

RESEARCH ARTICLE

IONIC GELATION-BASED DEVELOPMENT AND OPTIMIZATION OF FLURBIPROFEN NANOGEL FOR IMPROVED DERMAL DELIVERY IN ARTHRITIS

Saurabh Gupta^{*1}, S. K. Gupta², Jitender Kumar Malik²

Research Scholar¹, Professor², Faculty of Pharmacy, P. K. University, Shivpuri - 473665, India.

Article History

Received: 10 February 2025

Revised: 21 March 2025

Accepted: 18 June 2025

Published: 25 June 2025

Correspondence should be addressed to

Saurabh Gupta,
Research Scholar,
Faculty of Pharmacy, P. K.
University, Shivpuri - 473665, India.

Email- saurabh.gupta.gwalior@gmail.com

ABSTRACT: Arthritis is a persistent inflammatory disease that needs long term treatment, although traditional NSAIDs like flurbiprofen usually show side effects being systemic and low drug penetration at the inflamed location. As a way of overcoming these shortcomings, the current study was set out to design and optimize an ionically gelated flurbiprofen loaded nanogel. The nanoparticles were developed through different polymer concentration, cross-linker concentration, the speed of stirring, time of stirring, and time of sonication after which they were incorporated in a thermosensitive pluronic F127 gel. The optimized nanoparticles had a particle size of less than 200 nm, and a narrow PDI, positive zeta potential, and high entrapment. In vitro release experiments revealed a biphasic release which was characterized by an initial burst and sustained release over 24 hours. The end nanogel formulation was found to have appropriate pH, spreadability, and stability at refrigerated and accelerated conditions. In general, the flurbiprofen nanogel is optimized to be the most effective local drug delivery system in treating arthritis and it has good therapeutic efficacy, with little systemic adverse effects.

Keywords: Flurbiprofen; Nanogel; Ionic gelation; Chitosan nanoparticles; Topical drug delivery; Arthritis therapy; Sustained release; Pluronic F127

I. INTRODUCTION

Arthritis is an inflammatory disorder of the progressive and debilitating type, which affects millions of individuals all over the world and can be classified as one of the main causes of chronic pain and disability¹. Arthritis is a severe and chronic inflammation of the joints, stiffness, swelling as well as progressive loss of movement that can profoundly deteriorate the quality of life and social and economic performance of the victims. The long-term management is problematic, even with easily accessible pharmacological treatment, such as non-steroidal anti-inflammatory drugs (NSAIDs), corticosteroids, and disease-modifying antirheumatic drugs². Traditional oral NSAIDs like flurbiprofen are commonly used in symptomatic treatment but when administered systemically, they are often accompanied by gastrointestinal discomfort, renal failure, cardiovascular side effects and other dose related toxicities. Also, the low absorption of NSAIDs into inflamed synovial tissues and rapid clearance in the body is usually leading to suboptimal therapeutic levels at the site of action, thus requiring re-administration and decreasing the level of patient adherence³.

Drug delivery systems involving nanotechnology are an area where special interest has been given in recent years in order to overcome the drawbacks of conventional therapy. Nanogels, cross-linked, polymeric soft and nanoscale networks are among these systems which have shown great promise as a carrier of topical and localized delivery of anti-inflammatory drugs. Nanogels have a number of benefits such as the high

capacity of drug-loading, improved permeation through skin layers, high biocompatibility, controlled and sustained drug release and minimized systemic exposure. Their capacity to hold water, swell and react with the biological tissues enables effective deposition of therapeutic agents to the inflamed joints with minimal off-target effects⁴.

Flurbiprofen- a high-potency NSAID which belongs to the propionic acid group- is a good inhibitor of cyclooxygenase mediated synthesis of the prostaglandin, and is actively involved in the prevention of inflammation and pain related to arthritic conditions. Although the system has good therapeutic potential, the systemic adverse effects that are linked with oral administration and low effectiveness of traditional topical formulations indicate the necessity of a better delivery strategy⁵. By placing flurbiprofen in a nanogel matrix, the local bioavailability of the drug can be greatly stimulated, the permeation of the drug into the skin will be enhanced, the drug will be stabilized, the retention of the drug at the site of action will be increased, and finally, the therapeutic effect of the cell will be improved at fewer side effects⁶. The intention of the current study is to prepare and maximize a flurbiprofen-impregnated nanogel through the ionic gelation system, which is a gentle and solvent-free procedure incorporating chitosan and sodium tripolyphosphate. The formulation variables such as the polymer concentration, cross-linker concentration, stirring conditions and sonication time were systematically optimized to obtain nanoparticles with desired physico-chemical properties that could be incorporated into a thermosensitive Pluronic F127 gel.

