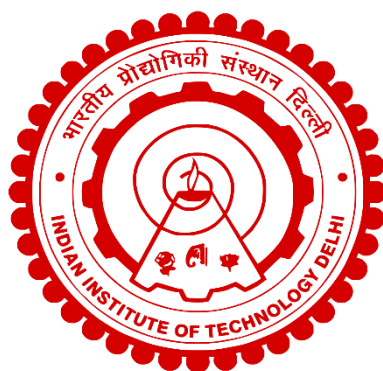


**POLYZWITTERIONIC GELS AND NANOGELS FOR
FIXATION AND/OR RELEASE OF ANIONS AND GASEOUS
MOLECULES AND THEIR APPLICATIONS**

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**DEPARTMENT OF MATERIALS SCIENCE AND ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
OCTOBER 2023**

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by

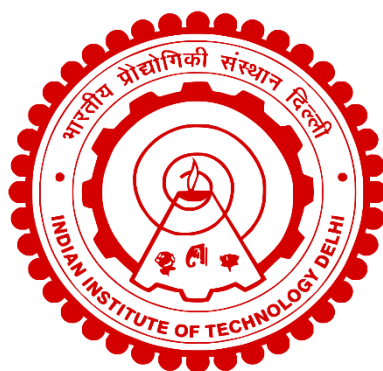
UJJAWAL BAIRAGI

Department of Materials Science and Engineering

Submitted

In fulfilment of the requirements of the degree of Doctor of Philosophy

to the



Indian Institute of Technology Delhi

OCTOBER 2023

Dedicated to my

Parents

Family

&

Kartik

CERTIFICATE

This is to certify that the thesis entitled “Polyzwitterionic gels and nanogels for fixation and/or release of anions and gaseous molecules and their applications” being submitted by **Ms. Ujjawal Bairagi** to the Indian Institute of Technology Delhi, New Delhi, for the award of degree of **Doctor of Philosophy** is a record of bonafide research work carried out by her. **Ms. Ujjawal Bairagi** has worked under my guidance and supervision and has fulfilled the requirements for the submission of her thesis, which to our knowledge has reached the requisite standard.

The results contained in this thesis are original and have not been submitted, in part or full, to any University or Institute for the award of any other degree or diploma.

Prof. Josemon Jacob

Professor

Department of Materials Science and Engineering

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Ujjawal Bairagi

(Ujjawal Bairagi)

ABSTRACT

Polyzwitterions have attracted considerable interest in recent years due to their wide range of applications in various fields such as drug delivery, tissue engineering, and environmental remediation. Polyzwitterions, which contain both positively and negatively charged groups within the same polymer chain, have emerged as a promising class of materials due to their excellent biocompatibility, antifouling properties, and high hydrophilicity. They exhibit a unique heterogeneous property profile combining the features of both ionic and non-ionic polymers. Due to their overall neutral charge and high hydrophilicity, polyzwitterions are naturally able to counter nonspecific protein adsorption, biofilm generation, and adhesion of bacteria to surfaces. By virtue of this variation in dipole moment, several polyzwitterion derivatives have been designed which can switch between their zwitterionic and non-zwitterionic structures. Other special properties of polyzwitterions augment these structural qualities such as pH sensitivity, temperature sensitivity, self-aggregation behaviour, and adjustable overall polymer charge density. These properties make them stimuli-responsive by design and lead to their categorization as smart adaptive polymers. Because of the electrostatic interactions between ionic groups, polyzwitterions show significantly contrasting behaviour as compared to non-ionic polymers. Moreover, counter-ion association and dissociation provide these polymers more functionalities for a variety of applications. The combined effect of dipole moment, electrostatic forces, and ability of counter-ion association and dissociation enable polyzwitterions as ideal materials for the fixation and potential release of various anions. In this context, polyzwitterionic gels and nanogels, which are crosslinked networks of zwitterionic polymers, have been investigated for their ability to fix and release anions and gaseous molecules. These materials have attracted considerable attention due to their potential applications in controlled and sustained delivery, environmental remediation, and anti-fouling applications.

