CHAPTER 1

INTRODUCTION

1.1 Hydrogels

Hydrogel is a polymeric network chain that are hydrophilic in nature[1]. These are cross linked polymer networks that absorb substantial amounts of water without being soluble into it. They are not soluble in water due to their physical and chemical cross linking. Swollen hydrogels are colloidal gels in having water as a dispersed medium[2]. Hydrogels have ability to absorb water enormously as compared to other materials.

In hydrogels absorbed water is hard to remove under pressure because water gets bounded with the network structure chemically. Hydrogels are highly absorbent (they can contain over 99% water). The hydrogels have ability to absorb large amount of water because of presence of functional groups between network which are hydrophilic in nature like –COOH, SO_3H, OH, $CONH_2$ etc[3]. Chemically hydrogels are polymeric chain which are cross linked by covalent bonds making hydrogel a single molecule regardless of its size.

Hydrogels occurs naturally and are produced synthetically. The well-known examples of naturally occurring hydrogels are cross linked polysachharides like alginate andagarose and times these are modified to produce better hydrogels[4]. Synthetic hydrogels are also very popular these days due to its variety of applications. The class of synthetic hydrogels include poly (acrylamide), poly (N-vinyl pyrrolidone), poly(vinyl alcohol), poly(acrylic acid) and poly (hydroxyalkylmethacrylates).

Hydrogels are unique compounds due to their interesting properties such as high biocompatibility and lack of toxicity[5]. The content of water in hydrogels affect many properties of hydrogels significantly as their mechanical strength gets highly decreased with increase in water content[6]. Its biocompatibility, permeability and surface properties are also affected by water content[7]. Hydrogels are used for biological, pharmaceutical and medical applications as the physical properties of hydrogels are similar to living tissue having high water content. Hydrogels have many properties which are similar to living tissue as they are soft consistent[8]. The interfacial tension of hydrogel with water or biological fluids is very low and they have high water content. Significant properties of hydrogels are their swelling behaviour and their mechanical strength. The pore size on the surface of hydrogels increases with increase in water content[9]. This property of hydrogels permits them for the use of drug delivery. Molecules of varying size are able to diffuse in hydrogels and come out of hydrogels at controlled rate. Factors such as composition of polymer, water content in it, density of cross linking and crystallinity are used to control the rate of release of drugs from hydrogels[10]. The pore size of hydrogels is also important for separation of protein molecules from their mixture.

1.2 Types of hydrogels

Hydrogels, due to its variety of uses and properties, are classified on various basis. Hydrogels have dynamic characteristics with varying environment. These undergo phase transition in terms of volume change in response of changing temperature, pH, solvent composition, and electrical stimuli. These properties of hydrogels make it useful stimuli responsive materials for these changes[11]. On the basis of their nature, hydrogels are classified as

- pH sensitive hydrogels
- temperature sensitive hydrogels
- enzyme sensitive hydrogels
- current sensitive hydrogels

pH sensitive hydrogels can be neutral or ionic in nature. In neutral network of hydrogels both negative and positive charged moieties are present, hence the driving force necessary for the swelling process arise due water-polymer thermodynamic mixing contributions and elastic polymer contributions. In case of cationic or anionic pH sensitive hydrogels there is an additional factor responsible for swelling mechanism is electrostatic interaction between charged polymer and free ions[12]. The mechanism of pH sensitive hydrogels is well understood now. For cationic hydrogels at pH values below $pK_a$of the acids, it remains in ionic (dissociated) form, so it remains highly hydrophilic and absorbs water with high rate, but at the pH value higher than pK_a it becomes undissociated and hydrophobic and then it excludes water[13]. Similar mechanism is followed in case of cationic pH sensitive hydrogels.

Temperature sensitive hydrogels have been classified in three groups as

negative thermo-sensitive, positive thermo-sensitive and thermally reversible gels. Examples of temperature sensitive hydrogels are poly(acrylamide), poly(acrylic acid) and poly(teramethyleneether glycol)[14].

Enzyme sensitive hydrogels are mainly used in the targeting of drugs that go to colon. The colon-specificity is achieved due to the presence of pH-sensitive and azo cross-linking agents in the hydrogel structure. Enzyme sensitive hydrogels are used as biosensors for medical and pharmaceutical applications.

1.3 Synthesis of hydrogels

There are various techniques reported for the synthesis of hydrogels. The most popular technique is copolymerization/cross-linking approach. In this approach a multifunctional co-monomer is added during the process of polymerization reaction initiated by a chemical initiator. The polymerization technique can be any of bulk, solution or suspension. The multifunctional co-monomer works a cross-linking material. Some of the cross-linking materials used include N,N'-methylenebisacrylamide (MBA), divinyl benzene and ethylene glycol dimethacylate.

Another method involves cross-linking of linear polymers by the use of radiation or chemical compounds.The monomer used in this technique has an ionizable group that undergoes substitution reaction when after the polymerization is completed

Solution polymerization / cross-linking

In this case, neutral or ionic monomers are mixed with multifunctional crosslinking agent in a common solvent. The polymerization is initiated by redox initiator[15]. The solution polymerization is preferred since the heat produced in polymerization process is controlled due to presence of solvent i.e. solvent absorbs the heat produced and thus temperature does not rises significantly[16]. Thus prepared hydrogel is washed in order to remove unreacted monomers, cross-linking agents and the initiator. The prepared hydrogel can be made pH sensitive by adding N-isopropylacrylamide or methacrylic acid as monomers.

Chemically cross-linked hydrogels

Polymers containing functional groups like OH, COOH, NH2 are soluble in water. The presence of these functional groups on the polymer chain can be used to prepare hydrogels by forming covalent linkages between the polymer chains and complementary reactivity, such as amine-carboxylic acid, isocyanate (OH/NH2) or by Schiff base formation[17].