The resulting nanogel was again tested in the areas of nanogel size, polydispersity, zeta potential, entrapment, pH, spreadability, in vitro drug release, and stability. In this way, the study aims at developing a more effective, safer and patient-friendly topical delivery system in the management of arthritis⁷.

2. Materials and Methods

2.1 Materials

The active pharmaceutical ingredient (API) was flurbiprofen. A medium molecular weight of chitosan was used as the main polymer in the formation of nanoparticles and sodium tripolyphosphate (TPP) was used as ionic cross-linker. The nanogel was prepared by the use of pluronic F127 as a thermosensitive gel base. The rest of the reagents and chemicals employed in the study were of an analytical grade and the use of double distilled water throughout all the experiments⁸.

2.2 Formulation of Flurbiprofen Nanoparticles (Ionic Gelation)

The nanoparticles of flurbiprofen were prepared by an ionic gelation method of chitosan and TPP on the basis of electrostatic interactions⁹.

Preparation of polymer solution

The required amount of the polymer was dissolved in 1% v/v acetic acid under magnetic stirring to form a clear solution of chitosan solution (0.2-1.0% w/v). The solution of flurbiprofen was put in the chitosan solution and stirred¹⁰.

Addition of TPP

TPP solution (0.2-1.0% w/v) was made under distilled water separately. A dropwise addition of the TPP solution to the drug-polymer solution started the ionic cross-linking and was performed at a controlled rate of about 2 mL/min¹¹.

Stirring process

Magnetic stirring was done on the mixture at different speeds (250-1250 rpm) and at different time periods (15 hours) to allow homogenous nanoparticle formation. Optimization studies that were performed included a modification of stirring parameters¹².

Sonication

To bring the nanoparticle dispersion to a smaller size and even density, the resulting was exposed to probe sonication (1-5 minutes, 35% amplitude). The resulting nanoparticles were harvested and kept at 4 °C awaiting use¹³.

2.3 Optimization Steps

To identify the most effective formulation, the variables were optimized using one-factor-at-a-time approach to systematically fit the following variables:

Polymer concentration variation

The concentration of chitosan used ranged between 0.2 and 1.0 percent w/v to determine the influence of the concentration on the size of particles, entrapment and stability¹⁴.

Cross-linker concentration variation

The concentration of TPP was also changed between 0.2 and 1.0% w/v to test its effects on the density of cross-linking and nanoparticle properties¹⁵.

Stirring speed variation

The impact of stirring rates (250-1250 rpm) on particle formation, homogenization and reducing their size was considered¹⁶.

Stirring time variation

The time of the stirring (1-5 hours) was adjusted to obtain the optimal time of nanoparticles formation¹⁷.

Sonication time variation

The time of sonication was kept at random between 1 and 5 minutes to achieve a minimum piece size and small size distribution of nanoparticles¹⁸.

2.4 Preparation of Flurbiprofen Nanogel

The optimized nanoparticle preparation was entrusted into a Pluronic F127 gel base to make the final nanogel. Pluronic F127 was stirred by magnetic stirring at 1000 rpm with cold distilled water to a concentration of 22% w/v and left overnight at 4-8 °C to allow sol-gel conversion. The nanoparticles of flurbiprofen previously made were safely suspended into the gel matrix by gentle stirring to generate a smooth homogeneous nanogel to be used in topical treatment¹⁹.

2.5 Characterization

Particle size analysis (DLS)

The size distribution and mean particle size of the nanoparticles were determined using Dynamic Light Scattering (DLS)²⁰.

Polydispersity Index (PDI)

The values of PDI were calculated in order to measure the homogeneity and uniformity of the nanoparticle dispersion²¹.

Zeta potential

Zeta potential analysis was done to check surface charge and colloidal stability²².

pH measurement

A digital pH meter was used to determine the pH of the nanogel and it was adjusted to a pH of 7.5 to enable its use in the skin²³.

