Emulgels in Pharmaceutical Research: Innovations in Preparation Techniques and Therapeutic Applications

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Abstract

Emulgels are hybrid semisolid dosage forms that integrate the benefits of emulsions and gels, offering a versatile platform for topical and transdermal drug delivery. This review outlines the formulation strategies, functional components, and innovative preparation techniques of emulgels. By overcoming the limitations of traditional gels and emulsions—such as poor solubility of lipophilic drugs or instability in emulsions—emulgels enable enhanced drug penetration, improved spreadability, and controlled release. Recent advancements such as nanoemulgels, stimuli-responsive systems, and herbal-based formulations have significantly broadened their therapeutic applications across dermatological, anti-inflammatory, analgesic, antifungal, and cosmetic domains. A detailed evaluation of physical characteristics, rheological behavior, drug content, in vitro drug release, and permeation studies ensures the development of safe and effective formulations. Additionally, the incorporation of natural phytochemicals in emulgel systems reflects the growing trend toward biocompatible and patient-friendly delivery vehicles. Overall, emulgels continue to evolve as a promising approach in modern pharmaceutical technology, merging scientific innovation with therapeutic efficacy.

Keywords: *Emulgel, Topical drug delivery, Nanoemulgel, Herbal formulation, Controlled release, Transdermal system, Semisolid dosage form.*

1. Introduction

Emulgels are a unique class of semisolid dosage forms that represent a hybrid of two well-established drug delivery systems: emulsions and gels. They are essentially emulsions—either oil-in-water (O/W) or water-in-oil (W/O)—that are incorporated into a gel base to enhance their consistency and application properties. This combination results in a formulation that

leverages the advantages of both systems, offering improved drug delivery, enhanced stability, and patient-friendly application characteristics. The significance of emulgels lies in their multifunctional nature. They offer excellent spreadability, ease of application, and a non-greasy feel, which are particularly advantageous for topical and transdermal applications. Moreover, the incorporation of both hydrophilic and lipophilic phases allows for the effective delivery of a broad range of active pharmaceutical ingredients (APIs), including poorly water-soluble drugs and natural phytochemicals. [1] Their enhanced permeation through the skin barrier and controlled drug release properties makes them highly suitable for localized therapy in dermatological, analgesic, anti-inflammatory, and cosmetic applications.

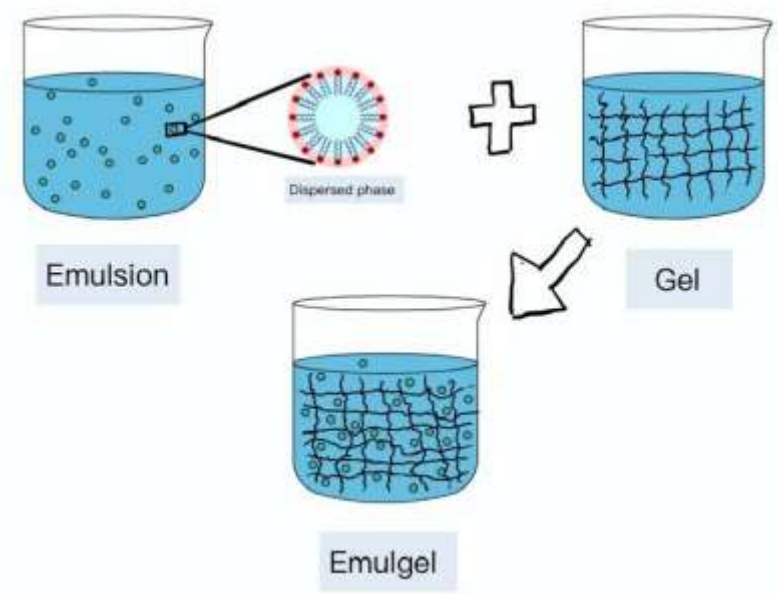


Figure 1. Formulation of Emulgel

The fusion of emulsions and gels into a single delivery system is driven by the limitations posed by each component when used independently. Emulsions, while effective in solubilizing poorly water-soluble drugs, often suffer from physical instability and low viscosity, making them less suitable for direct application. Gels, in contrast, offer excellent consistency, spreadability, and patient compliance, but have limited capacity for incorporating lipophilic drugs. By combining these two systems, emulgels successfully overcome the shortcomings of each. The emulsion phase enables efficient solubilization and dispersion of the drug, while the gel phase stabilizes the formulation and provides desirable mechanical properties. This synergistic combination enhances the overall performance of the formulation, particularly in terms of drug loading capacity, release kinetics, and dermal absorption. [2]