In the first section, a new functional polyelectrolyte poly[1-(carboxymethyl)-4-methacrylamidopyridin-1-ium] was synthesized. The zwitterionic polymer shows its isoelectric point at a pH of 4.2, bi-directional pH responsiveness, and formation of dendritic fractal self-aggregated structures. The free radical polymerization of the monomer (MNPA) using AIBN as the initiator generated the polymer PMNPA which was quaternized using bromoacetic acid to obtain the quaternized salt PMNPA-Br⁻. This was converted into its zwitterionic form by titration with NaOH to its isoelectric point. Using this as a common intermediate, a simple, direct, and scalable single-step protocol was established to introduce various elementary anions like NO₃⁻, HSO₄⁻, H₂PO₄⁻, F⁻, Cl⁻, Br⁻, I⁻, CH₃COO⁻ and HCOO⁻ in their salt forms by reaction with the corresponding acids. With an analogous approach, crosslinked polyelectrolytic gel PMNPAC-Z was synthesized. FESEM studies on crosslinked polymeric hydrogels established the macroporous nature of these materials with their pore size in the range of 10-15 μm. Bi-directional swelling behaviour was observed in these hydrogels from gel swelling kinetics and pH studies. Anion release studies in deionized water and buffer solutions showed ~82% and ~95% cumulative release for nitrate and phosphate anions, respectively in 72 h. Our studies suggest that multifunctional polyelectrolytic gels are promising intermediates in the fixation and release of anions like nitrate and phosphate with potential applications in agriculture and healthcare.

In the second section, to contribute to the objective of one of the most critical sustainable development goals for ensuring the availability of clean water, a novel approach for desalination of brackish/sea water using regenerative, highly porous, thermally stable environment-friendly, and highly efficient polyelectrolytic gels (labelled PZG-1, PZG-2, PZG-3, and PZG-4) was developed. Utilizing PZGs is a promising alternative to the traditional processes for desalination of water, as the results from this study showed their high efficiency for the removal of salts from wastewater even at considerably low concentrations. Moreover,

their ease of synthesis, inexpensive and readily available raw materials, environment-friendly product, and desalination process without employing external energy make these products highly desirable. The synthesized PZGs were used for the removal of commonly found salts from water by electrostatic interaction. The gels were investigated for their ability to absorb various salts from water and were found to be very efficient for NaF, NaCl, NaBr, NaI, NaNO₃, NaH₂PO₄, etc. The effect of various anions and cations, crosslink density in PZGs, and competitive absorption were systematically investigated to assess the impact of these parameters on the absorption capacity of the gels. The maximum absorption capacity observed was ~97% and ~89% for I⁻ anion and K⁺ cation, respectively. Langmuir isotherm model suggested a monolayer absorption of the salts by the PZGs. Regeneration studies demonstrated that the gels could be reused for more than five cycles with ~93% retention of absorption capacity. Our approach, when extended to sea and tap water samples, showed ~87% and 89% reduction in conductivity suggesting that polyzwitterionic gels are highly efficient and promising materials for water desalination.

In the subsequent section cytocompatible, charged polyzwitterionic nanogels (PZNGs) that can efficiently fix and release bicarbonate anions by a controlled and sustained mechanism were synthesized. Three different PZNGs were synthesized using free radical polymerization with N,N'-methylenebisacrylamide and Pluronic F-127 as crosslinker and non-ionic surfactant, respectively. The hydrodynamic size (D_h) from DLS analysis was found to be 68 ± 6 , 120 ± 3 , and 97 ± 9 nm for PZNG-1, PZNG-2, and PZNG-3, respectively. The fixation of HCO₃⁻ on PZNGs was done either by direct reaction with NaHCO₃ or by CO₂ gas bubbling into a dispersion of PZNGs, and the maximum loading efficiency was found to be ~ 87-95%. Accelerated stability studies showed good stability for 30 days at 2-25 °C for the nanogels. The cytocompatibility of the PZNGs from the MTT assay and live-dead test confirms their non-toxicity, safety, and potential for various biomedical applications. The *in-vitro* drug release

profile revealed a sustained and controlled release pattern of HCO_3^- with a maximum of ~90 % cumulative release in 168 h. The Korsmeyer-Peppas kinetic model suggests that the HCO_3^- anion release was regulated by diffusion of the anions and swelling of polymeric nanogels.

