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FORMULATION AND EVALUATION OF TOPICAL HYDROGEL OF ANTI-INFLAMMATORY DRUG

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Abstract:

Piroxicam is a potent non-steroidal anti-inflammatory drug (NSAID) widely used in the management of pain and inflammatory disorders. However, its oral administration is often associated with gastrointestinal adverse effects and variable bioavailability. The present study aimed to formulate and evaluate a piroxicam-loaded topical hydrogel to provide sustained drug release and improved patient compliance. Hydrogels were prepared using Carbopol 934P, HPMC K4M, and sodium alginate along with suitable co-solvents and excipients. The prepared formulations were evaluated for physical appearance, homogeneity, pH, viscosity, spreadability, extrudability, drug content, and in vitro drug release. All formulations exhibited satisfactory physicochemical properties and were suitable for topical application. Among the developed formulations, batch F3 demonstrated optimum viscosity, excellent spreadability, uniform drug content, and controlled drug release. Stability studies confirmed the formulation remained stable under storage conditions. The study concluded that the optimized piroxicam hydrogel is a promising topical drug delivery system for effective and sustained management of pain and inflammation.

Keywords: Piroxicam, Hydrogel, Topical Drug Delivery, Carbopol 934P, HPMC K4M, Sodium Alginate, Sustained Drug Release, Anti-inflammatory, NSAID, Topical Gel.

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INTRODUCTION:

Topical drug delivery has become an important approach for treating localized diseases because it delivers drugs directly to the affected site while minimizing systemic exposure. Unlike oral administration, topical formulations bypass hepatic first-pass metabolism and gastrointestinal degradation, resulting in improved therapeutic efficiency and patient compliance.[1] Conventional dosage forms such as ointments, creams, lotions, and pastes are widely used; however, they often exhibit drawbacks including poor spreadability, greasiness, limited drug retention, and the need for frequent application.[2]

Hydrogels have emerged as promising topical carriers owing to their three-dimensional hydrophilic polymeric network capable of retaining large amounts of water. Their high water content provides a cooling effect, maintains skin hydration, and creates a favorable environment for controlled drug release. In addition, hydrogels are biocompatible, non-greasy, transparent, and easy to apply, making them highly acceptable for long-term therapy.[3] Their physicochemical characteristics can be tailored by modifying polymer type, crosslinking density, and formulation composition to achieve sustained drug release and improved therapeutic outcomes.[4]

The human skin acts as both the target site and the primary barrier for topical drug delivery. It consists of the epidermis, dermis, and hypodermis, with the stratum corneum serving as the principal barrier to drug permeation.[5] Drug molecules permeate the skin mainly through transcellular, intercellular, or appendageal pathways, and successful delivery depends on factors such as molecular size, lipophilicity, and formulation characteristics.[6–8]

Hydrogels can be prepared using natural or synthetic polymers and may be classified according to their source, crosslinking mechanism, polymer composition, and responsiveness to external stimuli.[9–11] Drug release from hydrogels primarily occurs through diffusion, swelling, erosion, or stimuli-responsive mechanisms, allowing prolonged and controlled delivery.[12] The efficiency of topical formulations is also influenced by physiological factors such as skin hydration, thickness, temperature, age, and disease state.[13–15].

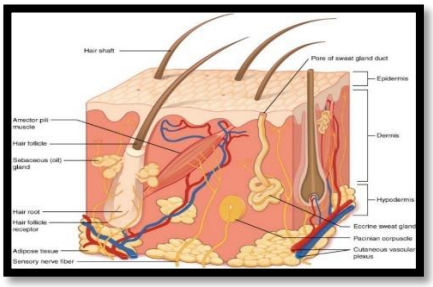

Figure 1: Cross-Sectional Structure of Human Skin

METHODS AND MATERIALS:

Materials Used

The materials selected for the formulation of piroxicam hydrogel were chosen based on their pharmaceutical compatibility, safety, and functional role in topical drug delivery. Piroxicam was used as the active pharmaceutical ingredient because of its potent anti-inflammatory activity. Carbopol 934P, HPMC K4M, and sodium alginate were employed as gelling polymers to provide the desired viscosity, mechanical strength, and sustained drug release characteristics.[16] Propylene glycol and ethanol served as co-solvents to improve the solubility of piroxicam, while glycerin functioned as a humectant to retain moisture within the gel. Menthol was incorporated as a permeation enhancer to facilitate drug transport across the skin. Triethanolamine (TEA) was used to neutralize Carbopol and convert the polymer dispersion into a clear hydrogel. Methylparaben was included as a preservative to prevent microbial contamination, and purified water was used as the dispersion medium.[17]