Suspension polymerization

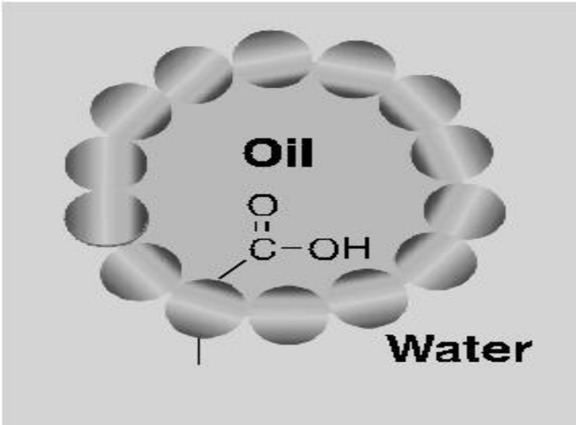
Spherical hydrogel micro-particles of size range 1 micro meter to 1 mm are stabilized by stabilizer. Chemical initiator is added which starts working by forming free prepared by this method. By the use of stabilizer monomer solution is dispersed in the non-solvent forming fine droplets. These droplets are radicals on thermal decomposition. Thus prepared spherical hydrogel is washed to remove impurities.

Hydrogel preparation by polymer complexation.

It involves mixing of dilute solution of oppositely charged polyelectrolyte. The colloidally dispersed polyelectrolyte complex is formed. The oppositely charged chain keep the network stable due to electrostatic attraction. To give colloidal stability one component has to be in excess because it will give charge to the colloidal particle. If stoichimetric charges will be used then it will precipitate. This method is attractive because it is relatively less expensive. The only problem faced in this method is preparation of small colloidal range polyelectrolyte chain is difficult.

EXOTIC HYDROGEL

These are called janus particles, each particle has two area or faces which have different properties[18].



1.4 CROSS LINKING IN HYDROGEL

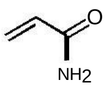
Cross linking is very essential for preparation of hydrogel because it keeps the polymer chains together. Optimum amount of crosslinking must be decided because less crosslinking inhibits the hydrogel formation and high crosslinking inhibits the swelling properties of hydrogel. The common crosslinking agents used are epichlorohydrin and Methelene bis acrylamide.

1.5 MONOMERS USED FOR PREPARATION OF HYDROGEL

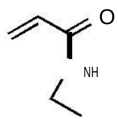
Vinyl monomers are used for synthesis of hydrogels[19]. These monomers also have a crosslinking functional group like –COOH, $-NH_2$, $-SO_3H$ etc.

Table 1.1 Vinyl monomers used to prepare hydrogels.

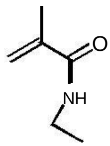
Monofunctional nonionic



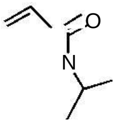
Acrylamide (AM)



N-Ethylacrylamide [126]

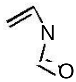


N-Ethyl methacrylamide [49]

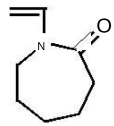


N-Isopropylacrylamide

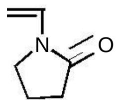
(NIPAM) [7]



N-Vinylformaleic anhydridemide (NVF) [51]

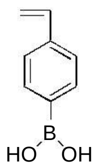


N-Vinyl caprolactam [127]

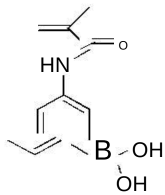


Vinylpyrrolidone [127]

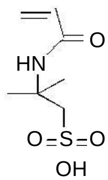
Anionic monofunctional



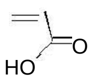
4-Vinylphenylboronic acid [128]



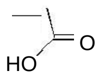
Phenylboronic acid methacrylamide [129]



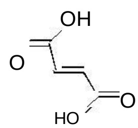
[130]



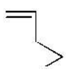
Acrylic acid



Methacrylic acid



Fumaleic anhydrideric acid [118]



1.6 CHARACTERISATION OF HYDROGEL

For the characterisation purpose various techniques have been used

a) SEM/TEM:
   This technique is used to visualise the surface morphology of the hydrogel. Swollen and dried hydrogel are taken together and the difference in surface morphology is studied.
b) X- Ray Diffraction
   This technique is also very useful as it allows to study a lot of properties like surface morphology, percentage crystallinity etc
c) FTIR :
   This is one of the most important technique for study of hydrogel because it allows the study of various bond formed in the hydrogel.

   Before characterisation the hydrogel is always centrifuged so that the impurities comes out of the hydrogel and results can be obtained usefully.

CHAPTER 2

EXPERIMENT METHOD

2.1 MATERIALS USED: Maleic anhydride and ammonium persulphate were obtained from CDH Laboratories. Methylene bis acryalamide and Acrylamide were obtained from MERCK.

2.2 LAB EQUIPMENT'S INVOLVED: Beaker, Test tubes, Magnetic stirrer, Magnetic beads, pH meter.

2.3 INSTRUMENTS USED: FTIR and XRD from BRUKER, SEM was recorded on the HITACHI 3700N.

2.4 SYNTHESIS OF HYDROGEL[1]

1 molar solution of two monomers was dissolved in 50 ml of water. 1 mole % of initiator and cross linker was mixed in the solution. The solution was kept on magnetic stirrer for 2 hours so that the solution becomes uniform. The solution is poured in test tube and kept in water bath for 4 hours at 60®C. After the polymerisation is complete test tube is broken and the hydrogel is cut in small pieces. The pieces are kept in distilled water overnight. Then the hydrogel are kept in vaccum drier and after complete the drying it is weighed.