1.2 Role in Modern Pharmaceutical Delivery

Emulgels play an increasingly important role as a platform for localized drug delivery. They address key challenges such as poor solubility, variable bioavailability, and limited patient adherence associated with conventional dosage forms. Emulgels allow for targeted application

directly to the affected area, thereby minimizing systemic side effects and improving the therapeutic index of the drug.

Moreover, advancements in formulation science—such as the use of nanocarriers, penetration enhancers, and biodegradable polymers—have further expanded the capabilities of emulgels. These improvements support their application in a wide range of therapeutic areas, including anti-inflammatory [3], antifungal [4], analgesic [5], and cosmetic treatments [6]. As a result, emulgels have emerged as a valuable tool in the development of safe, effective, and user-friendly topical drug delivery systems.

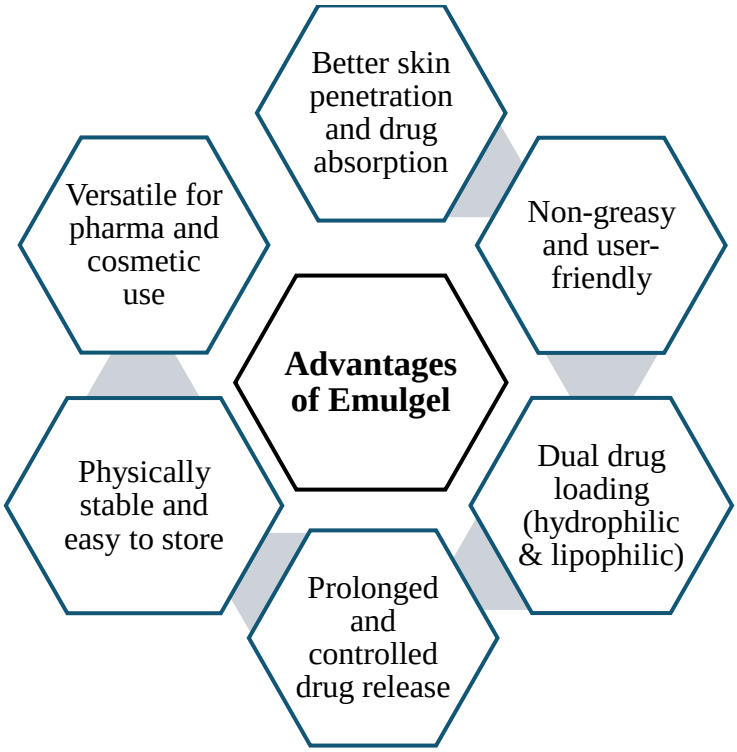


Figure. 2. Advantages of Emulgel

2. Components of Emulgel Formulations

The effectiveness, stability, and user acceptability of an emulgel depend greatly on the selection and compatibility of its key components. Each ingredient contributes a specific functional role in the formulation, from drug solubilization and consistency to skin permeability and therapeutic performance.

S.No	Component	Function	Examples
1	**Gelling Agents**	Provide viscosity, stability, and spreadability to the formulation	Carbopol 934/940, HPMC, Xanthan gum

2	**Emulsifiers & Surfactants**	Stabilize oil-water interface and prevent phase separation	Span 20/80 (lipophilic), Tween 20/80 (hydrophilic), PEG-based surfactants
3	**Oil Phase**	Solubilizes lipophilic drugs, enhances occlusion and skin hydration	Light liquid paraffin, Isopropyl myristate, Coconut oil, Olive oil
4	**Aqueous Phase**	Serves as continuous phase and solubilizes hydrophilic ingredients	Purified water, buffers
5	**Penetration Enhancers**	Increase drug diffusion through the skin barrier	Propylene glycol, Ethanol, DMSO, Eucalyptus oil, Menthol
6	**Active Pharmaceutical Ingredients (APIs)**	Provide therapeutic action; can be synthetic or herbal	Diclofenac, Ketoprofen, Curcumin, Aloe vera, Neem extract

