Indian Journal of
Advances in Chemical Science

Review Article

Some Distinctive Applications of Polyacrylamide Composite Hydrogels

Mini Gupta*, Saima Zehra, Meenakshi Singh

Department of Chemistry, Isabella Thoburn College, Lucknow, Uttar Pradesh, India

ABSTRACT

Hydrogels are among the favored biomaterials because of their biocompatibility and non-toxic properties. Hydrogels are known as smart polymers or smart materials because they are sensitive to environmental stimuli. The fundamental feature of this method is the ability to vary their mechanical properties, swelling capacity, hydrophilicity, bioactive molecules porousness, etc., influenced by varied stimuli such as temperature, time, pH, electromagnetic wave, field, and biological factors. The characterization studies of polyacrylamide (PAM) composite hydrogel disclosed that partial polyaniline chains have grafted on the nitrogen atom of PAM. These are usually prepared by polymer crosslinking. In this review, we have focused on the field of tissue engineering and biomedical applications of PAM hydrogel that has been used as controlled drug delivery systems in various fields such as agricultural fields, prescription drugs, medical specialty, and cosmetic business.

Key words: Antimicrobial, Conducting hydrogels, Cross-linked, Free radical polymerization, Polyacrylamide.

1. INTRODUCTION

Hydrogels were first reported by Wiehterle and Lim (1960), in biomedical field. The term hydrogel was coined in 1894 for explaining the working of colloidal gel [1]. Hydrogel is basically a type of gel in which the liquid component is water. These are generally 3D cross-linked polymer networks that possess an excellent water absorbing property and retaining a large amount of water [2]. Hydrogels based on cross-linked polyelectrolytes with a high degree of swelling not only absorb water in amounts and hence surpass their mass approximately hundreds to thousands of times but also having capability to retain water at certain pressure. The volume of a hydrogel changes during variations in temperature, pH, the chemical composition of the surrounding medium, and the voltage of the external electric field; hence, they are widely used as diverse promoting agents [3]. As a representative class of soft materials, the hydrogels of different functions and characteristics with modulate physical, chemical, and biological properties have been developed and utilized in a wide range of applications; that is, from tissue engineering to soft electronics [4-7]. Many hydrogels and acrylate-siloxane hydrogels (material for contact lenses) are both soft lenses made of plastic material. The material works as an absorbent and makes the lens soft when hydrated with water or solution. One of their most unique properties is oxygen permeability, which is required since the cornea lacks vasculature [8]. From the practical point, among all possible means of activation, the electric field has special importance because it allows effective control over the intensity of an external stimulus and integration of material in a space saving manner into electromechanical systems. However because of low inherent conduction of a hydrogel polymer network, the quantity response is delayed greatly. However, the solution of this problem can be solved through the development of composite systems composed of hydrogel matrix and a conducting component distributed in its volume [4].

2. TYPES OF HYDROGELS

Two types of hydrogel are usually available, that is, sheet-type hydrogels and amorphous-type hydrogels. Sheet types of hydrogels are generally wound dressing sheets. These are three-dimensional networks of hydrophilic polymers that are cross-linked and therefore insoluble in water and they also interact with aqueous solutions by swelling. They are highly permeable, conformable and can absorb varying amounts of sewerage, depending on their composition. Amorphous types of hydrogels are glycerin and water-based products. They are primarily manufactured for the reason of wound hydration. These dressings help maintain a moist wound healing environment, promote granulation and epithelialization, and facilitate autolytic debridement [9].

S. No.	Hydrogels	Applications
1.	Sodium carboxymethyl cellulose and polyvinyl alcohol	Oral drug delivery [10]
2.	Chitosan and dextran	Used in drug delivery for wound healing [11]
3.	Cellulose acetate and phospholipids	Blood purification [12]
4.	Cellulose/chitin beads	Water purification [13]
5.	Peptide and collagen-based hydrogel	Dental, implant, dressing cream [14]
6.	Hyaluronic acid	Plastic surgery, transdermal implant [15]
7.	Peptide hydrogel	Microparticles, nutraceutical [16,17]
8.	Silicon hydrogel	Used in contact lenses [18]

***Corresponding author:**
E-mail: minilko98@gmail.com

ISSN NO: 2320-0898 (p); 2320-0928 (e)
DOI: 10.22607/IJACS.2021.904013

Received: 10th October 2021;
Revised: 22nd October 2021;
Accepted: 23rd October 2021

