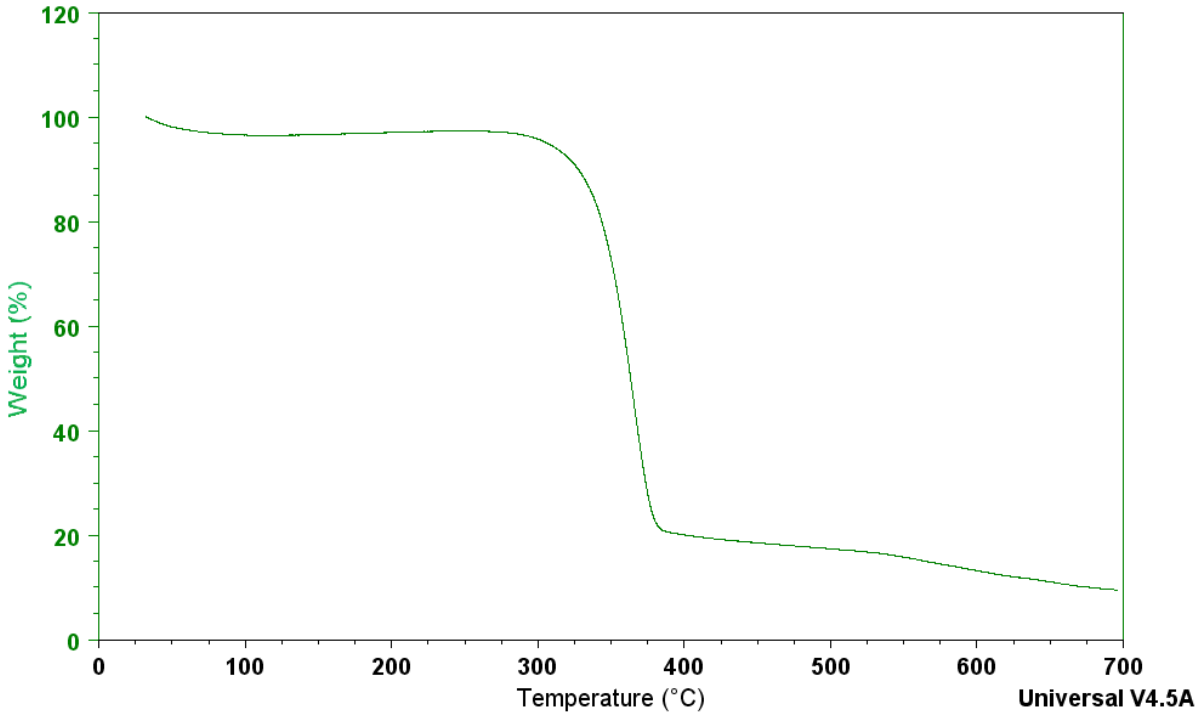


Figure 4-15 TGA curve of original cotton fabric

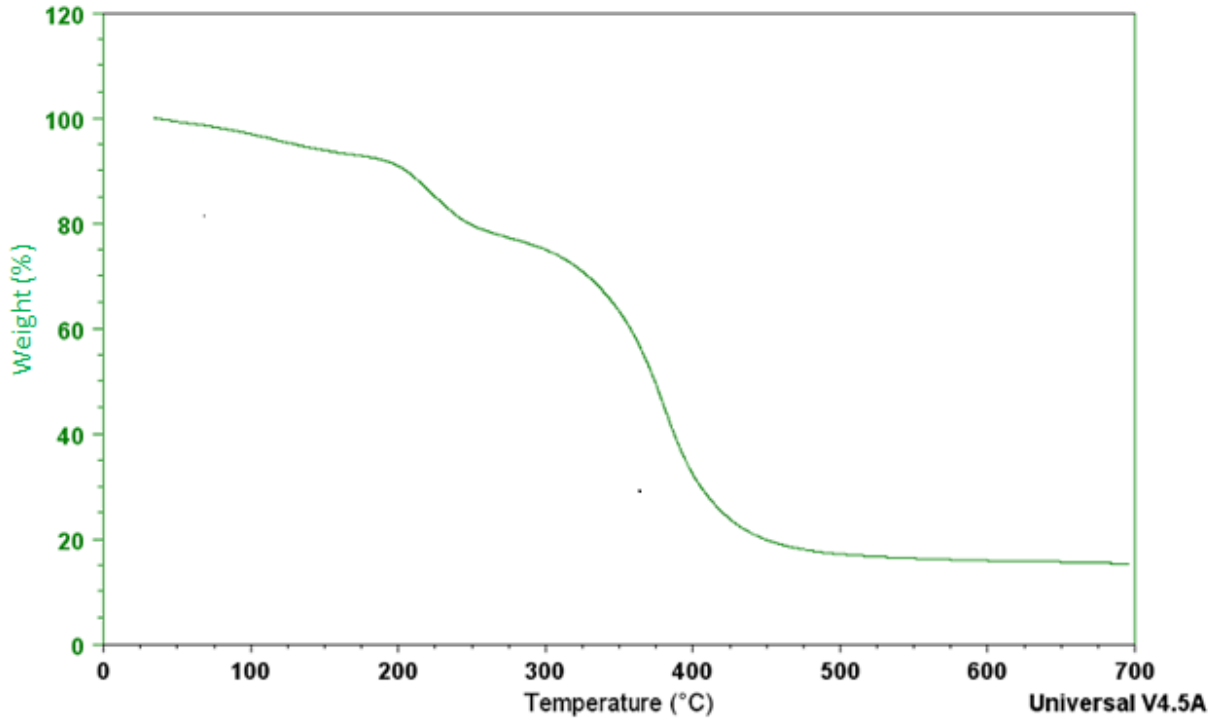


Figure 4-16 TGA curve of Poly (AAm-co-AAc) with PEG grafted cotton fabric

The thermal behaviour of dried sample of hydrogel grafted cotton fabric was also studied and is shown in Fig 4-16 as a TGA scan. The thermal degradation of polymer essentially takes place in three stages. A mass loss of about 8 % occurs in the first stage. The second stage ranging from 180 – 278 °C occurs with a mass loss of about 15 %. The third stage represents the total degradation of the hydrogel and fabric with a maximum at 370 °C and a mass loss of about 55 %. It is observed that beyond 258 °C, the hydrogel continues to absorb heat and decomposes finally at 500 °C.