The final chapter is comprised of the synthesis of NO_2^- and HS^- containing PZNGs for controlled and sustained release of NO and H_2S gaseous molecules and evaluation of their antimicrobial potential. Nanogels containing NO_2^- and HS^- ions as counter anions were synthesized from PZNGs by direct reaction with aqueous NaNO_2 and NaSH into a dispersion of PZNGs. The DLS data and TEM images of PZNGs show that each sample has a consistent, spherical morphology with good dispersity. The stability studies suggest that the ideal storage conditions for these nanogels are 2-25 °C. Also, these nanogels were found to be cytocompatible, suggesting the potential use of these nanogels in biomedical applications. For conversion of NO_2^- to NO and its release from nanogels, CuSO_4 , CoSO_4 , FeSO_4 , CuCl , citric acid (CA), ascorbic acid (AA), and a combination of CA and AA were utilized. H_2S release from the nanogels was studied with HCl , CA, and AA for conversion of HS^- to H_2S . The *in-vitro* drug release profile revealed a sustained and controlled release pattern of NO and H_2S with a maximum of ~94-96 % cumulative release in 96 h. Furthermore, antimicrobial studies were performed against *E. coli* and *S. aureus* bacterial strains, to establish their suitability as potential antibacterial agents.

सार

पॉलीज़विटेरियन ने हाल के वर्षों में दवा वितरण, ऊतक इंजीनियरिंग और पर्यावरण उपचार जैसे विभिन्न क्षेत्रों में अपने व्यापक अनुप्रयोगों के कारण काफी रुचि आकर्षित की है। पॉलीज़विटेरियन, जिसमें एक ही बहुलक श्रृंखला के भीतर सकारात्मक और नकारात्मक दोनों तरह के चार्ज किए गए समूह होते हैं, अपनी उत्कृष्ट जैव-अनुकूलता, गन्धगी-रोधी गुणों और उच्च हाइड्रोफिलिसिटी के कारण सामग्रियों के एक आशाजनक वर्ग के रूप में उभरे हैं। वे आयनिक और गैर-आयनिक पॉलिमर दोनों की विशेषताओं को मिलाकर एक अद्वितीय विषम संपत्ति प्रोफ़ाइल प्रदर्शित करते हैं। उनके समग्र तटस्थ चार्ज और उच्च हाइड्रोफिलिसिटी के कारण, पॉलीज़विटेरियन स्वाभाविक रूप से गैर-विशिष्ट प्रोटीन सोखना, बायोफिल्म पीढ़ी और सतहों पर बैक्टीरिया के आसंजन का मुकाबला करने में सक्षम हैं। द्विध्रुवीय क्षण में इस भिन्नता के आधार पर, कई पॉलीज़विटेरियन डेरिवेटिव डिज़ाइन किए गए हैं जो उनके ज़िवटरियोनिक और गैर-ज़िवटरियोनिक संरचनाओं के बीच स्विच कर सकते हैं। पॉलीज़विटेरियन के अन्य विशेष गुण इन संरचनात्मक गुणों जैसे कि पीएच संवेदनशीलता, तापमान संवेदनशीलता, स्व-एकत्रीकरण व्यवहार और समायोज्य समग्र बहुलक चार्ज घनत्व को बढ़ाते हैं। ये गुण उन्हें डिज़ाइन द्वारा उत्तेजक-उत्तरदायी बनाते हैं और स्मार्ट अनुकूली पॉलिमर के रूप में उनके वर्गीकरण की ओर ले जाते हैं। आयनिक समूहों के बीच इलेक्ट्रोस्टैटिक इंटरैक्शन के कारण, गैर-आयनिक पॉलिमर की तुलना में पॉलीज़विटेरियंस काफी विपरीत व्यवहार दिखाते हैं। इसके अलावा, काउंटर-आयन एसोसिएशन और पृथक्करण इन पॉलिमर को विभिन्न प्रकार के अनुप्रयोगों के लिए अधिक कार्यक्षमता प्रदान करते हैं। द्विध्रुवीय क्षण, इलेक्ट्रोस्टैटिक बलों, और काउंटर-आयन एसोसिएशन और हृदबंदी की क्षमता का संयुक्त प्रभाव विभिन्न आयनों के निर्धारण और संभावित रिलीज के लिए आदर्श सामग्री के रूप में पॉलीज़विटेरियंस को सक्षम करता है। इस संदर्भ में, पॉलीज़विटेरियोनिक जैल और नैनोगल्स, जो कि ज़िवटरियोनिक पॉलिमर के क्रॉसलिंकड नेटवर्क हैं, को आयनों और गैसीय अणुओं को ठीक करने और छोड़ने की उनकी क्षमता के लिए जांच की गई है। इन