3. POLYACRYLAMIDE (PAM) HYDROGELS

The main disadvantage is that the poor mechanical characteristics impose serious limitations on the conducting polymers and use in technology. These materials are exceptionally sensitive to change in pH [19]. Compared with additional type of biomaterials, PAM composite hydrogels have distinct properties such as deferential swelling behavior, ease of handling as well as biocompatibility that make them attractive for biomedical applications. PAMs are water-soluble synthetic linear polymers made of acrylamide or the combination of acrylamide and acrylic acid (Figure 1) [20,21]. PAM gel is antitoxic, stable, non-resorbable sterile watery gel, consisting of roughly a pair of 2.5% cross-linked PAM and non-pyrogenic water. PAM also finds applications in ophthalmic operations, paper and pulp production, agriculture, drug treatment, food packaging materials, and as a gelation in wastewater treatment [18,22].

4. SYNTHESIS

PAM gels are synthesized by free radical polymerization of acrylamide and a comonomer cross-linker like bis-acrylamide (Figure 2). Polymerization is initiated by ammonium persulfate (APS) with tetramethylethylenediamine as a catalyst [23]. Speed of polymerization depends on various factors such as monomer and catalyst concentration; temperature; and reagents purity.

5. APPLICATIONS

5.1. In Biomedical

5.1.1. Tissue engineering

Hydrogels are usually distinctive cluster of biocompatible 3D polymeric substances which may act as a scaffold and imitate the properties of assorted tissues within the body. The basic appliance is by incorporating cells in their structure and usually degrading themselves to leave behind only healthy tissue. These were based on their ability to retain high amount of water content, maintain porous structure, and adapt by globular sol-gel conditions. Their structural qualities allow composite hydrogels to be used as tissue scaffolds/bioactive systems in the body by promoting the inundation of cell metabolites and the predisposal of cell wastes through their pores [24]. Scaffolds are three-dimensional porous solid biomaterials. It provides a physical surface for adsorption of biomolecules, immobilization of proteins, growth factors, and some other biologically active biomaterials. These scaffolds/bioactive systems show great potential in tissue engineering and regenerative medicine in furnishing bioactivity and specificity to the scaffold structure. The polymer bioactive systems or scaffolds function as space-filling agents, transport vehicles for carrying bioactive peptides. In the field of tissue engineering, the main aim is to regenerating new biological tissues to replace and regenerate previously damaged structures [25]. Thus, it is essential for the bioactive systems to act as a substrate and has essential chemical and physical properties that are necessary to promote attachment of cell, differentiation, proliferation, and migration [26]. They deliver cells to the desired size among the patient's body and provides an area for new tissue formation, and potentially control structural and functional integrity of the newly designed tissue [1,27].

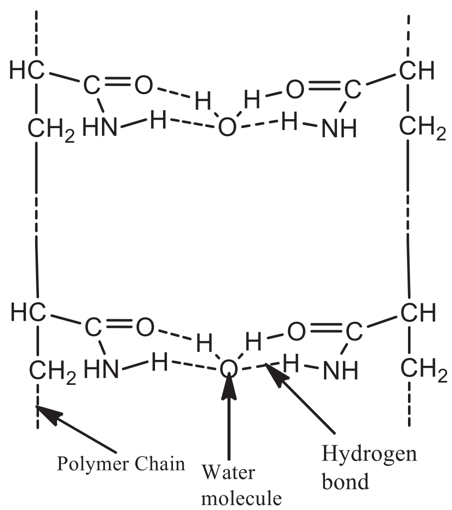
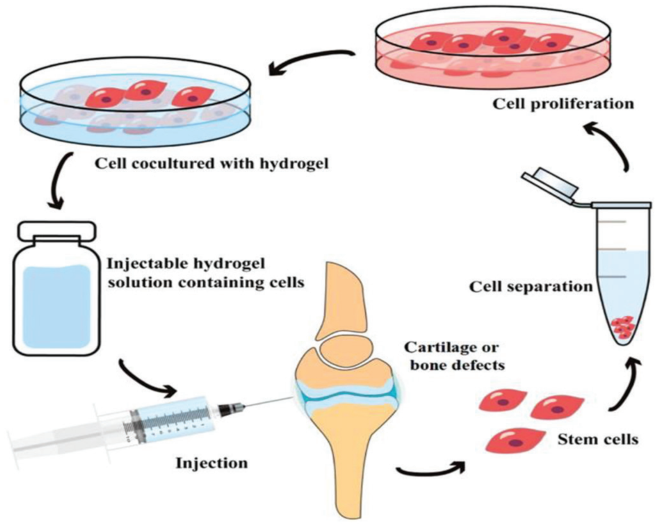


Figure 1: Polyacrylamide Hydrogel.