Similar result have been found by A. Thakur, et al, according to which polyacrylamide, polyacrylic acid and poly (AAm-co-AAC) have two step, three step and three step degradation respectively.

4.7 Scanning Electron Microscopy (SEM)

The surfaces of the ungrafted cotton fabric and the grafted cotton fabric were examined by SEM, and the results are shown in Figure 4-17.On comparing the scanning electron micrographs of ungrafted fabric, and its grafted fabric, it has been found that upon graft co-polymerization a considerable amount of monomer gets grafted onto the fibre backbone which causes morphological changes in the fibre. The morphology of grafted cotton fabric is different significantly from that of ungrafted cotton fabric substrate. The grafted surface shows a markedly bumpy texture, while ungrafted cotton fabric surface is very planar and smooth, which indicated that monomer AAm and AAc have been grafted onto the cotton fabric.

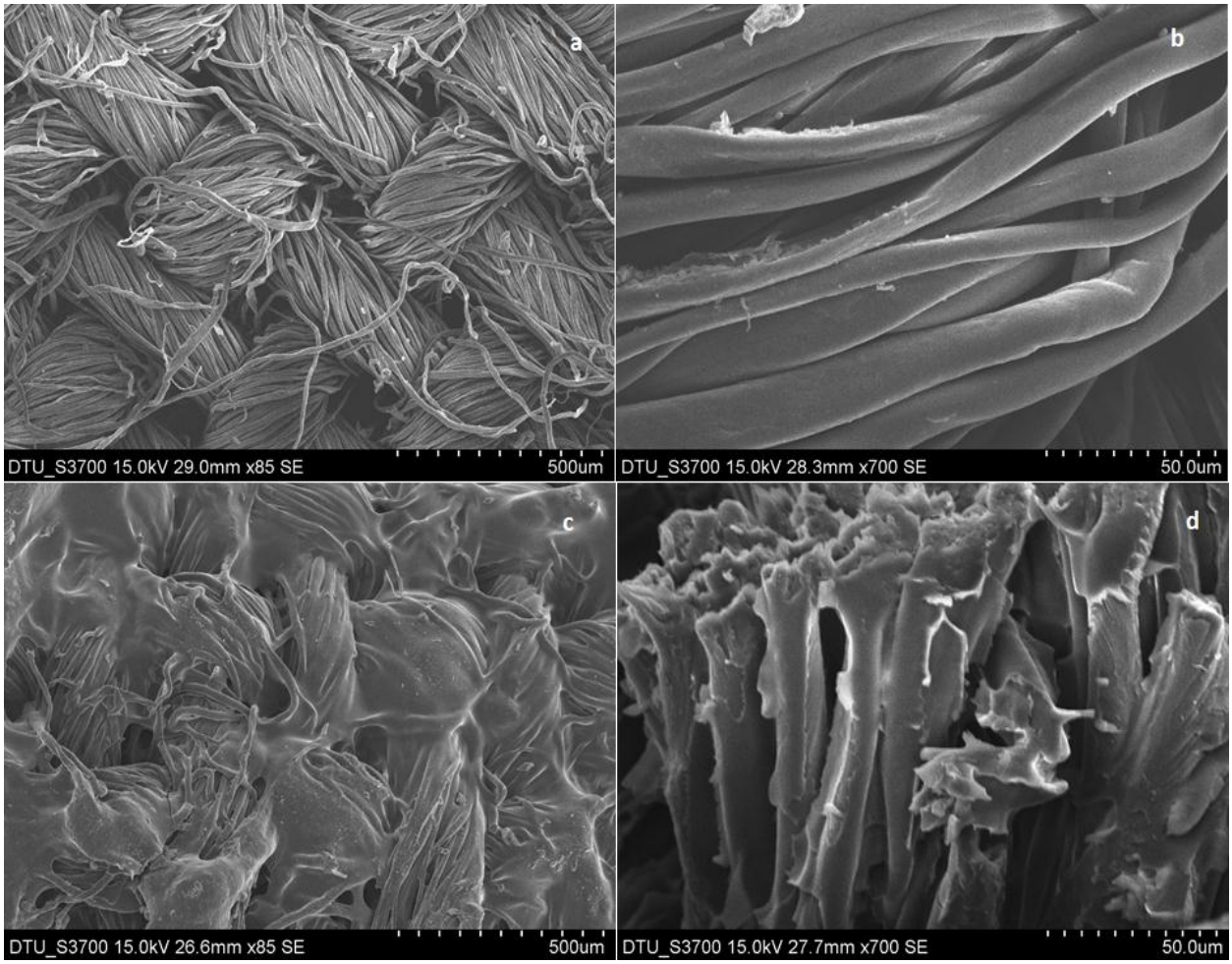


Figure 4-17 a and b Scanning electron micrographs of ungrafted cotton fabric

c and d Scanning electron micrographs of grafted cotton fabric

4.8 Swelling Properties of grafted fabric:

The swelling properties of hydrogels are of interest for many applications. The hydrogel swelling behaviour depends on the functional groups present. The degree of swelling usually depends on the pH and ionic strength of the solution. It is well known that while PAAm does not respond to changes in pH buffer solutions, PAAc is a typical pH-sensitive polymeric material that can deprotonate its carboxyl moieties in alkaline solution and protonate them in acidic solution. The dissociation degree of carboxyl groups is closely related to the pH value of the medium.