सामग्रियों ने नियंत्रित और निरंतर वितरण, पर्यावरणीय उपचार और दूषण-रोधी अनुप्रयोगों में अपने संभावित अनुप्रयोगों के कारण काफी ध्यान आकर्षित किया है।

पहले खंड में, एक नया कार्यात्मक पॉलीज़विटेरियन पॉली [1- (कार्बोक्सिमिथाइल) -4-मेथैक्रिलामिडोपाइरिडिन-1-आयम] संश्लेषित किया गया था। ज़्विटरियोनिक पॉलीमर 4.2 के पीएच पर अपना आइसोइलेक्ट्रिक बिंदु दिखाता है, द्वि-दिशात्मक पीएच जवाबदेही, और डेंड्रिटिक फ़ैक्टल स्व-एकत्रित संरचनाओं का गठन। आरंभकर्ता के रूप में AIBN का उपयोग करके मोनोमर (MNPA) के मुक्त मूलक पोलिमराइज़ेशन ने पॉलिमर PMNPA उत्पन्न किया जिसे क्वाटरनाइज़्ड साल्ट PMNPA-Br⁻ प्राप्त करने के लिए ब्रोमोएसिटिक एसिड का उपयोग करके चतुष्कृत किया गया। यह NaOH के समविद्युत बिंदु पर अनुमापन द्वारा अपने ज़्विटरियोनिक रूप में परिवर्तित किया गया था। इसका उपयोग करके एक सामान्य मध्यस्थ के रूप में, एक सरल, सीधा और स्केलेबल एकल-स्टेप प्रोटोकॉल स्थापित किया गया था ताकि संबंधित अम्लों के साथ प्रतिक्रिया करके NO₃⁻, HSO₄⁻, H₂PO₄⁻, F⁻, Cl⁻, Br⁻, I⁻, CH₃COO⁻ और HCOO⁻ जैसे विभिन्न प्राथमिक अम्लों को उनके नमकीय रूप में प्रस्तुत किया जा सके। एक समान दृष्टिकोण के साथ, क्रॉसलिंग किए गए पॉलीज़विटेरियोनिक जेल PMNPAc-Z को संश्लेषित किया गया था। क्रॉसलिंग्ड पॉलीमरिक हाइड्रोजेल पर FESEM अध्ययन ने इन सामग्रियों की मैक्रोपोरस प्रकृति को 10-15 माइक्रोन की सीमा में उनके ताकना आकार के साथ स्थापित किया। जेल सूजन कैनेटीक्स और पीएच अध्ययन से इन हाइड्रोजेल में द्वि-दिशात्मक सूजन व्यवहार देखा गया। विआयनीकृत पानी और बफर समाधानों में आयनों की रिहाई के अध्ययन ने क्रमशः 72 घंटे में नाइट्रेट और फॉस्फेट आयनों के लिए ~ 82% और ~ 95% संचयी रिलीज दिखाया। हमारे अध्ययनों से पता चलता है कि मल्टीफंक्शनल पॉलीज़विटेरियोनिक जेल कृषि और स्वास्थ्य देखभाल में संभावित अनुप्रयोगों के साथ नाइट्रेट और फॉस्फेट जैसे आयनों के निर्धारण और रिलीज में मध्यवर्ती का वादा कर रहे हैं।