Table. 1. Components of Emulgel Formulations

3. Preparation Emulsion Preparation

The initial stage focuses on creating a stable emulsion. This involves preparing two distinct phases separately: the oil phase and the aqueous phase. The oil phase typically contains lipophilic components such as oils, oil-soluble active pharmaceutical ingredients (APIs), and lipophilic surfactants like Span 80. The aqueous phase consists of water, hydrophilic surfactants like Tween 80, water-soluble APIs, preservatives, and humectants like glycerin. Both phases are heated to a temperature range of 60–70°C to reduce viscosity and interfacial tension. The hot oil phase is then gradually added to the hot aqueous phase under vigorous mechanical stirring (500-3000 RPM) to form an oil-in-water (O/W) emulsion, or vice versa for a water-in-oil (W/O) emulsion. High-shear mixing or homogenization is applied for 15-30 minutes to achieve a fine dispersion with small, uniform droplet size. [7] The formed emulsion is subsequently cooled to room temperature under reduced stirring to prevent droplet coalescence and ensure stability.

3.1 Gel Base Formation

The second stage involves preparing the gel matrix that will hold the emulsion. A suitable gelling agent, such as Carbopol (carbomer), Hydroxypropyl Methylcellulose (HPMC), or sodium alginate, is dispersed into purified water under moderate stirring (600-1000 RPM). This dispersion is continued for 20-60 minutes to ensure complete hydration and swelling of the polymer, resulting in a smooth, lump-free base. For ionic gelling agents like Carbopol, pH adjustment is a critical step; agents such as triethanolamine (TEA) or sodium hydroxide (NaOH) are used to carefully raise the pH to between 5.0 and 7.0. This neutralization ionizes the polymer's carboxylic acid groups, triggering significant thickening and transformation into

a gel. Non-ionic polymers like HPMC gel primarily through hydration and usually do not require pH adjustment. The prepared gel base is often allowed to stand undisturbed, typically for up to 24 hours, to ensure complete polymer hydration, achieve uniform viscosity, and allow entrapped air to escape.

3.2 Final Emulgel Preparation

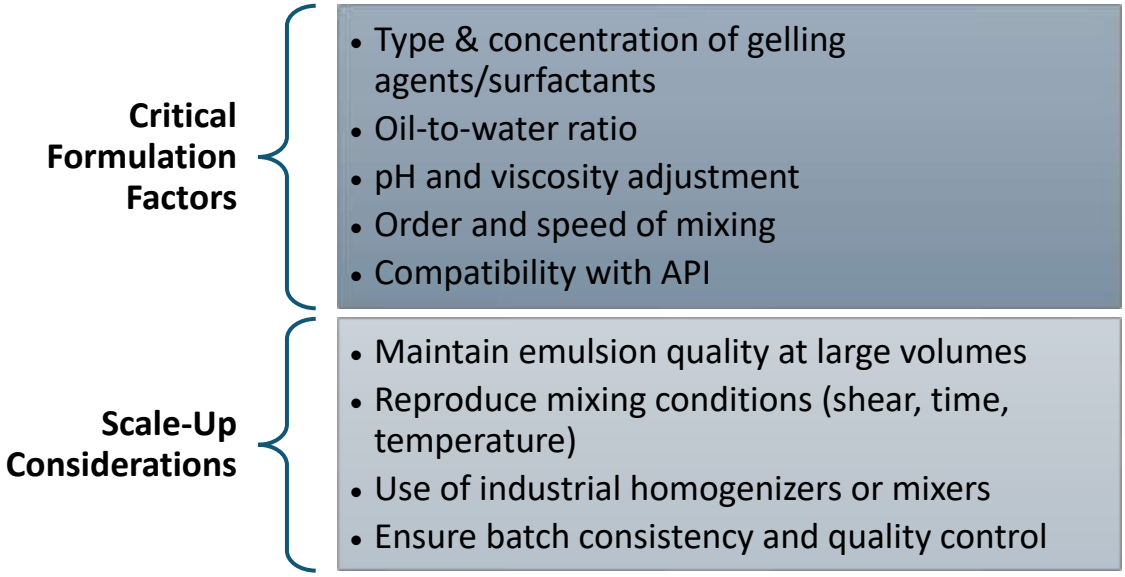
The third stage combines the emulsion and gel base to form the final emulgel. The pre-formed emulsion, constituting typically 10-40% of the final formulation weight, is slowly incorporated into the gel base under gentle, low-shear mixing (200-500 RPM). Careful mixing at this stage is crucial to avoid rupturing the delicate emulsion droplets or incorporating excessive air bubbles. Once the emulsion is fully integrated, the mixture undergoes homogenization (1000-5000 RPM for 10-20 minutes) to ensure a uniform distribution of the emulsion droplets throughout the gel matrix, resulting in a smooth, homogeneous product. Finally, the emulgel may be subjected to deaeration, either by vacuum degassing or allowing it to rest, to remove any residual entrapped air before packaging.