The swelling behaviour of grafted fabrics was analysed in distilled water at room temperature with span of time. The effect of composition on the swelling properties of grafted fabric is

shown in figure 4-18. It has been found that the fabric which has been grafted with AAm and AAc by using PEG as a crosslinking agent shows the better swelling behaviour than the others.

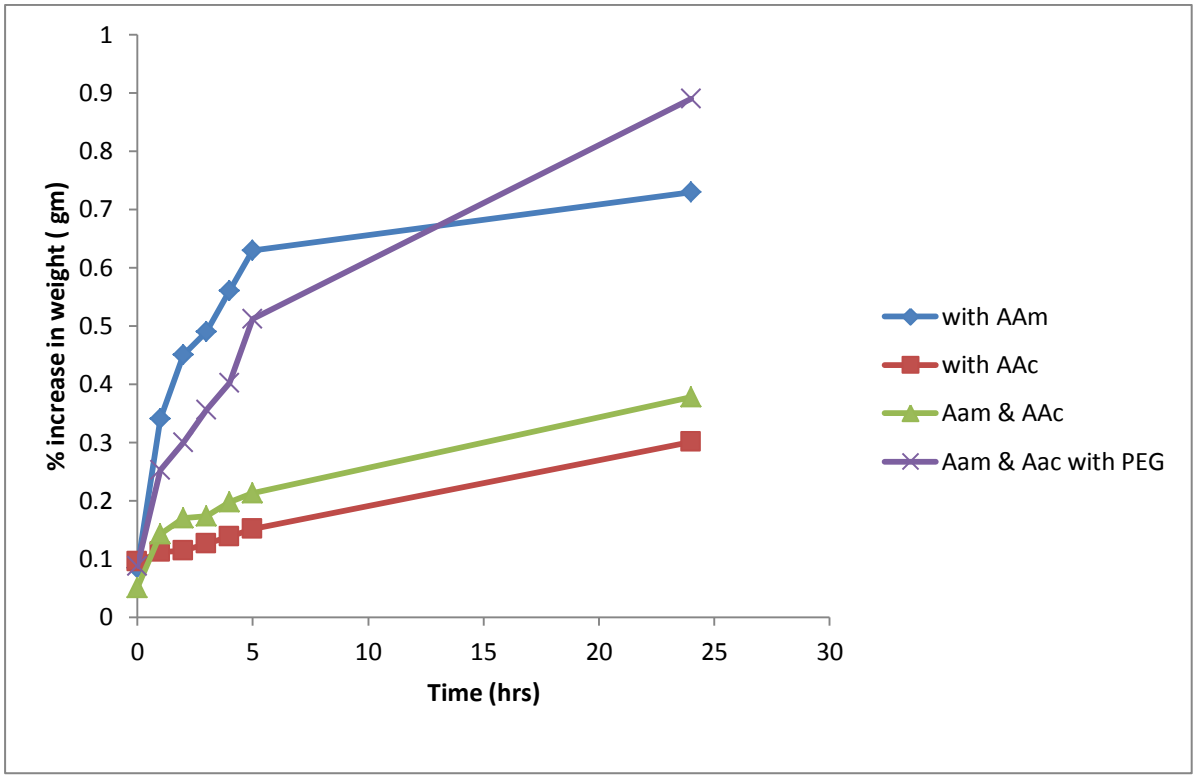


Fig 4-18 Swelling behaviour of PAAm, PAAc, Poly(AAm-co-AAc) and Poly(AAm-co-AAc-co-PEG) grafted cotton fabric

Further studies were carried out on this grafted sample. The effect of pH on the swelling properties of this grafted sample is shown in figure 4-19. pH buffer solutions were prepared by using Potassium dihydrogen orthophosphate and Di-potassium hydrogen orthophosphate.

To investigate the influence of pH value of the medium on the swelling behaviour for the grafted fabric, thus, three pH range is selected 5.5 (acidic), 7 (neutral) and 8.5(basic). In the acidic medium pH 5.5) the swelling behaviour of the grafted fabric drastically increase with time.it has been observed that from the fig 7 that the grafted fabric shows the better swelling behaviour in acidic medium (5.5 pH) than in neutral (7 pH) and in basic (8.5 pH) medium.