Spreadability

The spreadability was measured by putting the set amount of gel between two glass slides with standard weight and measuring the area covered²⁴.

Drug entrapment efficiency (EE%)

The level of entrapment was also calculated by measuring the quantity of flurbiprofen entrapped in the nanoparticles by means of UV-Visible spectroscopy following centrifugation²⁵.

Morphological evaluation

Scanning electron microscopy (SEM) or transmission electron microscopy (TEM) was used to measure the morphology of the nanoparticles in terms of shape and surface properties²⁶.

In vitro drug release

The dialysis bag technique was used to release the drugs in phosphate-buffered saline (pH 7.4) at controlled temperature and agitation, where samples were sampled after predetermined times²⁷.

Stability studies

To analyze the variations in the particle size, pH, and drug content over time, stability was measured in conditions of accelerated (40 °C ± 2°C, 75% RH) and refrigerated (4 °C) environments²⁸.

3. Results

Influence of Polymer Concentration

The concentration of polymer had a significant influence on nanogel properties. The increase in polymer content in Table 1 resulted in an increase in particle size, 165.73 nm up to 219.25 nm because of an increase in the viscosity, which constrained the breakup of droplets during ionic gelation. The entrapment efficiency also improved to 68.17% as compared to 61.49% as a result of better loading of drug with more polymer chains available. The values of the Zeta potential were steady, indicating that the degree of colloidal stability was good.

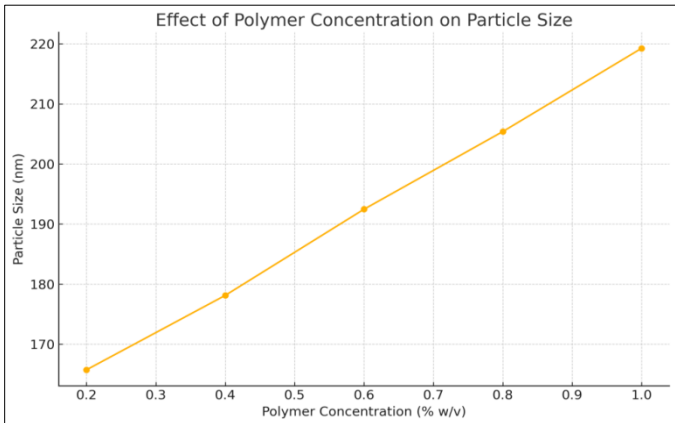


Figure 1: Effect of Polymer Concentration on Particle Size

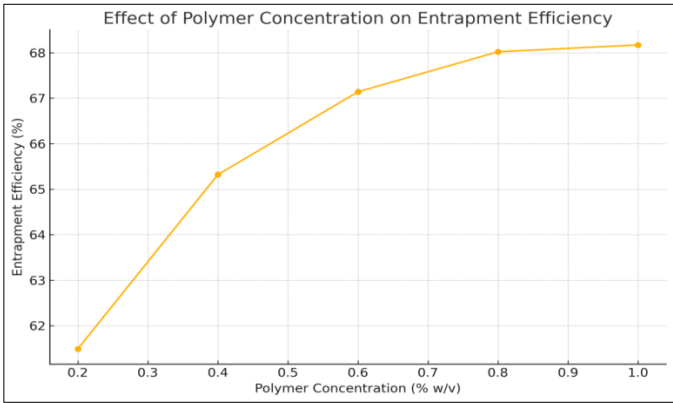


Figure 2: Effect of Polymer Concentration on Entrapment Efficiency

Table 1: Effect of Polymer Concentration on Nanoparticle Characteristics

Form.	Polymer %	Particle Size (nm)	EE (%)	Zeta Potential (mV)
F1	0.2	165.73±2.1	61.49±1.8	+28.6
F2	0.4	178.12±1.9	65.32±1.4	+29.4
F3	0.6	192.46±2.6	67.14±1.1	+30.1
F4	0.8	205.39±2.8	68.02±1.7	+30.7
F5	1.0	219.25±3.4	68.17±1.5	+31.2

Influence of Cross-Linker Concentration

When TPP concentration was raised to 0.2-1.0% the particle size steadily increased (Table 2), which was probably caused by the formation of a cross-linked network. The maximum efficiency of the trap was 0.8% TPP and reduced a little higher because of over-cross linking which limits the diffusion of the drug into the matrix.