3.2.1 Hot Emulsification Method

The hot emulsification method requires heating both the oil phase and the aqueous phase to an elevated temperature range of 60-80°C before mixing and homogenizing. This heat reduces interfacial tension significantly and enhances surfactant solubility, facilitating the formation of an emulsion with very fine droplet size and improved stability. This method is suitable for active ingredients and excipients that are thermally stable. It is commonly used for conventional drugs like non-steroidal anti-inflammatory drugs (NSAIDs e.g., diclofenac, ibuprofen) or formulations containing waxes, where the heat does not compromise the integrity or efficacy of the components.

3.2.2 Cold Emulsification Method

The cold emulsification method is performed entirely at ambient room temperature (25-30°C), without any heating of the phases. Mixing and homogenization occur under these cooler conditions. This approach is essential for incorporating heat-labile or volatile active ingredients that would degrade, denature, or evaporate if exposed to the elevated temperatures used in the hot method. Examples include certain antibiotics, peptides, enzymes, probiotics, and essential oils (e.g., tea tree oil, eucalyptus oil). While potentially resulting in slightly larger emulsion droplet sizes compared to the hot method, cold emulsification effectively preserves the stability and activity of sensitive compounds and is more energy-efficient. [8]



4. Evaluation Parameters of Emulgels

A thorough evaluation of emulgel formulations is essential to ensure their safety, efficacy, physical stability, and therapeutic performance. The following parameters are commonly assessed during preformulation and quality control stages.

4.1 Physical Evaluation

This includes basic visual and sensory inspections that assess:

- **Appearance:** The formulation should be smooth, uniform, and free from phase separation, lumps, or air bubbles.
- **Color and Odor:** Must be acceptable, consistent, and characteristic of the active ingredient or excipients.
- **pH:** Measured using a digital pH meter to ensure skin compatibility (usually between 5.5 and 7.0).
- **Viscosity:** Evaluated using a viscometer to determine flow behavior, which affects spreadability and drug release. [9]

4.2 Rheological and Spreadability Testing

- **Rheological Studies:** These determine the flow characteristics of the emulgel under stress, ideally showing pseudoplastic (shear-thinning) behavior. This ensures easy application and retention on the skin.
- **Spreadability:** Evaluated by applying a fixed quantity of emulgel between glass plates and measuring the spreading area. Higher spreadability indicates better patient acceptability.

4.3 Drug Content and Homogeneity

- **Drug Content Uniformity:** Determined by dissolving a specific amount of emulgel in a suitable solvent and analyzing the drug using spectrophotometric or chromatographic techniques.
- **Homogeneity:** Visually and microscopically assessed to confirm even distribution of the drug throughout the base.

4.4 In Vitro Drug Release Studies

- Conducted using diffusion cells (e.g., Franz diffusion cell) with a synthetic or semi-permeable membrane.
- Samples are collected over time and analyzed to determine the release profile.
- These studies help predict the drug's behavior once applied to the skin.

4.5 Skin Permeation and Bioadhesion

- **Skin Permeation Studies:** Often performed using excised animal or human skin to evaluate the extent and rate of drug penetration into or through the skin layers.
- **Bioadhesion:** Assessed to determine the emulgel's ability to remain adhered to the skin, which influences residence time and efficacy.

4.6 Stability Studies

- Carried out under accelerated (e.g., 40°C, 75% RH) and real-time conditions as per ICH guidelines.
- Parameters such as appearance, pH, viscosity, and drug content are monitored over time.
- Stability studies help determine the shelf life and optimal storage conditions.