Monomers used[1]

1) Acrylamide(1M) and maleic anhydride(1M)
2) Acrylamide(1M) and maleic anhydride(0.9M)
3) Acrylamide(1M) and maleic anhydride(0.8M)

Initiator used is Ammonium persulphate

Cross linker used is methylene bis acrylamide

2.5 SWELLING TEST

A) IN DISTILLED WATER

Weighed amount of each hydrogel is poured in distilled water. The weight is measured after 30, 60, 90, 120, 150, 180, 210, 240, 720 and 1440 min.

Swelling of each hydrogel was compared and analysed.

b) IN DIFFERENT pH SOLUTION

The hydrogel composition showing maximum swelling was taken and its swelling properties was analysed in pH of 4, 6, 8, 10, 12.

It was observed that at what pH the swelling is maximum.

CHAPTER: 3

RESULT

3.1 HYDROGEL PREPARATION: hydrogel with various concentration of maleic anhydride and unimolar concentration of acrylamide was prepared in 20 ml of the solution. The yield for each composition was also obtained.

1) HYDROGEL OF MALEIC ANHYDRIDE AND ACRYLAMIDE

S. NO.	Molarity of acrylamide	Molarity of maleic anhydride
1	1	0.8
2	1	0.9
3	1	1

Table2

Cross linker used is 1 mole% of MBA

Initiator used is 1 mole% ammonium persulphate.

Hydrogel produced

Concentration of hydrogel (MALEIC ANHYDRIDE : Acrylamide)	Weight of hydrogel in grams
0.8 : 1	4.389
0.9 : 1	4.218
1 : 1	3.987

Table 3

3.2 SWELLING IN DISTILLED WATER

a) Swelling of concentration of MALEIC ANHYDRIDE & ACRYLAMIDE (0.8 : 1) molar in distilled water

Time (min)	Weight (in grams)	Percentage swelling
0	0.065	0
30	0.096	50
60	0.131	102
90	0.195	200
120	0.344	430
150	0.389	498
180	0.410	530
210	0.439	575
240	0.476	632
720	0.546	740
1440	0.845	1200

Table 4

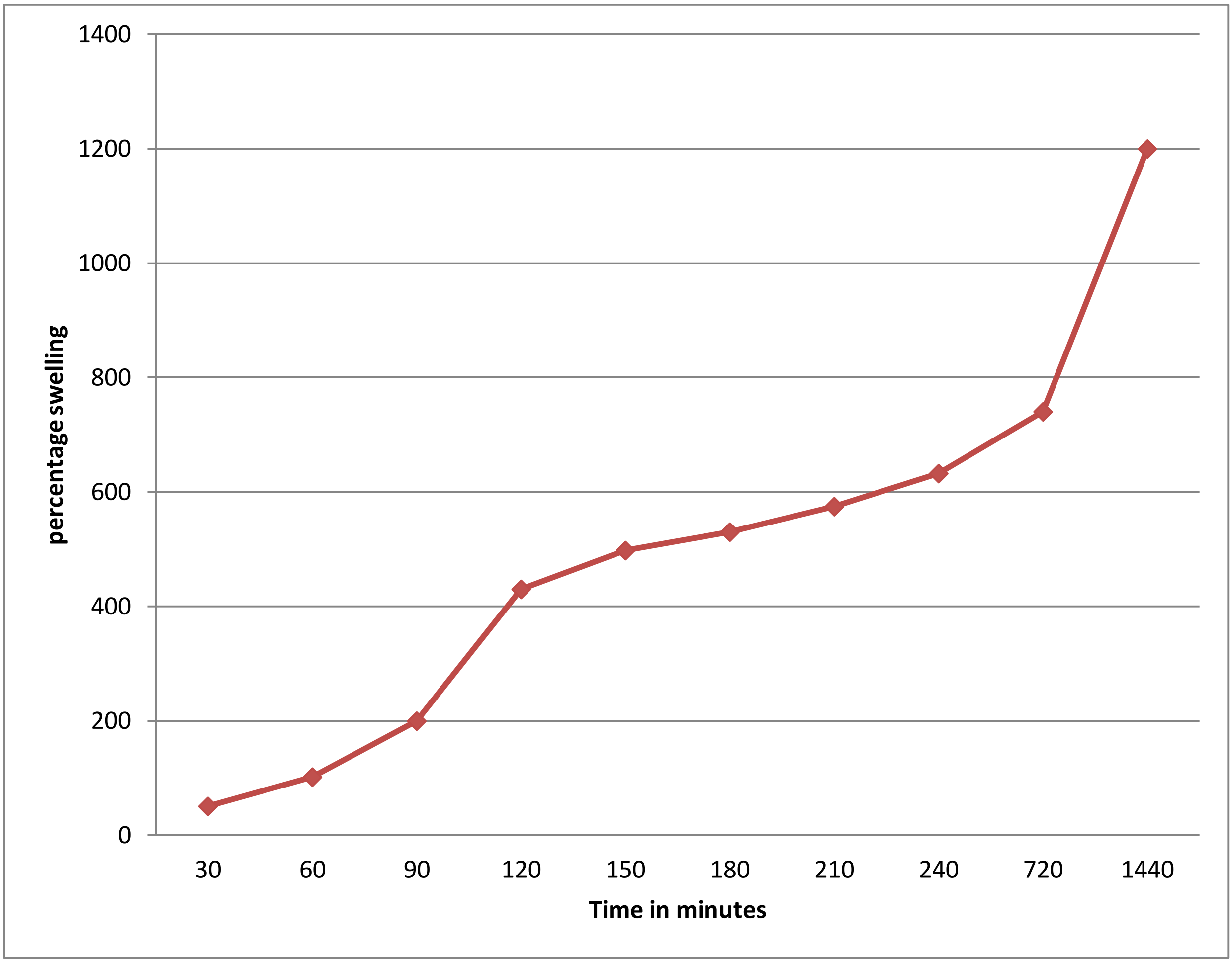


Figure1 : Graph of swelling of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (0.8 : 1) M