5.1.2. Drug delivery

The porous structure of composite hydrogels can be adapted to favor encapsulation of drugs in the matrix, besides modifying its release through changes which will affect its diffusion coefficient, which assurance a high drug concentration in the target site, for a long period of time. Considering these hydrogel properties, the applicability in different forms such as rectal, nasal, and injection may be optimized by adapting the mechanical and form properties that best match the desired parameters to maximize the effectivity and patient compliance [28]. Macroscopic hydrogels are appropriate for surgical implants, transepithelial, and transdermal drug delivery, which is required when the biological barriers display low permeability to the drug to be delivered [29]. A type of widely used polymeric particle is poly (lactic-co-glycolic acid) (PLGA), which releases the enclosed drug through hydrolysis [30].

5.2. In Soil Conservation

The most significant problem throughout the world is soil degradation. Use of soil amendments, which includes anionic PAM, is one in every of the foremost appropriate choices for shielding soil resources. As a soil conditioner, PAM can be used to stabilize soil aggregates as well as emulsify suspended particles. PAM also can be employed in furrow irrigation wherever it reduces erosion and get away whereas rising soil and water quality and water use potency and stabilize steep slopes in construction, main road cuts, and alternative distributed soil. [31,32]. When the hydrogel-rectified soil dries, the absorbed water by hydrogel particles (approximately 90–95% of the retained water) could gradually be released to the plants. In this way, hydrogel application might increase not only water holding capacity but also available water capacity of sandy soils and reduces capacity of water loss by deep percolation and fertilizer leaching [33]. Therefore, uses of composite hydrogels might enable longer intervals between irrigations

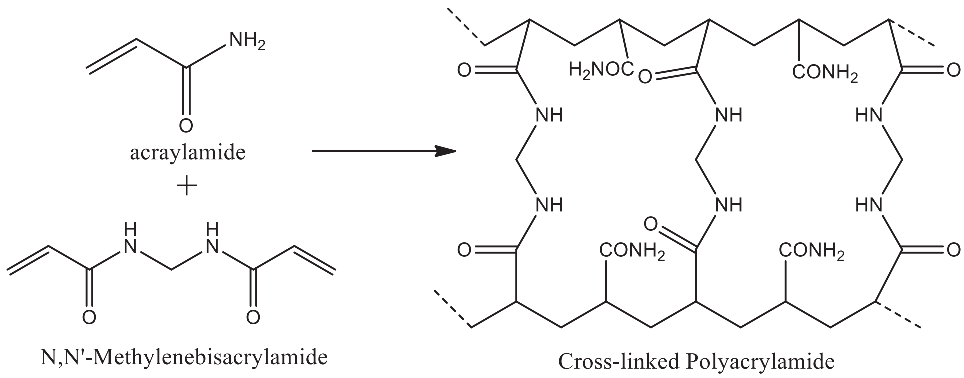
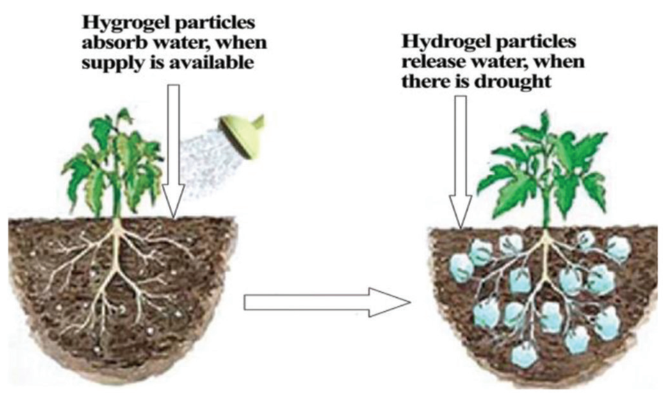


Figure 2: Synthesis of cross-linked polyacrylamide hydrogel.

and therefore provide a buffer against water stress and decrease the risk of temporary drought stress. In addition, another benefit of hydrogels is to enhance plant growth at early stages of production, reduce the failure of certain crops establishment or reduce yield losses of some crops at specific growth stages and assign seed germination, emergence, and increase the seedling survival. It also reduces soil bulk density, saturated hydraulic conductivity, and penetration resistance, while increases soil aggregation and porosity [34].