दूसरे खंड में, स्वच्छ पानी की उपलब्धता सुनिश्चित करने के लिए सबसे महत्वपूर्ण सतत विकास लक्ष्यों में से एक के उद्देश्य में योगदान करने के लिए, पुनर्योजी, अत्यधिक झरझरा, तापीय रूप से स्थिर पर्यावरण

के अनुकूल, और खारे/समुद्री पानी के विलवणीकरण के लिए एक नया दृष्टिकोण अत्यधिक कुशल पॉलीज़्विटरियोनिक जैल (PZG-1, PZG-2, PZG-3 और PZG-4 लेबल) विकसित किए गए थे। PZGs का उपयोग पानी के अलवणीकरण के लिए पारंपरिक प्रक्रियाओं का एक आशाजनक विकल्प है, क्योंकि इस अध्ययन के परिणामों ने अपशिष्ट जल से लवणों को काफी कम सांद्रता पर भी हटाने के लिए उनकी उच्च दक्षता दिखाई। इसके अतिरिक्त, उनके संश्लेषण की सरलता, सस्ती और आसानी से उपलब्ध कच्चे माल, पर्यावरण-सौहार्दपूर्ण उत्पाद, और बाह्य ऊर्जा के उपयोग के बिना तटस्थीकरण प्रक्रिया इन उत्पादों को अत्यंत आकर्षक बनाते हैं। विद्युतआक्सीक परस्परक्रिया के माध्यम से, ये तैयार किए गए PZGs जल से सामान्यतया पाए जाने वाले लवणों को हटाने के लिए उपयोग किए गए। जैल्स की क्षमता की जांच की गई ताकि वे जल से विभिन्न लवणों को शोषित करने में सक्षम हों, और इसके परिणामस्वरूप यह पाया गया कि NaF, NaCl, NaBr, NaI, NaNO₃, NaH₂PO₄, आदि के लिए ये बहुत प्रभावी हैं। PZGs में विभिन्न अनुयायियों और कैटायियों, क्रॉसलिंग घनत्व और प्रतिस्पर्धी शोषण का प्रभाव समग्रता से जांचा गया था ताकि जैल्स की शोषण क्षमता पर इन पैरामीटरों का प्रभाव मापा जा सके। अधिकतम शोषण क्षमता ~97% और ~89% के लिए क्रमशः I⁻ अनुयायी और K⁺ कैटायी के लिए देखी गई। लैंगम्यूइर आइसोथर्म मॉडल ने PZGs द्वारा नमकों के मोनोलेयर शोषण की सुझाव की। पुनर्संचयन अध्ययनों ने दिखाया कि इन जैल्स को पांच से अधिक साइकिल के लिए पुनः प्रयोग किया जा सकता है और शोषण क्षमता का ~93% रखाव बरकरार रह सकता है। हमारी दृष्टि, समुद्री और नलकूप जल नमूनों पर विस्तारित करने पर, विद्युतीकता में ~87% और ~89% की क्षमता कमी को सुझाते हुए दिखाई दी, जिससे प्रतिष्ठानात्मक जल तटस्थीकरण के लिए पॉलीजवितरात्मक जैल्स अत्यंत प्रभावी और आशापूर्ण सामग्री हैं।

आगामी खंड में, साइटोकॉम्पैटिबल, आवेशित पॉलिजवितरात्मक नैनोजैल्स (PZNGs) जो नियंत्रित और सतत तंत्र से बाइकार्बोनेट एनियन को कुशलतापूर्वक फिक्स और मुक्त कर सकते हैं, का संश्लेषण किया गया। तीन अलग-अलग PZNGs को मुक्त रेडिकल पॉलिमरीकरण का उपयोग करके तैयार किया गया,