Maximum swelling obtained after 1 day is 1200 percent. It means that the hydrogel synthesised has good swelling properties at this concentration. Thus this concentration can be used for further research.

b) Swelling of concentration of MALEIC ANHYDRIDE & ACRYLAMIDE (0.9 : 1) molar in distilled water

Time (min)	Weight (in grams)	Percentage swelling
0	0.070	0
30	0.110	57
60	0.148	112
90	0.231	230
120	0.391	458
150	0.431	515
180	0.455	550
210	0.484	592
240	0.518	640
720	0.599	755
1440	0.952	1260

Table 5

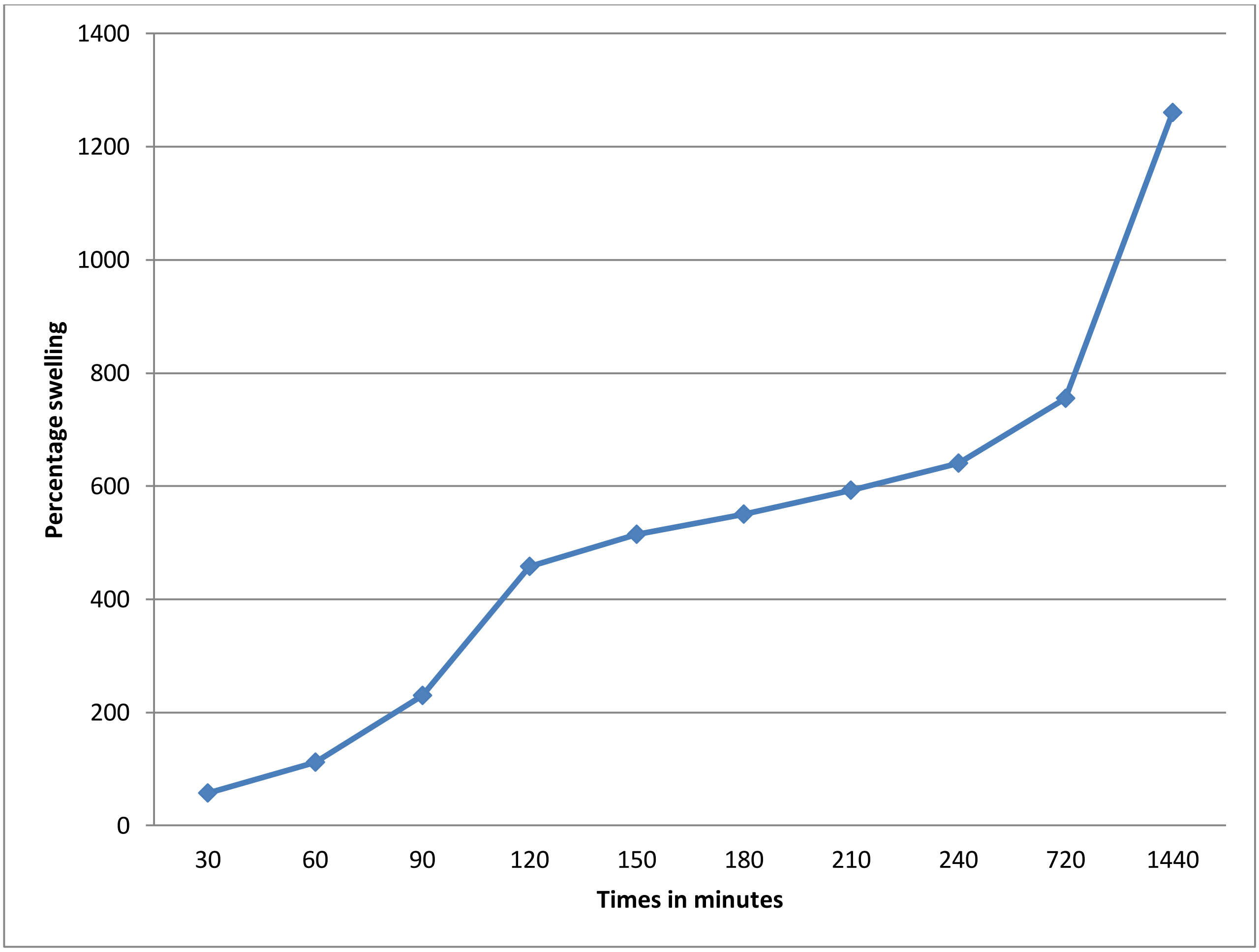


Figure 2 : Graph of swelling of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (0.9 : 1) M

Maximum swelling obtained after 24 hours is 1260%. . It means that the hydrogel synthesised has good swelling properties at this concentration. Thus this concentration can be used for further research.

c) Swelling of concentration of MALEIC ANHYDRIDE & ACRYLAMIDE (1 : 1) molar

Time (min)	Weight (in grams)	Percentage swelling
0	0.075	0
30	0.120	60
60	0.163	118
90	0.255	240
120	0.424	465
150	0.465	520
180	0.495	560
210	0.525	600
240	0.563	650
720	0.675	800
1440	1.058	1310