5.3. In Baby Diapers

PAM hydrogel is very beneficial to mankind. The confidential water absorbing chemical in a diaper is a superabsorbent polymer known as sodium polyacrylate. Super absorbent polymers (SAPs) are a material having capacity of absorbing approximately up to 300 times their weight in aqueous fluids. It can absorb liquid and traps it in the diaper. SAPs are non-toxic, it can get contaminated with acrylic acid during manufacturing process [35]. It's typically a water absorbing chemical compound that may absorb and retain very massive amounts of a liquid relative to its own mass. Superabsorbent polymers are also called as slush powder or sodium polyacrylate. Disposable diapers create use of the flexibility of hydrogels to require up and retain water, even fraught. They contain little crystals (about 1 mm in diameter) of hydrogel. Used hydrogel in baby diapers also contains urine which can be used as a soil conditioner and can supply nitrogen because urine generally contains ammonia (NH_3). Therefore, hydrogel from baby diaper waste can be used as water absorbent in agriculture for better irrigation management [35].

5.4. Antibacterial Activity and Wound Healing

Introduction of divalent ions in PAM hydrogels enhanced their mechanical property. Among different kinds of hydrogels, zinc cross-linked hydrogel had remarkable antibacterial ability against *Staphylococcus aureus* and *Escherichia coli*, cell viability. In addition, it may enhance the proportion of wound closure, albuminoid deposition, connective tissue, and angiogenesis. Zinc cross-linked hydrogel possessed less cytotoxicity, while strontium cross-linked hydrogel had prominent cell viability and promoted cell growth [36]. Therefore, Zn cross-linked hydrogels possessed the favorable antimicrobial property and biocompatibility, having the potential within the application of wound healing. Furthermore, these divalent ion cross-linked SA-PAM hydrogels have higher cell viability than no ion cross-linked SA-PAM hydrogels due to the decrease of the toxicity of monomer residues from SA-PAM hydrogels [37] Hydrogels, as being exposed to excessive zinc could cause toxic effects on cells [38], it is a necessary to identify an optimal concentration that minimizes the toxicity whereas reassuring the antibacterial activity. Hence, SA-PAM with different divalent ions cross-linked hydrogels is considered as promising dressings by providing not only a positive moist environment but also suitable physical (setting time, sol content, and degradation rate) and mechanical properties.

6. CONCLUSION

In this review article, we have tried to cover the broader aspect of the applications of PAM composite hydrogel as an effective tool in tissue engineering for the regeneration of soft tissues, efficient model for drug delivery, useful antibacterial agent, and widely used as an efficient absorbent. The challenge is to judiciously exploit the molecule for its more wider application in the field of medical science and as a more effective model for drug delivery.

7. REFERENCES

1. O. Wichterle, D. Lím, (1960) Hydrophilic gels for biological use, ***Nature***, **185:** 117-118.
2. W. Cai, R. B. Gupta, (2012) Hydrogels. In: ***Kirk-Othmer Encyclopedia of Chemical Technology***, Hoboken, NJ, USA: John Wiley and Sons, Inc., p0825041807211620.
3. M. Li, Y. Guo, Y. Wei, A. Macdiarmid, P. Lelkes, (2006) Electrospinning polyaniline-contained gelatin nanofibers for tissue engineering applications, ***Biomaterials***, **27:** 2705-2715.
4. S. E. Bakarich, R. Gorkin, M. in het Panhuis, G. M. Spinks, (2014) Three-dimensional printing fiber reinforced hydrogel composites, ***ACS Applied Materials and Interfaces***, **6:** 15998-16006.
5. G. Cai, J. Wang, K. Qian, J. Chen, S. Li, P. S. Lee, (2017) Extremely stretchable strain sensors based on conductive self-healing dynamic cross-links hydrogels for human-motion detection, ***Advanced Science***, **4:** 1600190.
6. K. Y. Lee, D. J. Mooney, (2001) Hydrogels for tissue engineering, ***Chemical Reviews***, **101:** 1869-1880.
7. S. Merino, C. Martín, K. Kostarelos, M. Prato, E. Vázquez, (2015) Nanocomposite hydrogels: 3D polymer-nanoparticle synergies for on-demand drug delivery, ***ACS Nano***, **9:** 4686-4697.
8. John Wiley & Sons, Inc., (Ed.), (2000) ***Kirk-Othmer Encyclopedia***