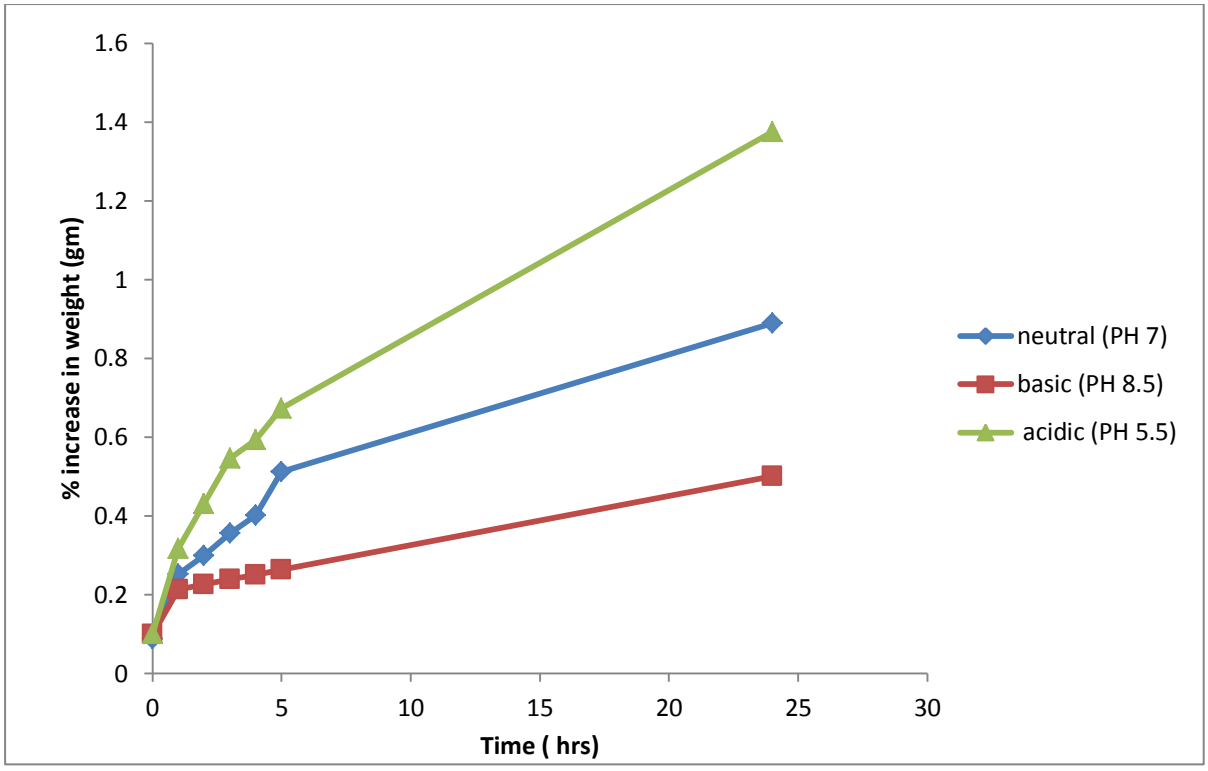


Fig 4-19 Swelling behaviour of Poly(AAm-co-AAc-co-PEG) grafted cotton fabric at different pH

4.9 Mechanical Properties

Mechanical properties, among all the properties are often most important properties. The material selection for variety of application is quite often based on mechanical properties such as tensile strength, modulus and elongation.

4.9.1 Tensile strength

One advantage of grafting hydrogel on the fabric surface other than using hydrogel alone is that the fabrics can provide a mechanical support and dimensional stability for the hydrogel. However, grafting of hydrogel changes the surface chain structure of fabrics. Some additives used may also react with the fabric molecular chains. These two factors influence the mechanical properties of grafted fabrics since woven fabrics have a large surface area. Therefore, the tensile

properties of original, hydrogel grafted Cotton fabric are tested.The results are shown in Figure 4-20.

A: original cotton

B: Cotton-g-PAAm

C: Cotton-g-PAAc

D: Cotton-g-Poly(AAm-co-AAc)

E: Cotton-g- Poly(AAm-co-AAc) with PEG

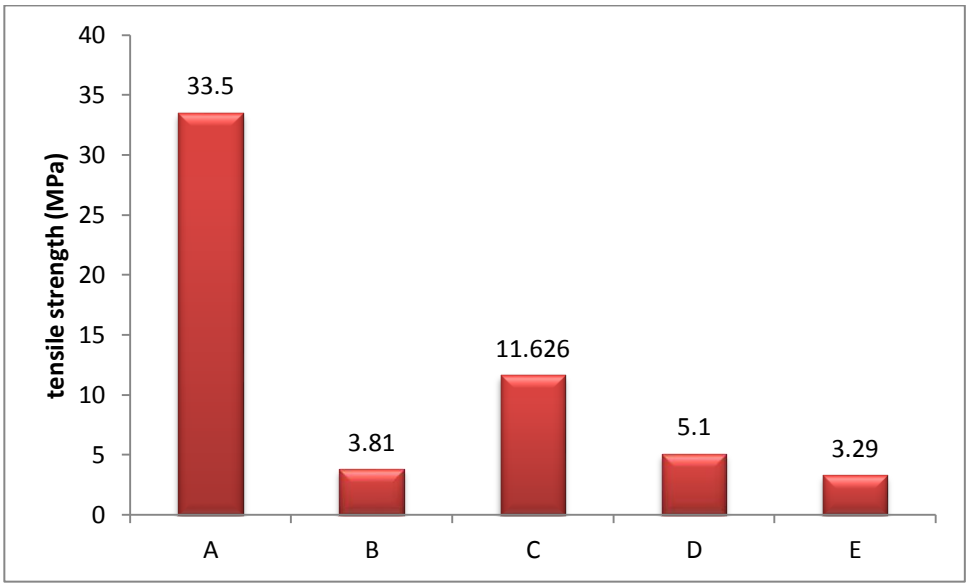


Figure 4-20 Tensile strength of original, PAAm grafted, PAAc grafted, Poly(AAm-co-AAc)and Poly(AAm-co-AAc)with PEG grafted cotton fabric.

It is shown in Figure 4-20 that there is significant difference in tensile strengths of original and grafted cotton fabric. Tensile strength of fabric decreases on grafting with hydrogel. Original cotton fabric shows the maximum tensile strength and poly (AAM-co-AAc) hydrogel with PEG crosslinker grafted fabric shows the minimum tensile strength. Crosslinking in hydrogel decrease the tensile strength of grafted cotton.

4.9.2 Modulus

It is shown in Figure 4-21 that the modulus of Poly(AAm-co-AAc) hydrogel(with PEG) grafted cotton fabric is about 186 MPa bigger than that of the original sample. This may be due to the crosslink effect.