Table 1: Materials Used in Hydrogel Formulation

Material	Functional Role
Piroxicam	Active drug
Carbopol 934P	Primary gelling agent
HPMC K4M	Thickening polymer
Sodium Alginate	Natural polymer
Propylene Glycol	Co-solvent
Ethanol	Solvent
Glycerin	Humectant
Menthol	Permeation enhancer
Triethanolamine	Neutralizing agent
Methylparaben	Preservative
Purified Water	Vehicle

Instruments and Equipment

Standard laboratory equipment and analytical instruments were used throughout the study to ensure reliable formulation and evaluation of the hydrogel. An analytical balance was used for accurate weighing of ingredients, while a magnetic stirrer facilitated polymer hydration and mixing. A Brookfield viscometer measured viscosity, and a digital pH meter was employed to determine formulation pH. Drug–excipient compatibility was evaluated using Fourier Transform Infrared (FTIR) spectroscopy, whereas thermal characteristics were studied using Differential Scanning Calorimetry (DSC). Drug content and in vitro release samples were analyzed using a UV–Visible spectrophotometer. A Franz diffusion cell was used for release studies under controlled conditions.[18]

Table. Instruments Used in the Study

Instrument	Purpose
Analytical Balance	Accurate weighing
Magnetic Stirrer	Mixing and hydration
Brookfield Viscometer	Viscosity measurement
Digital pH Meter	pH determination
FTIR Spectrophotometer	Compatibility study
DSC Analyzer	Thermal analysis
UV–Visible Spectrophotometer	Drug estimation
Franz Diffusion Cell	In vitro release study

Preformulation Studies

Preformulation studies were performed to determine the physicochemical characteristics of piroxicam before formulation. These studies provided information necessary for selecting suitable excipients and developing a stable hydrogel system.[19]

Organoleptic Characteristics

Organoleptic evaluation was carried out as a preliminary quality assessment of piroxicam before formulation. The drug was visually inspected under adequate lighting to determine its colour, appearance, odour, crystal nature, and texture. A small quantity of the powder was spread on a clean glass slide to observe its physical characteristics and ensure the absence of discoloration, contamination, or foreign particles. This simple evaluation provides valuable information regarding the identity and quality of the raw material and helps detect any changes caused by improper storage or degradation. A drug exhibiting the expected organoleptic properties is considered suitable for formulation into topical hydrogel systems.[20]

Solubility Study

The solubility behaviour of piroxicam was investigated to identify an appropriate solvent system for hydrogel formulation. Excess drug was added separately to purified water, ethanol, propylene glycol, phosphate buffer (pH 7.4), and sodium hydroxide solution. The mixtures were shaken until equilibrium was achieved, followed by filtration to remove undissolved particles. The concentration of dissolved drug was estimated using UV–Visible spectrophotometry. Since piroxicam exhibits limited aqueous solubility but improved solubility in organic solvents and alkaline media, the study aided in selecting suitable co-solvents and pH-adjusting agents required for uniform drug incorporation and enhanced dermal delivery.[21]

pH Analysis of Drug Dispersion

The intrinsic pH of the piroxicam dispersion was determined to assess its suitability for topical application and its influence on drug stability. A dispersion of the drug was prepared in purified water and stirred uniformly before measurement using a calibrated digital pH meter. The pH value provides important information regarding drug ionization, solubility, and compatibility with the skin. Maintaining the formulation within the physiological skin pH range is essential to minimize irritation while ensuring optimum drug stability and performance. The results of this study also guided the adjustment of formulation pH using triethanolamine during hydrogel preparation.[22]

Table 2: Preformulation Parameters and Their Significance

Parameter	Significance
Organoleptic properties	Confirms identity and quality of raw material
Solubility	Selection of suitable solvent system
pH	Ensures skin compatibility and formulation stability
Melting point	Confirms purity and identity
Partition coefficient	Predicts dermal permeation ability