Table 6

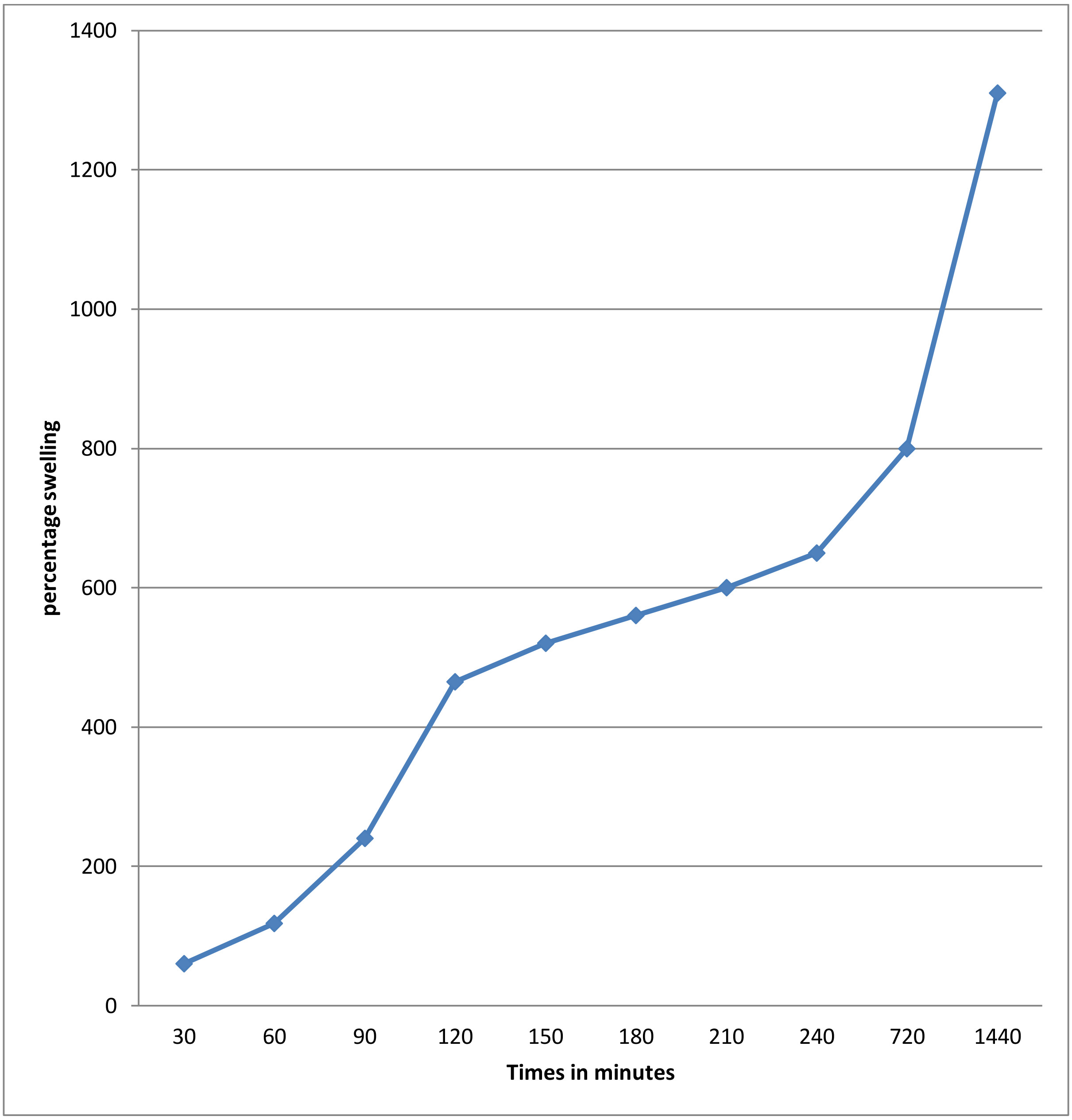


Figure 3: Graph of swelling of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (1 : 1) M

Maximum swelling obtained after 24 hours is 1310%. It is the maximum swelling percentage that can be obtained by hydrogel made of maleic anhydride and acrylamide. Thus for characterization and further investigation on swelling in different pH this hydrogel is considered.

From the swelling test it is concluded that as the concentration of maleic anhydride decreases swelling also decreases.

3.3 SWELLING AT DIFFERENT pH:

Hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (1 : 1) M is taken , weighed 5 samples of it. Each samples were placed in pH solutions of 2, 4, 6, 8, and 10. The optimum pH for its maximum swelling was analysed.

a) pH = 2

TIME(min)	WEIGHT (gram)	PERCENTAGE SWELLING
0	0.088	0
30	0.097	10
60	0.101	15
180	0.110	25
240	0.117	33
24 hrs	0.308	250

Table 7

b) pH = 4

TIME(min)	WEIGHT (gram)	PERCENTAGE SWELLING
0	0.078	0
30	0.096	25
60	0.113	45
180	0.156	100
240	0.265	240
24 hrs	0.538	590

Table 8

c) pH = 6

TIME(min)	WEIGHT (gram)	PERCENTAGE SWELLING
0	0.080	0
30	0.104	30
60	0.128	60
180	0.184	130
240	0.336	320
24 hrs	0.720	800

Table 9

d) pH = 8

TIME(min)	WEIGHT (gram)	PERCENTAGE SWELLING
0	0.084	0
30	0.134	60
60	0.189	125
180	0.596	610
240	0.672	700
24 hrs	1.302	1450

Table 10

e) pH = 10

TIME(min)	WEIGHT (gram)	PERCENTAGE SWELLING
0	0.090	0
30	0.131	45
60	0.179	99
180	0.549	510
240	0.644	615
24 hrs	1.224	1260