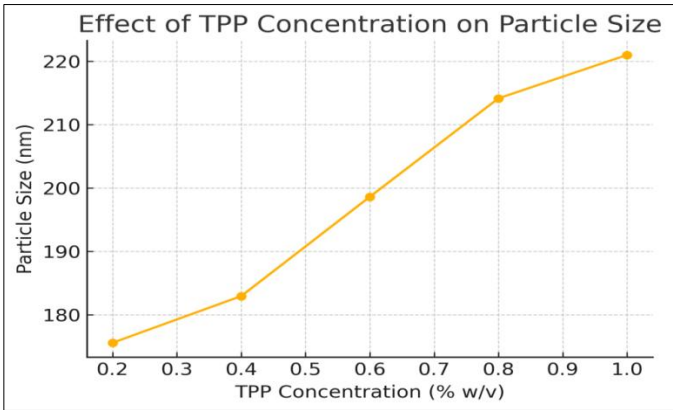


Figure 3: Effect of TPP Concentration on Particle Size

Table 2: Influence of Cross-Linker Concentration

TPP (%)	Particle Size (nm)	EE (%)
0.2	175.59 ± 2.3	64.12 ± 1.3
0.4	182.95 ± 2.2	67.25 ± 1.6
0.6	198.61 ± 2.7	71.86 ± 1.8
0.8	214.13 ± 3.1	73.52 ± 1.7
1.0	220.98 ± 3.4	72.94 ± 1.5

Influence of Stirring Speed

The speed of stirring had a significant influence on the formation of particles. Rising the speed by increasing 250 rpm to 1250 rpm resulted in a great decrease in particle size (Table 3) as the shear forces cause the formation of smaller droplets. Efficiency of entrapment declined marginally at a faster speed, and this may be attributed to the mechanical stress leading to loss of drugs in small amounts.

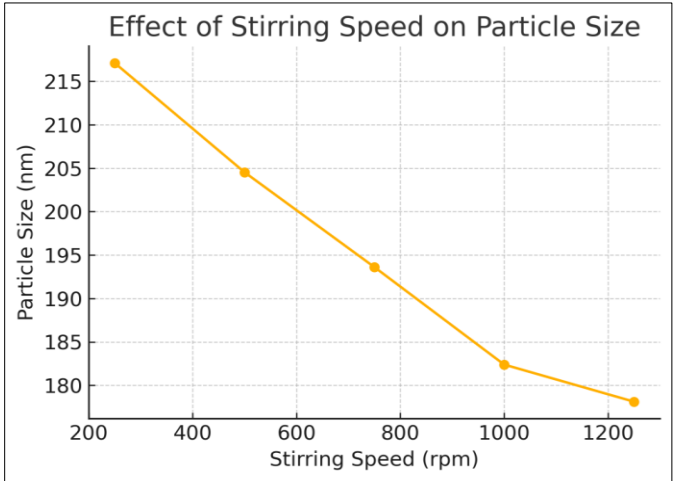


Figure 4: Effect of Stirring Speed on Particle Size

Table 3: Effect of Stirring Speed

Speed (rpm)	Particle Size (nm)	PDI	EE (%)
250	217.12 ± 3.1	0.41	74.26 ± 1.9
500	204.54 ± 2.8	0.36	73.84 ± 1.4
750	193.62 ± 2.4	0.29	72.56 ± 1.1
1000	182.39 ± 2.1	0.25	72.14 ± 1.3
1250	178.12 ± 1.9	0.23	71.62 ± 1.5

Influence of Stirring Time

Stirring time had an effect on maturation of nanoparticles. The size of the particles reduced to 177.02 nm (5 h) as compared to 197.02 nm (1 h) (Table 4). There was a minor decrease in the trap efficiency at longer mixing times which may be because of mild leakage of drugs.

Table 4: Effect of Stirring Duration

Time (h)	Particle Size (nm)	EE (%)
1	197.02 ± 2.6	73.86 ± 1.4
2	190.55 ± 2.4	73.22 ± 1.6
3	183.19 ± 2.3	72.41 ± 1.2
4	179.66 ± 2.1	71.82 ± 1.5
5	177.02 ± 1.9	71.07 ± 1.3

Influence of Sonication Time

The increase in duration of sonication resulted in a reduction in particle size as the duration of sonication was increased up to 5 minutes (189.43nm-174.16nm). PDI was reduced, and it signifies enhanced uniformity. Acoustic and thermal stress reduced the degree of trapment efficiency slightly.