Melting Point Determination

Melting point determination was performed using the capillary tube method to verify the purity and identity of piroxicam. A small quantity of the powdered drug was packed into a capillary tube and placed in a melting point apparatus. The temperature was gradually increased until the onset and completion of melting were observed. Pure drug substances exhibit a sharp melting range, whereas impurities generally broaden or depress the melting point. Therefore, this test served as an important quality control parameter before formulation development.[23]

Partition Coefficient Determination

The partition coefficient of piroxicam was determined using the n-octanol/water partition method to evaluate its lipophilic nature and predict skin permeation potential. Equal volumes of n-octanol and purified water were mixed with a known quantity of the drug and allowed to reach equilibrium after continuous shaking. Following phase separation, samples from both layers were analyzed using UV–Visible spectrophotometry. The ratio of drug concentration in the organic phase to that in the aqueous phase was calculated as the partition coefficient. This parameter is useful for selecting suitable permeation enhancers and optimizing the hydrogel formulation for effective topical drug delivery.[24]

FTIR Compatibility Study

Compatibility between piroxicam and the selected excipients was evaluated using Fourier Transform Infrared (FTIR) spectroscopy. Samples of the pure drug, individual polymers, and their physical mixtures were blended with potassium bromide and

compressed into transparent pellets before scanning over the range of 4000–400 cm^{-1}. The spectra were examined for the presence of characteristic functional group peaks and any significant peak shifts or disappearance. Preservation of the major absorption bands confirmed the absence of chemical interaction between the drug and excipients, indicating their compatibility and suitability for hydrogel formulation.[25]

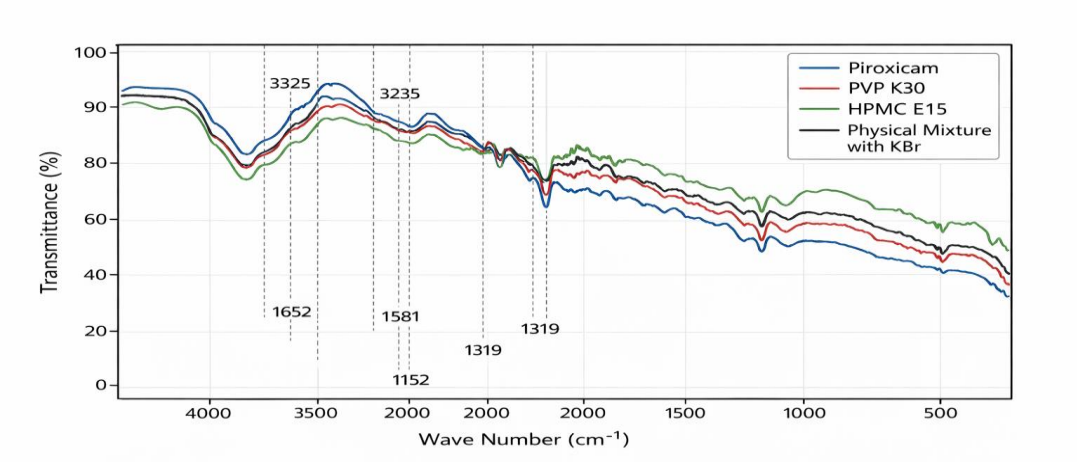

Figure 2: FTIR Spectral Mapping With Excipients

Formulation of Piroxicam Hydrogels

Piroxicam hydrogels were prepared using a systematic formulation approach to obtain stable, homogeneous, and effective topical gels. Multiple formulation batches were developed by varying the concentration of polymers and excipients while maintaining a constant drug concentration. The formulation process emphasized proper polymer hydration, uniform drug incorporation, controlled neutralization, and homogenization to achieve desirable physicochemical properties and sustained drug release.[26]

Preparation of Polymer Dispersion

The hydrogel base was prepared by accurately weighing Carbopol 934P and HPMC K4M, which were slowly dispersed into purified water under continuous stirring using a magnetic stirrer. Gradual addition of polymers prevented lump formation and ensured uniform dispersion. The polymer solution was allowed to stand for complete hydration and swelling. Sodium alginate, when included in the formulation, was hydrated separately in warm purified water before mixing with the hydrated Carbopol-HPMC dispersion. Proper hydration produced a stable polymeric network capable of entrapping the drug and maintaining suitable viscosity for topical application.[27]