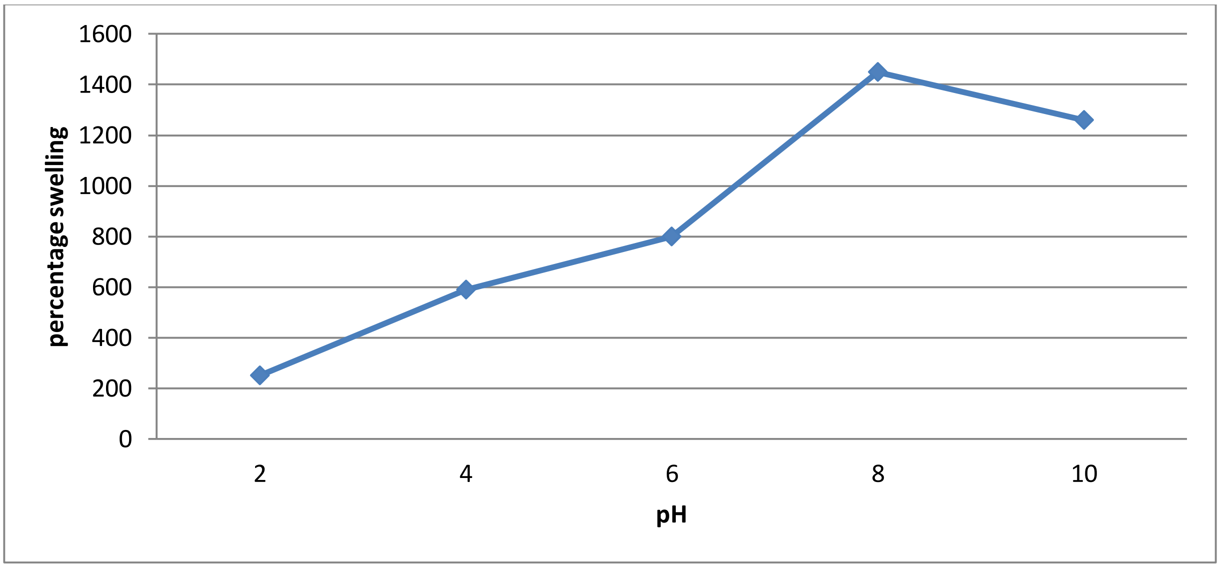
Table 11

f) MAximum percentage swelling after 24 hrs in different pH

pH	Percentage Swelling
2	250
4	590
6	800
8	1450
10	1260

Table 12

Figure 4: Graph showing swelling at different pH



Maximum swelling of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (1: 1) M was at pH 8 and decreased again at pH 10. This means that it is required to further investigate by taking pH ranges between 8 to 10. This experiment gives prelimainary range for maximum swelling.

CHARACTERISATION

3.4 SCANNING ELECTRON MICROSCOPE

The surface morphology of hydrogel of maleic anhydride and acrylamide (1:1) M was observed using SEM to determine the porosity and surface of hydrogel

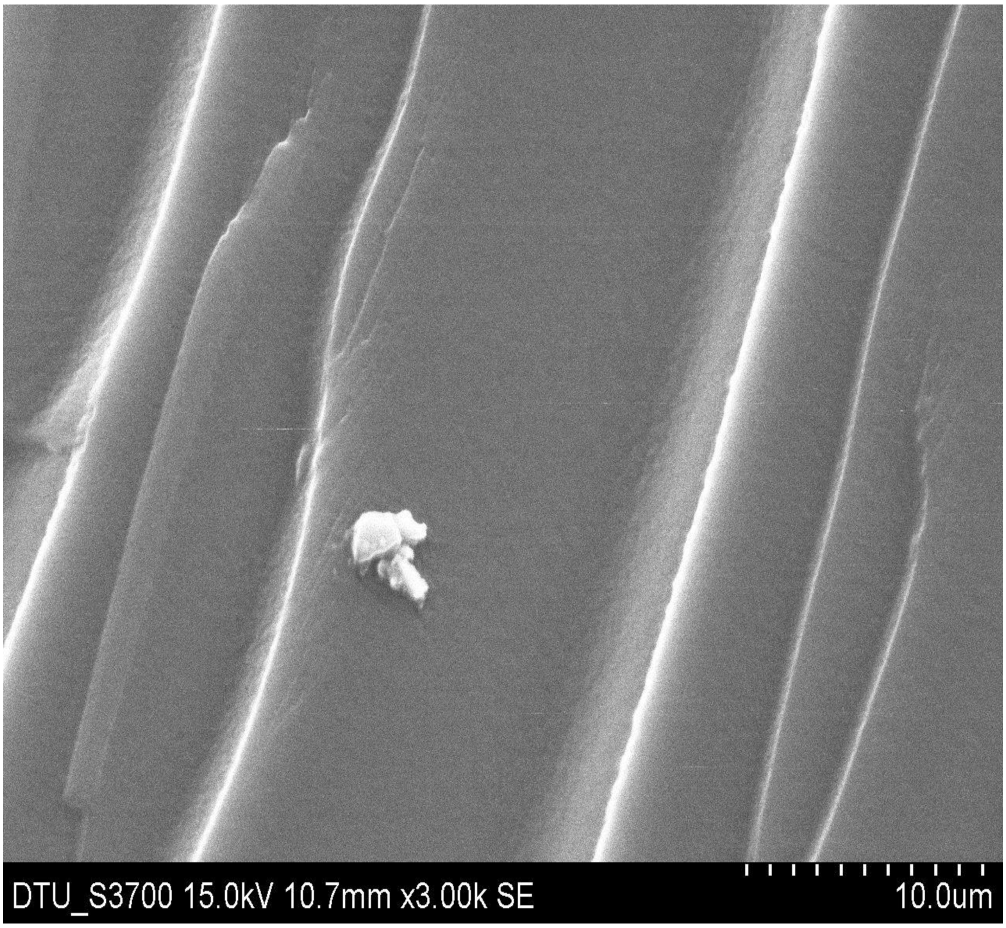


Figure 5: SEM of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (1: 1) M

The scanning electron image of hydrogel is observed that it is nonporous and has plain texture. Hydrogel has a surface structure that is smooth and even.