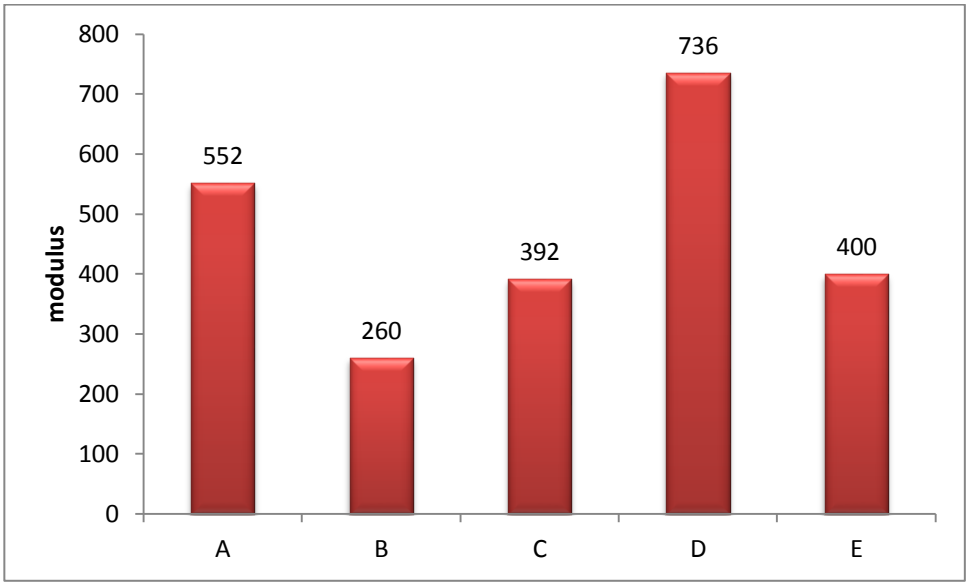


Figure 4-21 Modulus of original, PAAm grafted, PAAc grafted, Poly(AAm-co-AAc)and Poly(AAm-co-AAc)with PEG grafted cotton fabric.

. PEG addition may have resulted in surface crosslink, decrease of chain mobility and strain, and increase of modulus. The large amount of grafting and use of crosslinker decreased the modulus but copolymerization of AAm and AAc increases the modulus

A: original cotton

B: Cotton-g-PAAm

C: Cotton-g-PAAc

D: Cotton-g-Poly(AAm-co-AAc)

E: Cotton-g- Poly(AAm-co-AAc) with PEG

4.9.3 Elongation

It is shown in Figure 4-22 that there is a significant difference in elongation of original and grafted cotton fabric. Figure shows that maximum elongation is shown by cotton-g-PAAc .

PAAc gives the flexibility to the cotton fabric. Elongation decreases on copolymerization of AAm and AAc on fabric but increases on the addition of crosslinker.

A: original cotton

B: Cotton-g-PAAm

C: Cotton-g-PAAc

D: Cotton-g-Poly(AAm-co-AAc)

E: Cotton-g- Poly(AAm-co-AAc) with PEG

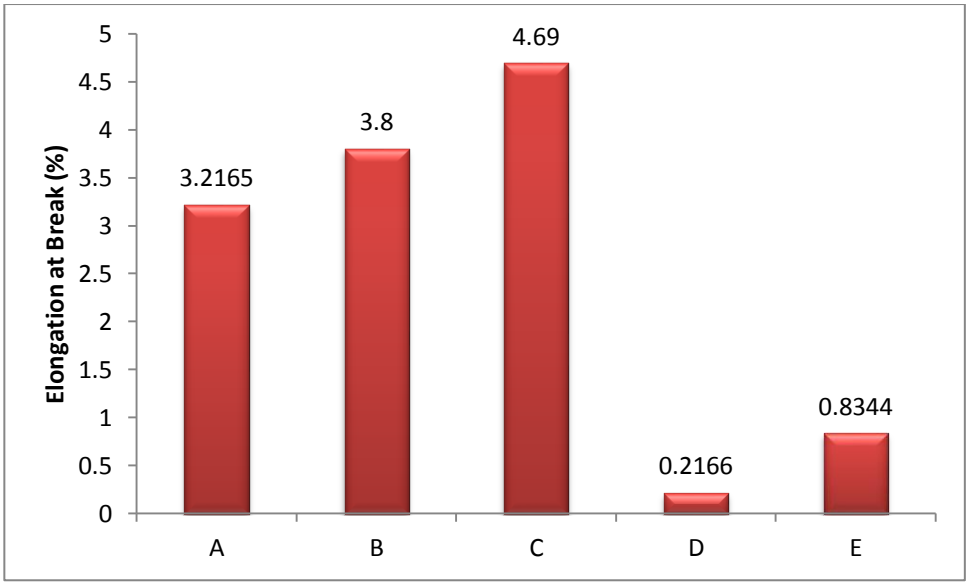


Figure 4-22 Elongation of original, PAAm grafted, PAAc grafted, Poly(AAm-co-AAc)and Poly(AAm-co-AAc)with PEG grafted cotton fabric.

4.10 BSA drug release studies

4.10.1 Drug release loading

Drug incorporation experiments were performed by immersing cotton supported hydrogels labeled as 1% (w/v) BSA solutions. Three days later, the swollen gels were reweighed and the concentrations of BSA left in the loading medium were determined by measuring the absorbance at 280 nm using UV-Vis spectrophotometer. After swelling equilibrium, all gels absorbed large

amount of water including the control one, and the BSA concentration left in the loading medium remained unchanged. It appeared that there was no detectable difference in swelling behaviour of protein-loaded and -unloaded gels, indicating that no osmotic pressure in the gels due to the dissolved protein was present which could affect the hydrogel swelling, and BSA incorporation depends only on swelling degree of cotton supported hydrogel, i.e. the properties of the cotton supported hydrogel, regardless of the drug concentration.