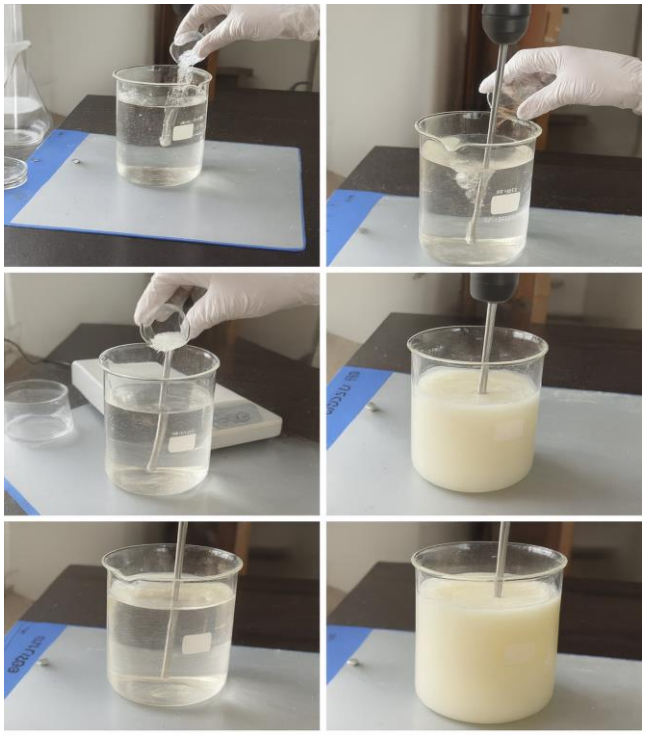

Figure 3: Polymer Hydration and Gel Network Formation

Preparation of Drug–Solvent Phase

A separate drug solution was prepared by dissolving accurately weighed piroxicam in a mixture of ethanol and propylene glycol under continuous stirring. The use of co-solvents improved the solubility of piroxicam and facilitated its uniform incorporation into the hydrogel matrix. Menthol was added as a permeation enhancer to improve drug penetration through the skin. The prepared drug solution was protected from excessive light and maintained under gentle stirring until complete dissolution was achieved, ensuring uniformity before mixing with the polymer base.[28]

Incorporation of Drug into Polymer Base

The prepared drug solution was gradually added to the fully hydrated polymer dispersion with continuous slow stirring. Controlled addition prevented phase separation and ensured uniform distribution of the drug throughout the gel matrix. Mixing was continued until a smooth, homogeneous dispersion free from visible aggregates or air bubbles was obtained. This step was essential to achieve uniform drug content and consistent therapeutic performance in all formulation batches.[29]

pH Adjustment and Neutralization

After complete mixing of the drug and polymer phases, triethanolamine was added dropwise under gentle stirring to neutralize Carbopol. Neutralization caused ionization of the polymer chains, resulting in rapid gel formation and a significant increase in viscosity. The pH of the formulation was carefully maintained within the range of 5.5–7.0 to ensure compatibility with the skin, improve drug stability, and provide patient comfort. Excessive addition of triethanolamine was avoided because over-neutralization may reduce gel stability and adversely affect rheological properties.[30]

Figure 3: Neutralization and Gelation Mechanism

Final Homogenization and Packaging

The prepared hydrogel was homogenized using a mechanical homogenizer to eliminate entrapped air bubbles and improve formulation uniformity. The gel was visually examined for colour, transparency, homogeneity, and absence of phase separation. The final product was then transferred into clean, airtight, light-resistant containers and properly labelled with formulation code and storage conditions. The formulated hydrogels were stored at room temperature until further evaluation.[31]

Table:3 Composition of Piroxicam Hydrogel Formulation Batches

Ingredient (% w/w)	F1	F2	F3	F4	F5	F6
Piroxicam	0.3	0.3	0.3	0.3	0.3	0.3
Carbopol 934P	0.5	0.75	1.0	0.5	0.75	1.0
HPMC K4M	0.5	0.5	0.5	1.0	1.0	1.0
Sodium Alginate	—	0.25	0.25	—	0.25	0.25
Propylene Glycol	10	10	15	10	15	15
Glycerin	5	5	5	3	3	5
Ethanol	10	15	15	10	10	15
Menthol	0.1	0.1	0.3	0.1	0.3	0.3
Methylparaben	0.05	0.05	0.05	0.05	0.05	0.05
Triethanolamine	q.s.	q.s.	q.s.	q.s.	q.s.	q.s.
Purified Water	To 100	To 100	To 100	To 100	To 100	To 100