जिनमें N, N'-मेथिलीनबिसएक्रिलएमाइड और प्लुरोनिक एफ-127 को क्रॉसलिंगर और गैर-आयनिक सर्फैक्टेंट के रूप में उपयोग किया गया। DLS विश्लेषण से हाइड्रोडायनामिक आकार (डी) का माप 68 ± 6 , 120 ± 3 और 97 ± 9 नैनोमीटर मिला PZNGs -1, PZNGs-2 और PZNGs -3 के लिए। PZNGs पर HCO_3^- का फिक्सेशन ना सिर्फ़ नाईट्रिक अम्ल के साथ सीधे प्रतिक्रिया से किया गया, बल्कि PZNGs के विस्तार में कार्बन डाइऑक्साइड गैस फुलाने द्वारा भी, और अधिकतम भारण क्षमता लगभग 87-95% की पाई गई। त्वरित स्थिरता अध्ययन ने नैनोजेल्स के लिए 2-25 °C पर 30 दिनों तक अच्छी स्थिरता की दिखाई। MTT परीक्षण और जीव-मृत परीक्षा से पता चलता है कि PZNGs की साइटोकॉम्पैटिबिलिटी अविषाणिकता, सुरक्षा और विभिन्न बायोमेडिकल अनुप्रयोगों की संभावना को साबित करती है। इन विट्रो दवा मुक्ति प्रोफाइल ने 168 घंटे में HCO_3^- के लिए एक सतत और नियंत्रित मुक्ति पैटर्न का प्रकट किया है, जिसमें लगभग ~90% संचयी मुक्ति होती है। कोरसीमायर-पेपास किनेटिक मॉडल का सुझाव है कि HCO_3^- एनियन की मुक्ति को एनियनों के प्रसार और पॉलिमेरिक नैनोजेल्स के सूजन द्वारा नियंत्रित किया जाता है।

अंतिम अध्याय में NO_2^- और HS^- युक्त PZNGs की संश्लेषण और NO और H_2S गैसी मोलेक्यूलों की नियंत्रित और सतत मुक्ति के लिए तथा उनकी एंटीमाइक्रोबियल क्षमता की मूल्यांकन की गई है। PZNGs के प्रसार में जलीय NaNO_2 और NaSH के साथ सीधे प्रतिक्रिया के माध्यम से PZNGs से NO_2^- और HS^- यौगिकों को संश्लेषित नैनोजेल्स बनाए गए। PZNGs के DLS डेटा और TEM छवियाँ दिखाती हैं कि प्रत्येक नमूने में एक सुसंगत, गोलाकार आकारवाली और अच्छी विस्तारिता होती है। स्थिरता अध्ययन सुझाते हैं कि इन नैनोजेल्स के लिए आदर्श संग्रहण शर्तें 2-25 °C हैं। इसके अलावा, ये नैनोजेल्स साइटोकॉम्पैटिबिल होने का पता चला है, जिससे साबित होता है कि ये नैनोजेल्स बायोमेडिकल अनुप्रयोगों में प्रयोग के पोर्टेशियल के साथ का उपयोग किया जा सकता है। NO_2^- को NO में परिवर्तित करने और नैनोजेल्स से उसकी मुक्ति के लिए CuSO_4 , CoSO_4 , FeSO_4 , CuCl , साइट्रिक एसिड (CA), एस्कोर्बिक एसिड (AA), और CA और AA का संयोजन उपयोग किया गया। नैनोजेल्स से H_2S की मुक्ति के लिए