Table 5: Influence of Sonication Duration

Time (min)	Particle Size (nm)	PDI	EE (%)
1	189.43 ± 2.0	0.31	72.98 ± 1.3
2	185.37 ± 1.9	0.27	72.64 ± 1.2
3	181.25 ± 1.8	0.25	72.23 ± 1.5
4	177.89 ± 1.6	0.22	71.81 ± 1.3
5	174.16 ± 1.5	0.21	71.45 ± 1.4

In Vitro Drug Release

The optimized formula had biphasic release where the first burst (surface-bound drug) was followed by persistent release to 24 h because of slow diffusion through the polymer matrix.

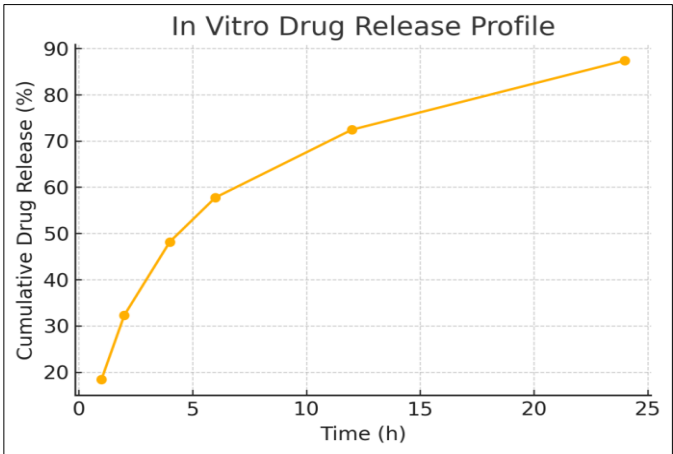


Figure 5: In Vitro Drug Release Profile

Table 6: In Vitro Drug Release Profile

Time (h)	% Release
1	18.42
2	32.28
4	48.16
6	57.73
12	72.41
24	87.39

Stability Studies

The stability results have verified that the nanogel was stable regarding particle size, pH as well as appearance in refrigerated, room temperature and accelerated conditions.

Table 7: Stability Summary

Condition	Particle Size Change	pH	Appearance
4°C	< 5 nm	Stable	Unchanged
25°C	< 10 nm	Stable	Unchanged
40°C/75% RH	~12 nm	Slight ↓	Acceptable

4. Discussion

The current work was able to design and optimize the flurbiprofen loaded nanogels via ionic gelation, proving that the variables of the formulation have a great impact on the behavior of nanoparticles. The concentration of polymer and

cross-linker had a direct impact on the particle size and entrapment efficiency, and an increase in the concentration of chitosan or TPP increased the particle size and rigidity but enhanced drug encapsulation to an optimum level. Process parameters were also important, more stirring speed and longer mixing time decreased the particle size through more droplet breakup and diffusion of the cross-linkers, but the redundant mixing increased entrapment a little because of mechanical stress. Additional enhancement of particle uniformity and reduction of size by cavitation was realized by sonication where 5 minutes was considered optimum without impairing drug loading.

The optimized nanoparticles had a particle size of less than 200 nm, small PDI, positive ZP, and high entrapment, which are desirable characteristics of nanoparticles in dermal delivery. The addition of a Pluronic F127 gel generated a thermosensitive, stable nanogel that could be used as topical. In vitro release experimentation revealed a burst release and a continuous release that is a favorable profile in maintaining extended therapeutic concentration in the arthritic joints. The stability experiments yielded good physical and chemical robustness at normal and accelerated conditions. Altogether, the results prove that ionic gelation is a promising method of creating flurbiprofen nanogels that can improve the localized delivery of the drug with minimized systemic side effects of NSAIDs.