Evaluation of Piroxicam Hydrogel Formulations

The prepared hydrogel formulations were evaluated for various physicochemical parameters to determine their suitability for topical application. The evaluation included assessment of physical appearance, homogeneity, pH, viscosity, spreadability, extrudability, drug content, and in vitro drug release. These parameters are essential for ensuring product quality, therapeutic efficacy, patient acceptability, and formulation stability.[32]

Physical Appearance and Homogeneity

The physical appearance of the formulated hydrogels was examined to assess their visual quality and uniformity. Each formulation was inspected for colour, clarity, consistency, and the presence of visible particles or phase separation. A small quantity of gel was spread on a clean glass

slide and observed under normal laboratory lighting. Homogeneity was further evaluated by gently rubbing the gel between the fingers to ensure smooth texture and uniform distribution of the drug and excipients. Hydrogels exhibiting a smooth, elegant appearance without lumps or grittiness were considered suitable for topical application, indicating effective mixing and proper formulation development.[33]

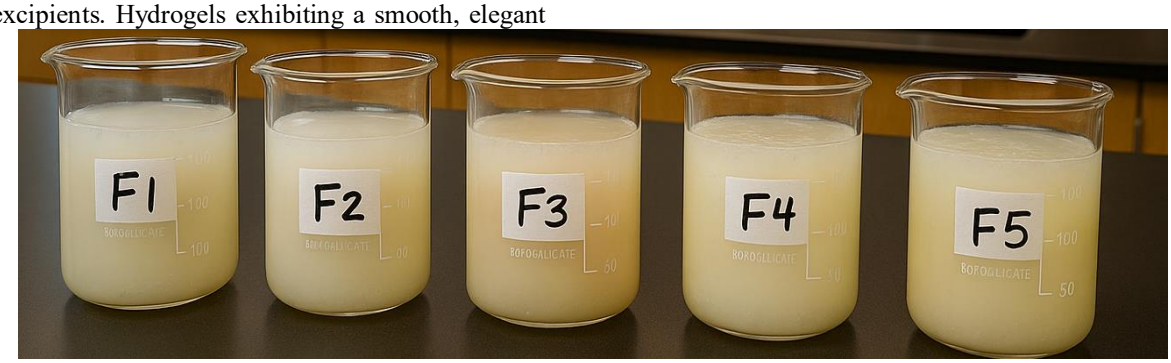

Figure 4: Visual and Structural Assessment of Hydrogel

pH Measurement

The pH of each hydrogel formulation was determined to ensure compatibility with the physiological pH of human skin. Approximately 1 g of hydrogel was dispersed in distilled water, and the pH was measured using a calibrated digital pH meter after obtaining a stable reading. The electrode was thoroughly rinsed with distilled water before analyzing each sample. Maintaining the pH within the range of 5.5–7.0 is essential to minimize skin irritation, preserve drug stability, and maintain the structural integrity of the hydrogel throughout storage.[34]

Table:4 Ideal Evaluation Parameters for Topical Hydrogels

Parameter	Acceptable Range
pH	5.5–7.0
Drug Content	95–105%
Spreadability	Smooth and uniform
Viscosity	Suitable for topical application

Viscosity Measurement

Viscosity is an important quality attribute influencing the spreadability, residence time, and drug release behaviour of topical hydrogels. The viscosity of each formulation was determined using a Brookfield viscometer equipped with an appropriate spindle at different rotational speeds. The gel sample was placed carefully in the sample holder, ensuring complete immersion of the spindle without entrapped air. Measurements were carried out at room temperature under controlled conditions. The viscosity values were used to compare the effect of different polymer concentrations on the rheological behaviour of the prepared formulations.[35]

Figure 5: Brookfield Viscometer

Spreadability Test

Spreadability was evaluated to determine the ease with which the hydrogel could be applied uniformly over the skin surface. A known quantity of gel was placed between two glass slides, and a fixed weight was applied for a specified period. The diameter of spread or the time required for the upper slide to move a predetermined distance was recorded. Good spreadability indicates ease of application, better patient compliance, and uniform distribution of the drug over the affected area. The spreadability of the hydrogel is mainly influenced by polymer concentration and viscosity.[36]