HCl, CA, और AA के साथ HS⁻ को H₂S में परिवर्तित करने का अध्ययन किया गया। इन विट्रो दवा मुक्ति प्रोफाइल ने 96 घंटे में NO और H₂S की एक सतत और नियंत्रित मुक्ति पैटर्न का प्रकट किया है, जिसमें लगभग ~94-96% संचयी मुक्ति होती है। इसके अलावा, *E-coli* और *S-aureus* बैक्टीरियल स्ट्रेन के खिलाफ एंटीमाइक्रोबियल अध्ययन किए गए, ताकि वे संभावित एंटीबैक्टीरियल एजेंट के रूप में उपयुक्तता स्थापित की जा सके।

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LIST OF ABBREVIATIONS

AAPH	2,2'-Azobis(2-methylpropionamide) dihydrochloride
AIBN	2,2'-azobisisobutyronitrile
CB	Carboxybetaine
CKD	Chronic kidney disease
CL	Crosslinker
CPR	Cumulative percentage release
DCC	N,N'-Dicyclohexylcarbodiimide
D_h	Hydrodynamic diameter
DLS	Dynamic Light Scattering
DMAEMA	2-(Dimethylamino)ethyl methacrylate
DMEM	Dulbecco's Modified Eagle's Medium
DMF	N,N-Dimethylformamide
DMPD	N,N-Dimethyl-p-phenylenediamine dihydrochloride
DMSO	Dimethylsulfoxide
DPBS	Dulbecco's phosphate-buffered saline
FESEM	Field emission scanning electron microscopy
FRP	Free-radical polymerization
FTIR	Fourier transform infrared
GPC	Gel permeation chromatography
LCST	Lower critical solution temperature
MA	Metabolic acidosis
MACl	Methacryloyl chloride
MPC	Methacrylated phosphobetaine
MTT	3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide

NVI	N-vinylimidazole
PAN	Poly(acrylonitrile)
PEGMA	Poly(ethylene glycol monomethyl ester methacrylate)
PEI	Poly(ethylene imine)
PES	Poly(ethersulfone)
pI	Isoelectric point
PI	Propidium iodide
PMNPA	Poly[1-(carboxymethyl)-4-methacrylamidopyridin-1-ium]
PTMA	Poly(2-methacryloyloxy ethyl)trimethyl ammonium chloride
PZG	Polyzwitterionic gels
PZNG	Polyzwitterionic nanogels
RAFT	Reversible addition fragmentation chain-transfer polymerization
RDRP	Reversible deactivation radical polymerization
RO	Reverse osmosis
ROMP	Ring-opening metathesis polymerization
SATO	S-arylothiooxime
SB	Sulfobetaine
TDS	Total dissolved solids
TEM	Transmission electron microscopy
T _f	Final decomposition temperature
TGA	Thermogravimetric analysis
TMS	Tetramethylsilane
T _{onset}	Initial decomposition temperature
UCST	Upper critical solution temperature

LIST OF CHEMICAL FORMULAE

CDCl_3	Deuterated chloroform
CH_3COOH	Acetic acid
CO_2	Carbon-dioxide
$\text{CuSO}_4 \cdot 7\text{H}_2\text{O}$	Copper Sulfate Heptahydrate
D_2O	Deuterated water
$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$	Ferrous sulfate heptahydrate
H_2O	Water
H_2SO_4	Sulfuric acid
H_3PO_4	Phosphoric acid
HBr	Hydrobromic acid
HCl	Hydrochloric acid
HCOOH	Formic acid
HF	Hydrofluoric acid
HI	Hydroiodic acid
HNO_3	Nitric acid
K_2HPO_4	Potassium hydrogen phosphate
KCl	Potassium chloride
KH_2PO_4	Potassium dihydrogen phosphate
KI	Potassium iodide
LiCl	Lithium chloride
Na_2CO_3	Sodium carbonate
NaBr	Sodium Bromide
NaCl	Sodium chloride
NaF	Sodium fluoride

NaH_2PO_4	Sodium dihydrogen phosphate
NaHCO_3	Sodium hydrogen carbonate
NaI	Sodium iodide
NaNO_2	Sodium nitrite
NaNO_3	Sodium nitrate
NaOH	Sodium hydroxide
NaSH	Sodium hydrosulfide