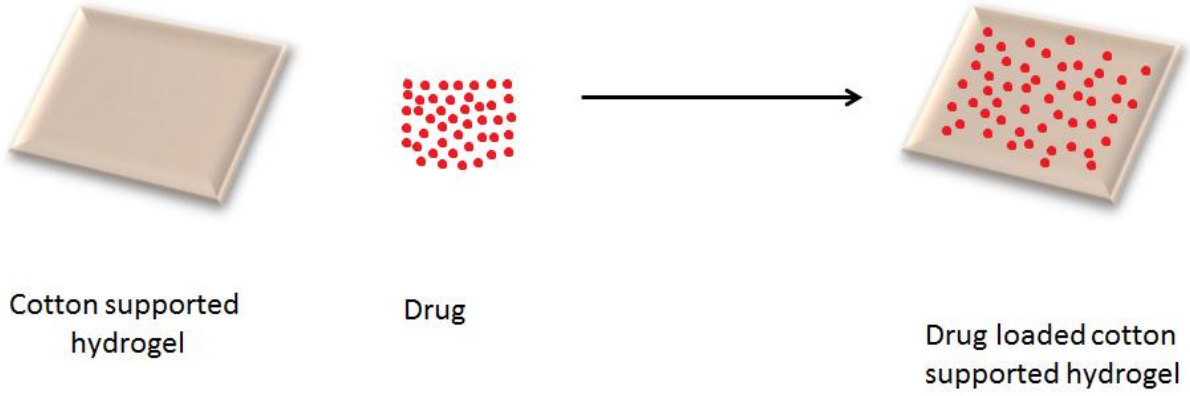


Figure 4-23 BSA Drug loading

4.10.2 BSA drug release

The pH-dependent release of BSA from the cotton supported hydrogels was performed by swelling BSA incorporated gels in different pH solution for 3 days.

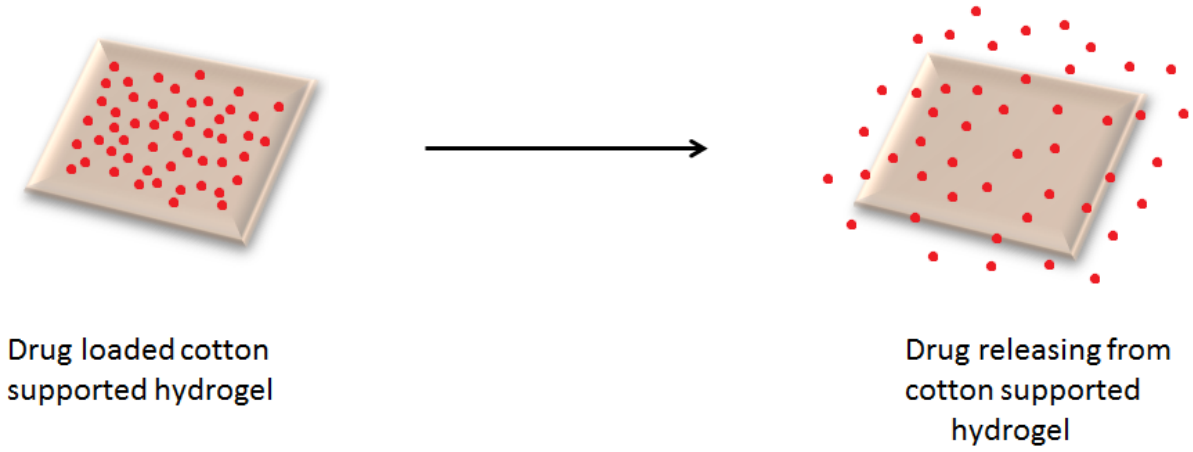


Figure 4.24 BSA drug releasing

The releases of BSA from cotton supported hydrogel were performed by immersing the BSA-incorporated samples in pH 5.5, 7 and 8.5 buffer solutions, respectively.