Extrudability Test

Extrudability was determined to evaluate the ease with which the hydrogel could be dispensed from collapsible tubes during normal use. The prepared formulations were filled into aluminium tubes, and a constant force was applied to extrude the gel. The amount of gel extruded and the smoothness of extrusion were observed. Formulations that extruded uniformly with minimum force were considered acceptable, as they provide better patient convenience and reduce product wastage during application.[37]

Table:5 Physical Evaluation Parameters

Evaluation Test	Purpose
Appearance	Visual quality
Homogeneity	Uniform drug distribution
Viscosity	Flow behaviour
Spreadability	Ease of application
Extrudability	Ease of dispensing

Drug Content Determination

Drug content estimation was carried out to determine the uniform distribution of piroxicam in the prepared hydrogels. A known quantity of gel was accurately weighed and dissolved in a suitable solvent system consisting of ethanol and phosphate buffer. The solution was filtered to remove polymeric residues and analyzed using a UV–Visible spectrophotometer at the predetermined wavelength of piroxicam. The drug concentration was calculated using a standard calibration curve. Drug content within the acceptable pharmacopeial range confirmed uniform incorporation of the active ingredient during formulation.[38]

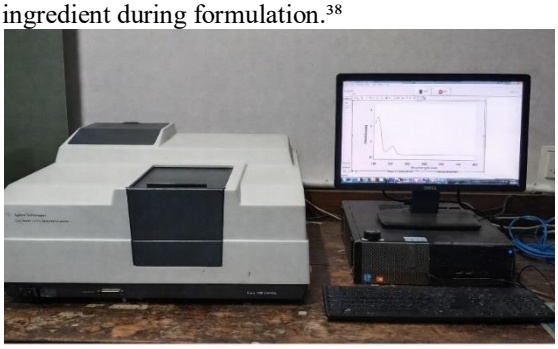

Figure 6: UV–Visible Spectrophotometer

In Vitro Drug Release Study

The in vitro drug release study was performed using a Franz diffusion cell to evaluate the release profile of piroxicam from the hydrogel formulations. A predetermined quantity of gel was placed in the donor compartment, while phosphate buffer (pH 7.4) maintained at 37 ± 0.5°C served as the receptor medium. A suitable diffusion membrane separated the donor and receptor compartments. Samples were withdrawn at predetermined intervals and replaced with an equal volume of fresh buffer to maintain sink conditions. The collected samples were analyzed using a UV–Visible spectrophotometer to determine cumulative drug release. The study helped compare the release characteristics of different formulations and identify the optimized hydrogel batch.[39]

Figure 7: Franz Diffusion Cell

Release Kinetic Modeling

The release data obtained from the diffusion study were fitted to different mathematical models, including Zero-order, First-order, Higuchi, and Korsmeyer–Peppas models, to determine the mechanism of drug release. The model showing the highest correlation coefficient was considered the best fit for explaining the release behaviour of piroxicam from the hydrogel matrix. Kinetic modeling provides valuable information regarding diffusion, erosion, and swelling-controlled drug release mechanisms and assists in selecting the optimized formulation for topical application.[40]

RESULTS AND DISCUSSION:

Preformulation Study Results

Preformulation studies were carried out to evaluate the physicochemical properties of piroxicam before formulation. These studies provided valuable information regarding drug identity, purity, compatibility with excipients, and suitability for incorporation into the hydrogel system. The results confirmed that piroxicam possessed the required characteristics for developing a stable and effective topical hydrogel formulation. The data obtained from these studies were used for selecting appropriate polymers, solvents, and formulation conditions.

Table:6 Preformulation Study Results of Piroxicam

Parameter	Result	Observation
Appearance	Pale yellow crystalline powder	Complied with reported characteristics
Odour	Odourless	Acceptable
Solubility	Soluble in ethanol and propylene glycol; slightly soluble in water	Suitable for topical hydrogel formulation
Melting Point	198–201°C	Indicates purity of drug
pH of Drug Dispersion	6.18 ± 0.04	Suitable for topical application
Partition Coefficient (Log P)	2.18 ± 0.06	Indicates good lipophilic nature for skin permeation
FTIR Compatibility	No significant interaction observed	Drug compatible with selected excipients

The organoleptic evaluation confirmed that piroxicam was a pale yellow, odourless crystalline powder without any visible impurities or discoloration. These observations were consistent with the reported characteristics of pure piroxicam, indicating that the drug sample was suitable for formulation development.