3.5 XRD of hydrogel

This technique was used to investigate the crystal lattice arrangements and also to determine the sample degree of crystallinity the x- ray patterns of hydrogel.

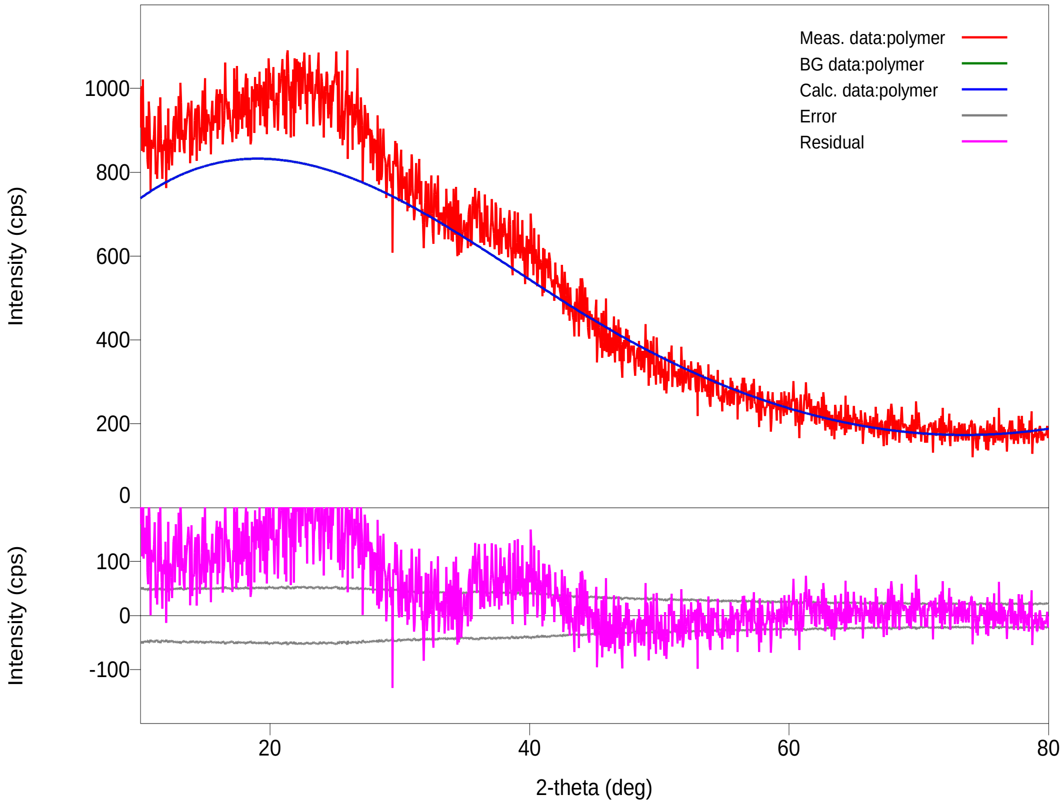


Figure 6: XRD of hydrogel of MALEIC ANHYDRIDE and ACRYLAMIDE (1 : 1) M

There is no sharp diffraction peak but high peak intensity of 1000 count is obtained at 2Ɵ = 25^0. Thus it can be concluded that there is no much crystallinity in the hydrogel. It indicates that the hydrogel doesnot have crystalline nature it has more of amorphous nature. Crystalline nature means perfectly ordered arrangement. But as the polymerisation is based on free radical mechanism the arrangement is not of long range order and hence there is amorphous character.