CONCLUSION

The current research was able to design and optimize a nano gel loaded with flurbiprofen through the ionic gelation method and proved that the concentration of the polymer, the level of cross-linkers, the stirring rate, and sonication duration have a strong impact on the properties of the nanoparticles. The optimized nanoparticles had their desirable characteristics such as particle size of less than 200 nm, narrow PDI, positive Zeta potential, and high entrapment efficiency, which rendered them applicable in the topical drug delivery process. Adding to a Pluronic F127 gel led to a stable, thermosensitive nanogel with desirable pH and spreadability and in vitro release testing found an initial burst of release and followed by sustained release of the drug in the therapeutic nanogel. Analysis of stability also established the strength of the formulation. On the whole, the optimized nanogel has a high probability of being a dependable and effective localized delivery system of arthritis treatment, which is more effective with fewer side effects on the system.

ACKNOWLEDGEMENT: Author is thankful to his guide for valuable guidance during his work.

CONFLICT OF INTEREST: Nil

REFERENCES:

- Jahid M, Khan KU, Ahmed RS. Overview of rheumatoid arthritis and scientific understanding of the disease. *Mediterranean journal of rheumatology*. 2023;34(3):284-91.
- Gérard B, Bailly F, Trouvin AP. How to treat chronic pain in rheumatic and musculoskeletal diseases (RMDs)—A pharmacological review. *Joint Bone Spine*. 2024 Jan 1;91(1):105624.
- Dhiman A, Garkhal K. Leflunomide applicability in rheumatoid arthritis: drug delivery challenges and emerging formulation strategies. *Drugs and Drug Candidates*. 2025 Aug 1;4(3):36.
- Ezike TC, Okpala US, Onoja UL, Nwike CP, Ezeako EC, Okpara OJ, Okoroafor CC, Eze SC, Kalu OL, Odoh EC, Nwadike UG. Advances in drug delivery systems, challenges and future directions. *Heliyon*. 2023 Jun 1;9(6).
- Sasso O, Migliore M, Habrant D, Armirotti A, Albani C, Summa M, Moreno-Sanz G, Scarpelli R, Piomelli D. Multitarget fatty acid amide hydrolase/cyclooxygenase blockade suppresses intestinal inflammation and protects against nonsteroidal anti-inflammatory drug-dependent gastrointestinal damage. *The FASEB Journal*. 2015 Mar 10;29(6):2616.
- Oktay AN, Celebi N, Ilbasimis-Tamer S. Investigation of flurbiprofen pharmacokinetics in rats following dermal administration of optimized cyclodextrin-based nanogel. *European Journal of Pharmaceutical Sciences*. 2025 Mar 1;206:107021.
- Park KM, Kim CK. Preparation and evaluation of flurbiprofen-loaded microemulsion for parenteral delivery. *International journal of pharmaceutics*. 1999 Apr 30;181(2):173-9.
- Kumari P, Kant V, Chandratre GA, Ahuja M. Formulation and Evaluation of Pluronic F-127 Thermoresponsive Nanogels Containing Juglone for In vivo Wound Healing Potential. *BioNanoScience*. 2024 Dec;14(5):4710-32.
- Pedroso-Santana S, Fleitas-Salazar N. Ionotropic gelation method in the synthesis of nanoparticles/microparticles for biomedical purposes. *Polymer International*. 2020 May;69(5):443-7.
- Nagavarma BV, Yadav HK, Ayaz AV, Vasudha LS, Shivakumar HG. Different techniques for preparation of polymeric nanoparticles-a review. *Asian J. Pharm. Clin. Res*. 2012 Jun;5(3):16-23.
- Ao Q, Wang A, Cao W, Zhang L, Kong L, He Q, Gong Y, Zhang X. Manufacture of multimicrotubule chitosan nerve conduits with novel molds and characterization in vitro. *Journal of Biomedical Materials Research Part A: An Official Journal of The Society for Biomaterials, The Japanese Society for Biomaterials, and The Australian Society for Biomaterials and the Korean Society for Biomaterials*. 2006 Apr;77(1):11-8.
- Idris AH, Che Abdullah CA, Yusof NA, Abdul Rahman MB. One-pot synthesis of iron oxide nanoparticles: effect of stirring rate and reaction time on its physical characteristics. *Inorganic and Nano-Metal Chemistry*. 2024 May 3;54(5):443-9.
- Show KY, Mao T, Lee DJ. Optimisation of sludge disruption by sonication. *Water Research*. 2007 Dec 1;41(20):4741-7.
- Masarudin MJ, Cutts SM, Evison BJ, Phillips DR, Pigram PJ. Factors determining the stability, size distribution, and cellular accumulation of small, monodisperse chitosan nanoparticles as candidate vectors for anticancer drug delivery: application to the passive encapsulation of [14C]-doxorubicin. *Nanotechnology, science and applications*. 2015 Dec 11:67-80.
- Pan C, Qian J, Zhao C, Yang H, Zhao X, Guo H. Study on the relationship between crosslinking degree and properties