Solubility studies revealed that piroxicam exhibited limited solubility in purified water but dissolved readily in ethanol and propylene glycol. The use of these co-solvents significantly improved drug solubilization, ensuring uniform incorporation into the hydrogel matrix. Improved solubility is essential for achieving homogeneous drug distribution and consistent therapeutic performance.

The melting point of piroxicam was found to be within the reported range of 198–201°C, confirming the purity and identity of the drug. A sharp melting range indicated the absence of significant impurities or degradation products, suggesting that the drug was chemically stable before formulation.

The pH of the drug dispersion was 6.18 ± 0.04, which lies within the acceptable physiological range for topical preparations. This pH is compatible with human skin and minimizes the possibility of irritation while maintaining the stability of the drug within the hydrogel matrix.

The partition coefficient value (Log P = 2.18 ± 0.06) indicated that piroxicam possesses moderate lipophilicity, which is advantageous for topical drug delivery. Adequate lipophilicity facilitates penetration through the stratum corneum while maintaining sufficient solubility within the formulation, thereby enhancing dermal drug absorption.

FTIR compatibility studies demonstrated that the characteristic absorption peaks of piroxicam remained unchanged after mixing with Carbopol 934P, HPMC K4M, sodium alginate, and other formulation excipients. No significant peak shifting, disappearance, or formation of additional peaks was observed, confirming the absence of chemical interactions between the drug and excipients. These findings established that the selected formulation components were compatible and suitable for the preparation of a stable piroxicam hydrogel.

The overall preformulation study confirmed that piroxicam possesses appropriate physicochemical properties, excellent compatibility with selected excipients, and adequate stability for incorporation into topical hydrogel formulations. These findings provided a strong scientific basis for the successful formulation and subsequent evaluation of the developed hydrogels using different polymer combinations.

RESULTS AND DISCUSSION:

Evaluation Results of Piroxicam Hydrogel Formulations

The prepared piroxicam hydrogel formulations (F1–F6) were evaluated for their physicochemical properties to determine their suitability for topical application. Parameters including physical appearance, pH, viscosity, spreadability, extrudability, drug content, and in vitro drug release were assessed. The obtained results demonstrated that variation in polymer concentration significantly influenced the quality, stability, and release characteristics of the prepared hydrogels. Overall, all formulations complied with acceptable pharmaceutical standards; however, formulation F3 exhibited the most desirable balance of physicochemical properties and sustained drug release, making it the optimized formulation.

Table 7: Evaluation Results of Piroxicam Hydrogel Formulations

Parameter	F1	F2	F3	F4	F5	F6
Appearance	Slightly opaque	Translucent	Clear translucent	Opaque	Translucent	Clear
Homogeneity	Smooth	Uniform	Excellent	Smooth	Good	Very smooth
pH	6.10 ± 0.05	6.35 ± 0.04	6.42 ± 0.03	6.15± 0.06	6.28 ± 0.05	6.48 ± 0.04
Viscosity (cP)	12,500	17,800	21,600	15,200	18,500	24,800
Spreadability (g·cm/sec)	18.4	15.6	14.2	17.9	15.1	12.8
Extrudability (g)	65	72	85	68	79	102
Drug Content (%)	96.8	98.5	101.2	97.6	99.3	100.6
Drug Release at 8 h (%)	78.3	72.4	69.1	79.8	74.6	61.5

Physical Appearance and Homogeneity

The physical appearance study demonstrated that all prepared hydrogel formulations possessed satisfactory visual characteristics without evidence of phase separation or particulate matter. The optimized formulations containing balanced concentrations of Carbopol and HPMC produced smooth, translucent gels with excellent homogeneity. Formulation F3 exhibited the most elegant appearance and uniform consistency, confirming proper hydration of polymers and successful incorporation of piroxicam.

pH Evaluation

The pH values of all formulations ranged between **6.10 and 6.48**, remaining within the physiological skin pH range. Maintaining the pH close to that of healthy skin minimizes irritation and supports long-term stability of the formulation. The slightly higher pH observed in formulations containing increased Carbopol concentration was attributed to neutralization with triethanolamine. Formulation F3 showed an optimum pH of **6.42**, making it highly suitable for topical administration.