of Chemical Technology, 1st ed., Hoboken, New Jersey: Wiley.
9. V. Falanga, (2005) Wound healing and its impairment in the diabetic foot, ***The Lancet***, **366:** 1736-1743.
10. S. Banerjee, L. Siddiqui, S. S. Bhattacharya, S. Kaity, A. Ghosh, P. Chattopadhyay, A. Pandey, L. Singh, (2012) Interpenetrating polymer network (IPN) hydrogel microspheres for oral controlled release application, ***International Journal of Biological Macromolecules***, **50:** 198-206.
11. Y. Zhao, X. Zhang, Y. Wang, Z. Wu, J. An, Z. Lu, L. Mei, C. Li, (2014) *In situ* cross-linked polysaccharide hydrogel as extracellular matrix mimics for antibiotics delivery, ***Carbohydrate Polymers***, **105:** 63-69.
12. L. Weng, L. Zhang, D. Ruan, L. Shi, J. Xu, (2004) Thermal gelation of cellulose in a NaOH/thiourea aqueous solution, ***Langmuir***, **20:** 2086-2093.
13. K. Gelin, A. Bodin, P. Gatenholm, A. Mihranyan, K. Edwards, M. Strømme, (2007) Characterization of water in bacterial cellulose using dielectric spectroscopy and electron microscopy, ***Polymer***, **48:** 7623-7631.
14. T. Aigner, (2003) Collagens major component of the physiological cartilage matrix, major target of cartilage degeneration, major tool in cartilage repair, ***Advanced Drug Delivery Reviews***, **55:** 1569-1593.
15. J. R. E. Fraser, T. C. Laurent, U. B. G. Laurent, (1997) Hyaluronan: Its nature, distribution, functions and turnover, ***Journal of Internal Medicine***, **242:** 27-33.
16. L. E. Wyatt, J. D. Sinow, J. S. Wollman, D. A. Sami, T. A. Miller, (1998) The influence of time on human breast capsule histology: Smooth and textured silicone-surfaced implants, ***Plastic and Reconstructive Surgery***, **102:** 1922-1931.
17. D. R. Shanklin, D. L. Smalley, (1999) Dynamics of wound healing after silicone device implantation, ***Experimental and Molecular Pathology***, **67:** 26-39.
18. J. Kopecek, (2009) Hydrogels: From soft contact lenses and implants to self-assembled nanomaterials: Highlight, ***Polymer Science, Part A: Polymer Chemistry***, **47:** 5929-5946.
19. S. Machida, S. Miyata, A. Techagumpuch, (1989) Chemical synthesis of highly electrically conductive polypyrrole, ***Synthetic Metals***, **31:** 311-318.
20. W. Funke, O. Okay, B. Joos-Müller, (1998) Microgels-intramolecularly crossünked macromolecules with a globular structure, In: S. DiMari, W. Funke, M. A. Haralson, D. Hunkeler, B. Joos-Müller, A. Matsumoto, O. Okay, T. Otsu, A. C. Powers, A. Prokop, T. G. Wang, R. R. Whitesell, (Eds.), ***Microencapsulation Microgels Iniferters***, Berlin Heidelberg: Springer, p139-234.
21. N. Orakdogen, O. Okay, (2006) Correlation between crosslinking efficiency and spatial inhomogeneity in poly(acrylamide) hydrogels, ***Polymer Bulletin***, **57:** 631-641.
22. J. D. Andrade, (Ed.), (1976) ***Hydrogels for Medical and Related Applications***, Washington, DC: American Chemical Society.
23. H. L. Gonçalves, P. B. L. Fregolente, M. R. W. Maciel, L. V. Fregolente, (2021) Formulation of hydrogels for water removal from diesel and biodiesel, ***Separation Science and Technology***, **56:** 374-388.
24. S. Mantha, S. Pillai, P. Khayambashi, A. Upadhyay, Y. Zhang, O. Tao, H. M. Pham, S. D. Tran, (2019) Smart hydrogels in tissue engineering and regenerative medicine, ***Materials***, **12:** 3323.
25. M. Razavi, (Ed.), (2017) Hydrogels: Types, structure, properties, and applications. In: *Frontiers in Biomaterials*, Vol. 4. UAE: Bentham Science Publishers Ltd., p143-169.
26. J. F. Mano, G. A. Silva, H. S. Azevedo, P. B. Malafaya, R. A. Sousa, S. S. Silva, L. F. Boesel, J. M. Oliveira, T. C. Santos, A. P. Marques, N. M. Neves, R. L. Reis, (2007) Natural origin biodegradable systems in tissue engineering and regenerative medicine: Present status and some moving trends, ***Journal of the Royal Society Interface***, **4:** 999-1030.