3.6 FTIR

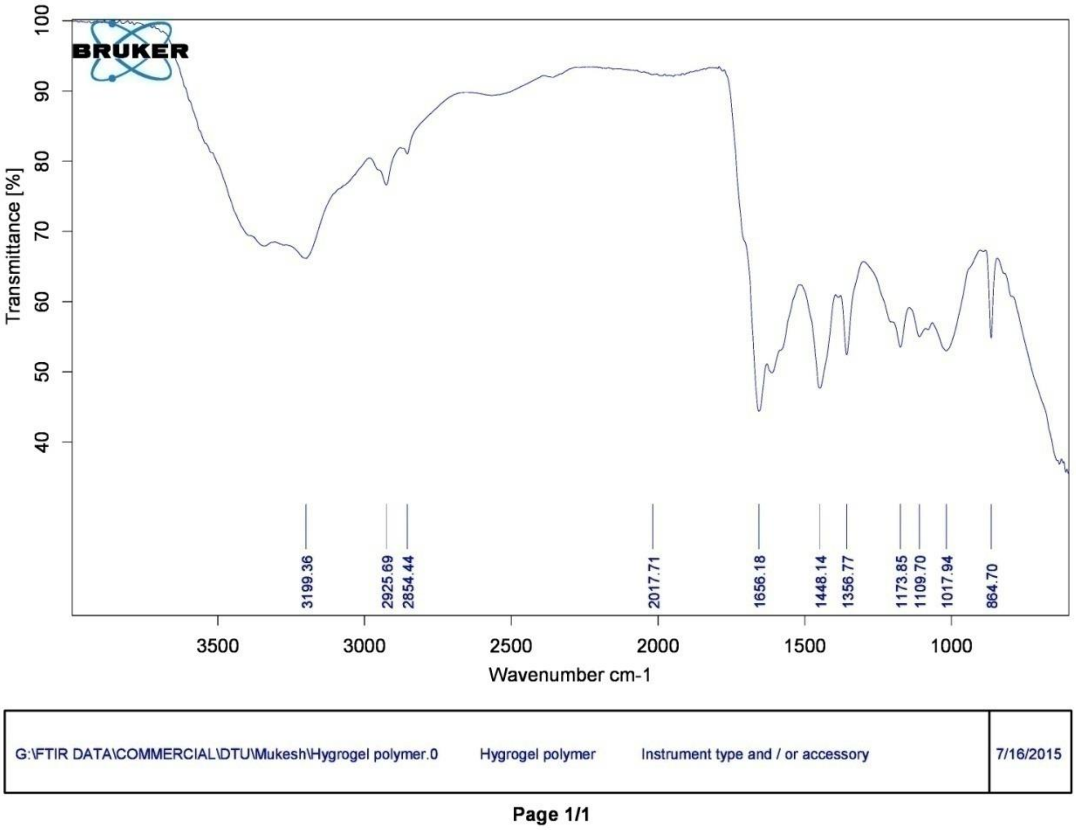


Figure 7: FTIR data of hydrogel

The ftir has various peaks which denote various types of bonds. The sharp peak at 1656 /cm is the carbonyl group related to amide groups. The broader peak in the region of 3100 and 3500 cm^{-1} are O-H and N-H bands related to polymeric bands. The weak peak at 1600 cm^{-1} is a characteristic peak of OH group of carboxylic acid. The weak peak at 2854 cm^{-1} are of $–CH_2$- group. The weak peaks at 1000 and 1200 cm^{-1} are due to C-N bonds.

5. CONCLUSION

The hydrogel of maleic anhydride and acrylamide can be synthesized by free radical initiator. It showed very good swelling properties but swelling properties were less than . But with the decrease in concentration of maleic anhydride the mass swelling decreased. The pH test proves that hydrogel is pH sensitive and maximum swelling is obtained at pH 8.

FTIR results shows that the polymerisation is random. Because free -COOH and amide llinkage are present.

X – Ray diffraction proved that the hydrogel synthesised doesnot have crystalline character.

SEM showed that the hydrogel has nonporous and smooth structure.

Before using it for various purposes there is need to test for its kinetics of swelling and deswelling.

6. APPLICATION

The hydrogel can be checked for drug delievery as it is pH sensitive. It can also be used for dye absorbtion and heavy metals recovery of various effluents of leather industry and textile industry.

7. REFERENCES

1) Agbugba, C.B., Hendriksen, B.A., Chowdhry, B.Z., and Snowden, M.J. (1998) The redispersibility and physico-chemical properties of freeze-dried colloidal microgels. Colloids Surf. A, 137, 155–164.

2) Pelton, R.H. and Chibante, P. (1986) Preparation of aqueous lattices with N-isopropylacrylamide. Colloids Surf., 20, 247–256.

3) Wolfe, M.S. and Scopazzi, C. (1989) Rheology of swellable microgel dispersions: influence of crosslink density. J. Colloid Interface Sci., 133, 265–277.

4) Osada, Y. and Ross-Murphy, S.B. (1993) Intelligent gels. Sci Am., 268, 82–87.

5) Nolan, C.M., Gelbaum, L.T., and Lyon, L.A. (2006) 1H NMR investigation of thermally triggered insulin release from poly(N-isopropylacrylamide) microgels.

6) Zhang, Y.J., Guan, Y., and Zhou, S.Q. (2006) Synthesis and volume phase transitions of glucose-sensitive microgels. Biomolecules, 7, 3196–3201.

7) Hoare, T. and Pelton, R. (2007) Engineering glucose swelling responses in poly(N-isopropylacrylamide)-based microgels. Macromolecules, 40, 670–678.

8) Hoare, T. and Pelton, R. (2008) Charge-switching, amphoteric glucose-responsive microgels with physiological swelling activity. Biomacromolecules, 9, 733–740.

9) Vinogradov, S.V. (2006) Colloidal microgels in drug delivery applications. Curr. Pharm. Des., 12, 4703–4712.

10) Kawaguchi, H., Kisara, K., Takahashi, T., Achiha, K. et al. (2000) Versatility of thermosensitive particles. Macromol. Symp., 151, 591–598.

11) Ballauff, M. and Lu, Y. (2007) “Smaleic anhydridert” nanoparticles: preparation, characterization and applications. Polymer, 48, 1815–1823.

12) Zhang, J. and Pelton, R. (1999) Poly(N-isopropylacrylamide) microgels at the air–water interface. Langmuir, 15, 8032–8036.

13) Fujii, S., Ryan, A.J., and Armes, S.P. (2006) Long-range structural order, Moire patterns, and iridescence in latex-stabilized foams. J. Am. Chem. Soc., 128, 7882–7886.

14) Bromberg, L.E. and Temchenko, M. (2003) Responsive microgel and methods related thereto. Pat. US 2003/0152623 Al, Aug. 14.

15) Okay, O. and Funke, W. (1990) Steric stabilization of reactive microgels from 1,4-divinylbenzene. Makromol. Chem. Rapid Commun., 11, 583–587.

16) Saito, R. and Ishizu, K. (1997) Flower type microgels. 1. Synthesis of the microgels. Polymer, 38, 225–229.

17) Suzuki, D., Tsuji, S., and Kawaguchi, H. (2005) Development of anisotropic thermo-sensitive hairy particles using living radical graft polymerization. Chem. Lett., 34, 242–243.

18) Hoare, T. and Pelton, R. (2004) Highly pH and temperature responsive microgels functionalized with vinylacetic acid. Macromolecules, 37, 2544–2550.

19) Kim, K.S., Cho, S.H., and Shin, J.S. (1995) Preparation and characterization of monodisperse polyacrylamide microgels