5. Marketed Emulgel Products and Commercial Outlook

Emulgels have gained substantial commercial acceptance in both pharmaceutical and cosmetic markets due to their superior formulation properties and consumer-friendly application. Their ability to deliver both lipophilic and hydrophilic drugs through the skin has led to the successful commercialization of various topical products.

Brand Name	Active Ingredient	Therapeutic Use	Manufacturer
Voltaren Emulgel	Diclofenac diethylamine	Anti-inflammatory, pain relief	Novartis / GSK Consumer Healthcare
Luligee Emulgel	Luliconazole	Antifungal	Glenmark Pharmaceuticals
T-Gel Emulgel	Terbinafine	Antifungal (athlete's foot, etc.)	Cipla

Curcuma Emulgel	Curcumin (herbal)	Anti-inflammatory, antioxidant	Various Ayurvedic/Cosmetic Brands
Aloe Vera Emulgel	Aloe vera extract	Skin hydration, wound healing	Herbal & Cosmetic Companies

Table. 2. Examples of Marketed Emulgel Products

6. Recent Innovations in Emulgel Formulation

The field of emulgel technology has seen notable advancements in recent years, driven by the need for more effective, stable, and patient-friendly drug delivery systems. These innovations focus on improving drug solubility, enhancing skin penetration, enabling targeted delivery, and achieving better therapeutic control.

6.1 Nanoemulgels: Integration of Nanotechnology

One of the most significant advancements in emulgel formulation is the incorporation of nanotechnology, leading to the development of nanoemulgels. These are emulgels in which the emulsion droplet size is reduced to the nanometer scale, typically below 200 nm. This size reduction significantly enhances the surface area, promoting faster and deeper penetration of the drug through the skin barrier. Nanoemulgels are especially useful for poorly soluble or unstable drugs, improving their bioavailability and therapeutic performance. Additionally, they offer improved physical stability, reduced irritation, and the potential for targeted delivery in dermal and transdermal therapies. [10]

6.2 pH-Sensitive and Temperature-Responsive Emulgels

Stimuli-responsive emulgels represent a promising innovation for on-demand drug delivery. These systems are engineered to undergo structural or functional changes in response to environmental triggers such as pH or temperature.

- **pH-sensitive emulgels** are particularly beneficial for targeting inflamed or infected tissues, where local pH levels may differ from normal skin.
- **Thermo-responsive emulgels** undergo sol–gel transitions when exposed to body temperature, allowing ease of application and sustained drug release at the site of action.

6.3 Polymer-Based Controlled Release Systems

The incorporation of advanced polymers in emulgel formulations has enabled controlled and sustained drug delivery. Polymers such as poloxamers, Eudragit, and chitosan are used to modify the rheological and release characteristics of emulgels. These polymers allow drugs to be released over an extended period, reducing the frequency of application and improving patient compliance. Additionally, biodegradable and bioadhesive polymers can enhance the residence time of the formulation on the skin, ensuring prolonged therapeutic action.

6.4 Herbal and Phytochemical-Based Emulgels

The growing interest in natural and plant-based medicines has led to the development of herbal emulgels. These formulations incorporate bioactive phytochemicals with anti-inflammatory, antioxidant, antimicrobial, or wound-healing properties. Herbal extracts such as curcumin, aloe vera, neem, tulsi, and green tea have been successfully used in emulgels for treating various dermatological and inflammatory conditions. This innovation aligns with the demand for safer, eco-friendly, and biocompatible alternatives to synthetic drugs. Furthermore, herbal emulgels often exhibit synergistic effects, combining the therapeutic action of multiple plant compounds in a single formulation.