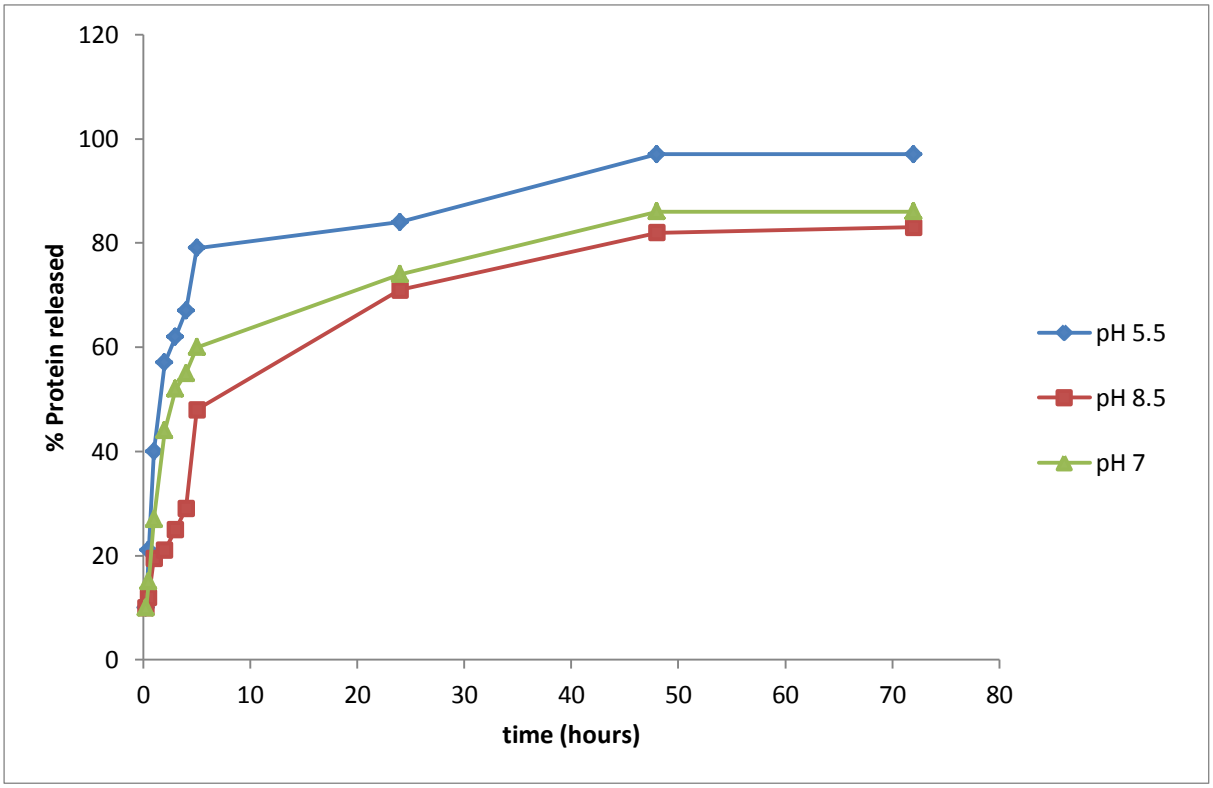


Figure 4-25 BSA drug release with time at different pH

Fig 4-25 depicts the release profiles of BSA from cotton supported hydrogel in pH 5.5, 7 and 8.5 buffer solutions at room temperature (37^{o} C). Study was carried out for a period of 3 days. Within the first 5 h, 79 %, 60 % and 48 % of loaded BSA was released from the cotton supported hydrogels in pH 5.5, 7 and 8.5 buffer solutions respectively. This is considered as a burst effect and it has been attributed to the unbound excess of BSA on the surface of the polymer. Then, all gels gave a slow drug release up to 48 h after initial burst effect. And 2 days later, BSA was steadily release from all gels, reaching a cumulative drug release of 97%, 83 % and 86 % in 3 days.Initial release of BSA from these samples is proportional to the time. This indicates that the pore sizes of the hydrogels are larger than the hydrodynamic radius of BSA, and that the release of the unbound BSA followed the Fickian diffusion. This suggests that most BSA loaded in the

gel were unbounded to the gel matrix. At this stage, the cotton supported hydrogels serve as diffusion barriers and the proteins were released mainly by diffusion mechanism. As shown in Fig. 5, after the initial burst, more than 30% loaded drug was still entrapped in the gel. This suggests that some BSA loaded in the gel were bounded to the gel network due to strong intermolecular interactions between BSA and cotton supported hydrogel.

CHAPTER 5

GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

A wound dressing was developed in this study by grafting AAm and AAc on cotton fabric using APS as initiator and PEG as crosslinker. The optimum reaction conditions obtained for grafting of AAm and AAc onto cotton fabric were: APS concentration 5% (w/v), monomers concentration 15 % (w/v), temperature of reaction 45°C, polymerization time 45 min and PEG addition time 30 min. The % grafting for optimized samples is 682 %. The characterization of the grafted cotton by means of FTIR, XRD, TGA and SEM furnished the evidence of grafting of AAm and AAc onto the cellulosic material. Fabric supported hydrogel was loaded with model drug BSA. It was conclude that fabric supported hydrogel showed control drug release in all pH medium but maximum drug release in acidic medium.

5.2 Future scope of the work

Stimuli responsive hydrogel could be used to prepare the fabric supported hydrogel.

Nonwoven cotton fabric could be used to prepare dressing materials having better strength than the woven cotton fabric based dressing material.

REFERENCES

(1) Wound Care Hand Book

(2) Bhuvnesh Gupta, roopali agarwal & M S Alam:Textile Based smart Wound Dressing (2010)

(3) Payam Zahedia, Iraj Rezaeian, Seyed-Omid Ranaei- Siadatb, Seyed-Hassan Jafari and Pitt Supaphol : A review on wound dressings with an emphasis on electrospun nanofibrous polymeric bandages (2009)

(4) *Baljit Singh, Lok Pal*: Sterculia crosslinked PVA and PVA-poly(AAm) hydrogel wound dressings for slow drug delivery: Mechanical, mucoadhesive, biocompatible and permeability properties (2012)

(5) Anal Neil : An over view of Composite Wound Dressing Innovation and Adoption

(6) Hand Book of Hydrogel

(7) David B. Stein: Handbook of Hydrogels: Properties, Preparation & Applications (2009)

(8) Janusz M. Roisak et al : Radiation formation of hydrogel for biomedical Application

(9) Ting Yang: MECHANICAL AND SWELLING PROPERTIES OF HYDROGELS (2012)

(10) K. PAL, A. K. BANTHIA and D. K.MAJUMDAR Polymeric Hydrogels: Characterization and Biomedical Applications –A mini review (2009)

(11) Syed K. H. Gulrez, Saphwan Al-Assaf and Glyn O Phillips: Hydrogels: Methods of Preparation,Characterisation and Applications

(12) O. Okay : General Properties of Hydrogels

(13) Fariba Ganji and Ebrahim Vasheghani-Farahani: Hydrogels in Controlled Drug Delivery Systems (2009)

(14) Anisha Singh, Pramod Kumar Sharma, Vipin Kumar Garg, Garima Garg : HYDROGELS: A REVIEW (2010)

(15) Mark A. Ward and Theoni K. Georgiou: Thermoresponsive Polymers for Biomedical Applications (2011)

(16) Eylem Turan, Tuncer C¸ aykara: Swelling and Network Parameters of pH-Sensitive Poly(acrylamide-co-acrylic acid) Hydrogels(2007)

(17) A. Thakur, R. K. Wanchoo, and P. Singh: Hydrogels of Poly(acrylamide-*co*-acrylic acid): *In-vitro* Study on Release of Gentamicin Sulfate (2012)

(18) W. Li, H. Zhao*, P.R. Teasdale, R. John, S. Zhang: ynthesis and characterisation of a polyacrylamide–polyacrylicacid copolymer hydrogel for environmental analysis of Cu and Cd (2002)

(19) Hitesh V. Chavda, Chhaganbhai N. Patel: Preparation and Characterization of Swellable Polymer-Based Superporous Hydrogel Composite of Poly (Acrylamide-co-Acrylic Acid)(2010)