- of TPP crosslinked chitosan nanoparticles. Carbohydrate Polymers. 2020 Aug 1;241:116349.
16. Anarjan N, Jafarizadeh-Malmiri H, Nehdi IA, Sbihi HM, Al-Resayes SI, Tan CP. Effects of homogenization process parameters on physicochemical properties of astaxanthin nanodispersions prepared using a solvent-diffusion technique. International journal of nanomedicine. 2015 Feb 4;1109-18.
 17. Hui BH, Salimi MN. Production of iron oxide nanoparticles by co-precipitation method with optimization studies of processing temperature, pH and stirring rate. In IOP conference series: materials science and engineering 2020 Feb 1 (Vol. 743, No. 1, p. 012036). IOP Publishing.
 18. Fang RH, Aryal S, Hu CM, Zhang L. Quick synthesis of lipid-polymer hybrid nanoparticles with low polydispersity using a single-step sonication method. Langmuir. 2010 Nov 16;26(22):16958-62.
 19. Hamzah ML. Formulation and evaluation of Flurbiprofen nanogel. Research Journal of Pharmacy and Technology. 2020 Nov 1;13(11):5183-8.
 20. Yeap SP, Lim J, Ngang HP, Ooi BS, Ahmad AL. Role of particle-particle interaction towards effective interpretation of Z-average and particle size distributions from dynamic light scattering (DLS) analysis. Journal of nanoscience and nanotechnology. 2018 Oct;18(10):6957-64.
 21. Danaei MR, Dehghankhold M, Ataei S, Hasanzadeh Davarani F, Javanmard R, Dokhani A, Khorasani S, Mozafari YM. Impact of particle size and polydispersity index on the clinical applications of lipidic nanocarrier systems. Pharmaceutics. 2018 May 18;10(2):57.
 22. Midekessa G, Godakumara K, Ord J, Viil J, Lattekivi F, Dissanayake K, Kopanchuk S, Rinken A, Andronowska A, Bhattacharjee S, Rinken T. Zeta potential of extracellular vesicles: toward understanding the attributes that determine colloidal stability. ACS omega. 2020 Jun 30;5(27):16701-10.
 23. Sahu P, Kashaw SK, Jain S, Sau S, Iyer AK. Assessment of penetration potential of pH responsive double walled biodegradable nanogels coated with eucalyptus oil for the controlled delivery of 5-fluorouracil: In vitro and ex vivo studies. Journal of Controlled Release. 2017 May 10;253:122-36.
 24. Alexander I, KRASNYUK II. Dermatologic gels spreadability measuring methods comparative study. Int J Appl Pharm. 2022;14(1):164-8.
 25. Jain SK, Chourasia MK, Masuriha R, Soni V, Jain A, Jain NK, Gupta Y. Solid lipid nanoparticles bearing flurbiprofen for transdermal delivery. Drug delivery. 2005 Jan 1;12(4):207-15.
 26. Buhr E, Senftleben N, Klein T, Bergmann D, Gnieser D, Frase CG, Bosse H. Characterization of nanoparticles by scanning electron microscopy in transmission mode. Measurement science and Technology. 2009 Jun 30;20(8):084025.
 27. D'Souza SS, DeLuca PP. Methods to assess in vitro drug release from injectable polymeric particulate systems. Pharmaceutical research. 2006 Mar;23(3):460-74.
 28. Muthu MS, Feng SS. Pharmaceutical stability aspects of nanomedicines. Nanomedicine. 2009 Dec 1;4(8):857-60.

How to Cite this article:

Gupta S, S. K. Gupta SK, Malik JK. Ionic gelation-based development and optimization of flurbiprofen nanogel for improved dermal delivery in arthritis. International Journal of Pharmaceutical Science and Medicine 2025; 3(2): 53-58.