S.No	Plant Extract	Polymer Used	Biological Activity	Type of Emulgel	Method of Preparation	Reference
1	Aloe vera	Carbopol 934, HPMC	Anti-inflammatory, wound healing	O/W	Emulsion formation + Gel mixing (Stirring)	Sharma et al. (2023) [11]
2	Curcumin (Turmeric)	Carbopol 940, Sodium CMC	Antioxidant, anti-arthritic	O/W	High-shear homogenization + Gel base	Patel et al. (2023) [12]
3	Neem (*Azadirachta indica*)	Poloxamer 407, Carbopol 934	Antimicrobial, antifungal	O/W	Cold method with emulsification	Khan et al. (2022) [13]
4	Tea Tree Oil (*Melaleuca*)	Chitosan, HPMC K4M	Antibacterial, anti-acne	O/W	Homogenization followed by gel integration	Gupta & Singh (2023) [14]
5	Eucalyptus oil	Carbopol 934, PVA	Analgesic, anti-inflammatory	O/W	Stirring method, oil addition to gel base	Joshi et al. (2022) [15]
6	Ginger extract	Xanthan gum, Carbopol 940	Anti-arthritic, analgesic	O/W	Emulsification + Phase inversion technique	Verma et al. (2023) [16]
7	*Calendula officinalis*	Sodium alginate, Carbopol 934	Wound healing, anti-inflammatory	O/W	Aqueous phase + oily phase + gelling	Deshmukh et al. (2022) [17]

8	Clove oil	HPMC, Carbopol 940	Antimicrobial, analgesic	O/W	Ultrasonic emulsification + gel blending	Nair et al. (2023) [18]
9	Lavender oil	Carbopol 934, PVP K30	Antiseptic, soothing effect	O/W	Emulsion mixing + vortexing with gel	Mehta & Sharma (2022) [19]
10	Turmeric & Tulsi	Carbopol 940, HPMC E15	Antibacterial, wound healing	O/W	High-speed homogenization + gentle mixing	Reddy et al. (2023) [20]
11	Basil (*Ocimum sanctum*)	Carbopol 934, HPMC	Antioxidant, antimicrobial	O/W	Oil-in-gel phase addition via stirring	Singh et al. (2023) [21]
12	Fenugreek (*Trigonella foenum*)	Carbopol 940, Xanthan gum	Anti-inflammatory, antioxidant	O/W	Two-step emulsification and gel blending	Raut et al. (2023) [22]
13	Holy Basil (*Ocimum tenuiflorum*)	Carbopol 934, PEG 400	Anti-acne, antimicrobial	O/W	Cold mechanical mixing method	Kumar et al. (2022) [23]
14	Turmeric & Aloe vera	Carbopol 940, HPMC	Anti-inflammatory, skin regeneration	O/W	Phase-wise addition and emulsification	Das et al. (2023) [24]
15	Green Tea (*Camellia sinensis*)	Chitosan, Carbopol 934	Antioxidant, anti-aging	O/W	Nanoemulsion technique + gelling	Banerjee et al. (2022) [25]

Table 3. Recent Advancement in Herbal Emulgel Formulation

7. Future Perspectives

The field of emulgel formulation is advancing rapidly, offering multiple avenues for innovation in drug delivery. While current formulations have demonstrated considerable success in topical therapies, future developments are expected to address more complex therapeutic challenges and expand the scope of clinical utility. Emulgels are well-positioned as next-generation carriers for both synthetic and natural therapeutics, especially for drugs with poor aqueous solubility or those requiring sustained release. Future research may focus on:

- **Site-specific and transdermal delivery** for systemic diseases
- **Incorporation of biologics**, peptides, and gene-based therapies

- **Combination emulgel therapies** for multifactorial skin disorders (e.g., anti-inflammatory + antimicrobial)
- **Use in non-dermatological areas**, such as mucosal drug delivery (e.g., oral, vaginal, or ocular applications)

  The integration of **smart drug delivery systems**, such as nanoemulgels, thermoresponsive gels, or stimuli-sensitive carriers, opens new possibilities for personalized medicine.

8. Conclusion

Emulgels have emerged as a robust and adaptable drug delivery system, effectively bridging the limitations of conventional topical formulations. Their ability to incorporate both hydrophilic and lipophilic drugs, combined with superior spreadability, stability, and patient compliance, has made them an attractive option for localized therapy. The integration of nanotechnology, biodegradable polymers, and herbal extracts has further expanded the scope and utility of emulgels, enabling enhanced drug permeation, targeted action, and sustained release. With growing commercial interest and ongoing research into stimuli-responsive and multifunctional emulgel systems, these formulations are poised to address complex therapeutic needs. As future developments focus on site-specific delivery and the inclusion of biologics or gene therapies, emulgels are likely to play a pivotal role in advancing personalized and effective topical treatments.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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