(20) I. Katime, R. Novoa, E. Dı´az de Apodaca, E. Mendiza´bal, J. Puig: Theophylline release from poly(acrylic acid-co-acrylamide) Hydrogels (1998)

(21) Yudong Zhang: Preparation of Copolymers of Acrylic Acid and Acrylamide for Copper (II) Capture from Aqueous Solutions (2009)

(22) Michel Bocourt Povea1, Waldo Argüelles Monal2, Juan Valerio Cauich Rodríguez3, Alejando May Pat3, Nancy Badas Rivero1, Carlos Peniche Covas1 Interpenetrated Chitosan-Poly(Acrylic Acid-Co-Acrylamide) Hydrogels. Synthesis, Characterization and Sustained Protein Release Studies (2011)

(23) Fausto Becerra-Bracamontes, Juan C. Sánchez-Díaz, Alejandro González-Álvarez, Pedro Ortega-Gudiño, Enrique Michel-Valdivia, Agustín Martínez-Ruvalcaba: Design of a drug delivery system based on poly(acrylamide-*co*-acrylic acid)/chitosan nanostructured hydrogels (2007)

(24) CUI Jin-lei, ZHOU Wen-wen, QIU Yu-qin, GAO Yun-hua: Study on the Protein Diffusion Behavior in the Poly(Acrylamide-co-Acrylic Acid) Copolymer by FRAP Technique(2011)

(25) Ray D, Mohapantra DK, mohapantra GP, Mohanta GP,Sahoo PK: Synthesis and colon-specific drug delivery of a poly(acrylic acid-co-acrylamide)/MBA nanosized hydrogel (2008)

(26) Cotton 101 (2013)

(27) Wakelyn, Phillip. CRC Press: project cotton (2006)

(28) Textile fashion study, Chemical composition of cotton fiber (2012)

(29) Raghavendra R. Hegde, Atul Dahiya, M. G. Kamath: COTTON FIBRES (2004)

(30) Textile fashion study, Physical and chemical properties of cotton fiber (2012)

(31) Cotton…The Most Popular Fabric in the World

(32) A. Bhattacharya, B.N. Misra: Grafting: a versatile means to modify polymers Techniques, factors and applications (2004)

(33) Amit Bhattacharya James W. Rawlins Paramitra: Polymet grafting and crosslinking

(34) Liu Jianqin, Zhai Maolin, Ha Hongfei: Pre-irradiation grafting of temperature sensitive hydrogel on cotton cellulose fabric

(35) Hitoshi Kubota *, Noriyuki Shiobara: Photografting of N-isopropylacrylamide on cellulose and temperature-responsive character of the resulting grafted celluloses (1997)

(36) Kh. M. Mostafa: Grafting of Methacrylamide onto Cotton Yarn Part I: Tensile Strength (2005)

(37) Audrey Tourrette et al: Incorporation of poly(N-isopropylacrylamide)/chitosan microgel onto plasma functionalized cotton fibre surface (2009)

(38) P. Gupta , M. Bajpai∗, and S. K. Bajpai: Investigation of Antibacterial Properties of Silver Nanoparticle-loaded Poly (acrylamide-co-itaconic acid)-Grafted Cotton Fabric (2008)

(39) Adelaida Ávila, Karina Bierbrauer, Graciela Pucci, Mar López-González, Miriam Strumia: Study of optimization of the synthesis and properties of biocomposite films based on grafted chitosan

(40) Jyh-Ping Chen∗, Chang-Yi Kuo, Wen-Li Lee: Thermo-responsive wound dressings by grafting chitosan and poly(N-isopropylacrylamide) to plasma-induced graft polymerization modified non-woven fabrics (2012)

(41) Jen Ming Yang et al: Chitosan containing PU/Poly(NIPAAm) thermosensitive membrane for wound dressing (2007)

(42) Saiqa Ikram, Mamta Kumari, Bhuvanesh Gupta: Thermosensitive membranes by radiation-induced graft polymerization of *N*-isopropyl acrylamide/acrylic acid on polypropylene nonwoven fabric

(43) L.C. LopeÂrgolo et al: Development of reinforced hydrogels Ð I. Radiation induced graft copolymerization of methylmethacrylate on non-woven polypropylene fabric (2000)

(44) Ko-Shao Chen, Jui-Che Tsai, Chih-Wei Chou, Mu-Rong Yang, Jen-Ming Yang: Effects of additives on the photo-induced grafting polymerization of N-isopropylacrylamide gel onto PET film and PP nonwoven fabric surface (2002)

(45) Bhuvanesh Gupta, Swaiti Mishra, Shalini Saxena: Preparation of thermosensitive membranes by radiation grafting of acrylic acid/*N*-isopropyl acrylamide binary mixture on PET fabric (2008)

(46) *R. Khullar, V. K. Varshney*1*, S. Naithani, P. L. Soni*: Grafting of acrylonitrile onto cellulosic material derived from bamboo (*Dendrocalamus strictus*) (2008)

(47) Éva Borbély, József Erdélyi:Grafting of Industrial Cellulose Pulp with Vinyl acetate Monomer by Ceric Ion Redox System as Initiator

(48) A S SINGHA, ANJALI SHAMA and VIJAY KUMAR THAKUR: Pressure induced graft-co-polymerization of acrylonitrile onto Saccharum cilliare fibre and evaluation of some properties of grafted fibre(2007)

(49) Faraj A. Abu-Ilaiwi et al: Graft Copolymerization of Methyl Methacrylate onto Rubber-Wood Fiber Using H2O2 and Fe^{2+} as anInitiator System(2002)

(50) J.R. Witono, I.W. Noordergraaf, H.J. Heeres, L.P.B.M. Janssen: Graft copolymerization of acrylic acid to cassava starch—Evaluation of theinfluences of process parameters by an experimental design method (2012)