27. J. Zhu, R. E. Marchant, (2011) Design properties of hydrogel tissue-engineering scaffolds, ***Expert Review of Medical Devices***, **8:** 607-626.
28. S. Salatin, J. Barar, M. Barzegar-Jalali, K. Adibkia, M. A. Milani, M. Jelvehgari, (2016) Hydrogel nanoparticles and nanocomposites for nasal drug/vaccine delivery, ***Archives of Pharmacal Research***, **39:** 1181-1192.
29. J. Li, D. J. Mooney, (2016) Designing hydrogels for controlled drug delivery, ***Nature Reviews Materials***, **1:** 16071.
30. J. Xu, M. Tam, S. Samaei, S. Lerouge, J. Barralet, M. M. Stevenson, M. Cerruti, (2017) Mucoadhesive chitosan hydrogels as rectal drug delivery vessels to treat ulcerative colitis, ***Acta Biomaterialia***, **48:** 247-257.
31. A. J. J. Souza, R. J. Guimarães, A. W. Dominghetti, M. S. Scalco, T. T. Rezende, (2016) Water-retaining polymer and seedling type when planting irrigated coffee, ***Revista Ciência Agronômica***, 47: 334-343.
32. N. Thombare, S. Mishra, M.Z. Siddiqui, U. Jha, D. Singh, G. R. Mahajan, (2018) Design and development of guar gum based novel, superabsorbent and moisture retaining hydrogels for agricultural applications, ***Carbohydrate Polymers***, **185:** 169-178.
33. S. Banedjschafie, W. Durner, (2015) Water retention properties of a sandy soil with superabsorbent polymers as affected by aging and water quality, ***Journal of Plant Nutrition and Soil Science***, 178: 798-806.
34. J. El-Asmar, H. Jaafar, I. Bashour, M. T. Farran, I. P. Saoud, (2017) Hydrogel banding improves plant growth, survival, and water use efficiency in two calcareous soils: Water, clean, ***Soil Air Water***, **45:** 1700251.
35. A. Mignon, J. Vermeulen, D. Snoeck, P. Dubruel, S. Van Vlierberghe, N. De Belie, (2017) Mechanical and self-healing properties of cementitious materials with pH-responsive semi-synthetic superabsorbent polymers, ***Mater Struct***, **50:** 238.
36. E. Gentleman, Y. C. Fredholm, G. Jell, N. Lotfibakhshaiesh, M. D. O'Donnell, R. G. Hill, M. M. Stevens, (2010) The effects of strontium-substituted bioactive glasses on osteoblasts and osteoclasts in vitro, ***Biomaterials***, **31:** 3949-3956.
37. G. Patras, G. G. Qiao, D. H. Solomon, (2000) Characterization of the pore structure of aqueous three-dimensional polyacrylamide gels with a novel cross-linker, ***Electrophoresis***, **21:** 3843-3850.
38. J. R. Nilsson, (2003) How cytotoxic is zinc? A study on effects of zinc on cell proliferation, endocytosis, and fine structure of the ciliate Tetrahymena, ***Acta Protozoologica***, **42:** 19-29.

***Bibliographical Sketch**

Miss Mini Gupta is a post graduation student in the Department of Chemistry Isabella Thoburn College Lucknow. She has done her graduation in science from Isabella Thoburn College and recently completed her 1 month internship from Central Institute of Petrochemicals Engineering and Technology (CIPET), Lucknow.

Miss Saima Zehra is a post graduate student in the Department of Chemistry, Isabella Thoburn College, Lucknow. She has done an internship in synthesis, characterization, computational studies and biological activity evaluation of thiosemicarbazones from Integral University, Lucknow. She has one review article to her credit in Oriental Journal of Chemistry.

Dr. Meenakshi Singh is an M.Sc, NET and PhD qualified professor. Her area of specialization is based on Synthetic and Natural product Chemistry. She has worked for PhD in the Department of Medicinal Chemistry CDRI, Lucknow. She has also worked for research associate project and visiting associate project in Central Institute of Medicinal and Aromatic Plants, Lucknow. Currently, working as an Associate Professor in the Department of Chemistry Isabella Thoburn College, Lucknow with 25 years of teaching experience.