Viscosity Evaluation

Viscosity evaluation revealed that increasing polymer concentration significantly enhanced gel consistency. Higher Carbopol levels produced stronger polymeric networks that increased resistance to flow. Although formulation F6 possessed the highest viscosity, excessive gel thickness reduced its ease of application. In comparison, formulation F3 demonstrated an optimum viscosity that provided adequate retention on the skin while allowing comfortable spreading and sustained drug release.

Spreadability Evaluation

Spreadability is an important parameter influencing patient compliance and therapeutic effectiveness. The results demonstrated that formulations with lower viscosity spread more easily, whereas highly viscous formulations required greater force. Formulation F3 maintained an excellent balance between viscosity and spreadability, enabling uniform application over the skin surface without excessive flow or stiffness.

Extrudability Evaluation

Extrudability testing confirmed that all formulations could be dispensed from collapsible tubes; however, the force required increased with increasing viscosity. Formulation F3 showed satisfactory extrudability, allowing smooth and controlled dispensing while maintaining sufficient gel consistency. This characteristic is advantageous for routine patient use and minimizes formulation wastage during application.

Drug Content Determination

Drug content determination indicated excellent uniformity among all hydrogel formulations. The measured drug content ranged from **96.8% to 101.2%**, satisfying pharmacopeial acceptance criteria. The absence of drug precipitation or crystallization confirmed efficient mixing and stable incorporation of piroxicam within the hydrogel matrix. Formulation F3 exhibited the highest drug content uniformity, reflecting superior formulation quality.

In Vitro Drug Release Study

The in vitro drug release study demonstrated that polymer composition markedly influenced drug diffusion from the hydrogel matrix. Formulations containing lower Carbopol concentrations released piroxicam more rapidly because of their relatively loose polymer network, whereas formulations with higher polymer concentrations produced a slower and more sustained release profile. Formulation F3 exhibited an optimum controlled-release pattern, releasing approximately **69%** of the drug over eight hours. This release behaviour is considered suitable for maintaining prolonged anti-inflammatory activity while reducing the frequency of topical application.

Based on the overall evaluation, formulation **F3** demonstrated the most desirable physicochemical characteristics, including excellent appearance, optimum pH, appropriate viscosity, satisfactory spreadability, acceptable extrudability, uniform drug content, and controlled drug release. These findings

indicate that the selected polymer combination successfully produced a stable hydrogel capable of providing sustained topical delivery of piroxicam. Therefore, formulation F3 was selected as the optimized batch for further stability evaluation and future pharmaceutical development.

SUMMARY AND CONCLUSION:

The present study successfully developed and evaluated a **piroxicam-loaded topical hydrogel** using Carbopol 934P, HPMC K4M, and sodium alginate as gelling polymers. Appropriate co-solvents and excipients were selected to improve drug solubility, stability, spreadability, and patient acceptability. The prepared formulations were systematically evaluated for physicochemical characteristics, including appearance, pH, viscosity, spreadability, extrudability, drug content, and in vitro drug release. All formulations exhibited acceptable pharmaceutical properties suitable for topical application. Among the developed batches, **F3** demonstrated the most desirable characteristics, including optimum viscosity, satisfactory spreadability, excellent drug content uniformity, and a controlled drug release profile. Stability studies confirmed that the optimized formulation remained physically and chemically stable under the tested conditions. Overall, the study established that piroxicam hydrogel is a promising topical drug delivery system capable of providing sustained anti-inflammatory activity, improved patient compliance, and enhanced therapeutic effectiveness for the management of pain and inflammatory conditions.

FUTURE SCOPE

The developed piroxicam hydrogel provides a strong foundation for further research in topical drug delivery. Future investigations may focus on the development of stimuli-responsive or smart hydrogels capable of releasing the drug in response to changes in pH, temperature, or external stimuli. Incorporation of nanocarriers such as nanoparticles, liposomes, or nanoemulsions within the hydrogel matrix may further enhance skin permeation and therapeutic efficacy. Additional in vivo pharmacokinetic, pharmacodynamic, and clinical studies are required to confirm the safety, efficacy, and patient acceptability of the optimized formulation. Large-scale manufacturing studies, process optimization, and advanced packaging systems should also be explored to facilitate commercial production. Long-term stability studies and regulatory evaluations will further establish product quality and shelf-life. The hydrogel platform may also be adapted for delivering other anti-inflammatory, analgesic, antimicrobial, or herbal therapeutic agents, expanding its applications in modern topical pharmaceutical therapy.

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