Formulation and Evaluation of Polymer-Based Paints: A Review

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Abstract

Paints are widely used for protection, decoration and to enhance the durability of the surface. Polymer-based paints have various applications due to their properties such as adhesion, drying time, durability, flexibility and environmental resistance. The formulation of polymer-based paints includes the addition of pigments, solvent, binder, and additives in a definite proportion and then determining their physical properties to gain excellent performance. Evaluation parameters like viscosity, drying time, adhesion, water resistance, pH determination and gloss contribute to paint quality. Recent developments in eco-friendly paints and nanotechnology-based coatings have improved the performance of paint. This review summarizes the formulation and evaluation methods. It also focuses on recent advancements and development of eco-friendly polymer-based paints to reduce environmental impact.

Keywords

Polymer-based paints, paint formulation, paint evaluation, emulsion polymerization, eco-friendly paints, coatings, environmental impact.

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Introduction

Paint is a liquid that adheres to the surface of the object and protects it from any damage or corrosion **[1]**. After the application of the paint on a given surface, it forms a thin solid layer which when dried, becomes indistinguishable from the surface **[2]**. Polymers are the key components of a paint. Polymers are formed by monomers. Monomers are small repeating units which combine to form a long chain, called a polymer **[3]**. These units are not linked in a fixed manner. This factor contributes to the formation of different types of polymers. The types of polymers include, Natural and synthetic polymers. **[4]**

Importance of polymer-based paints: Polymers form a major part in paint formation. The polymers have a variety of properties which make paints durable and strong. The polymer acts as "binders", that hold all the components together and are responsible for the formation of a continuous, evenly distributed film all over the surface **[5]**. Acrylic, epoxy, polyurethane and alkyd polymers are used in paint formulation in industries.

Properties of Paints

The properties of paints **[6]** are explained below-

1) Binding property: The binding nature of a paint helps to put all the constituents together in one place.
2) Adhesion: The property of a paint to adhere to the surface on which it is applied is called adhesion. It helps the paint to stick to the surface.
3) Film formation: The property of a paint to form a film on the surface is called film formation. It is liquid in nature but when applied on the surface, it becomes solid and gets attached to the surface evenly.
4) Durability: The paints are durable in nature and remain intact in the long run.
5) Non-corrosive: The paint is environmentally and human-friendly, and it protects the surface from corrosion.
6) Crack-resistant: The paint protects the surface and does not allow the cracks to develop. It gives a smooth texture.
7) Easy application: When paint is applied on a surface, it becomes smooth and easy to handle. The application process is easy.
8) Gloss enhancement: Paint gives a glossy texture to the surface.
9) Easy to clean: Cleaning a surface becomes easy when paint is applied on it. Stable under different conditions: The paint helps the surface to withstand

various environmental conditions, such as, heat, light, pressure, moisture, etc.

10) Stable under different conditions: The paint helps the surface to withstand various environmental conditions, such as, heat, light, pressure, moisture, etc.

Composition of Polymer-Based Paints

It is known that paint is a solution or mixture formed by different constituents in a definite proportion. These constituents include binder, solvent, pigment, additives, etc. Each of them is explained in detail.

1. Binders: It is one of the most important ingredients of paint. These are polymers that help in binding all the particles together. These are responsible for adhesion. It helps in the formation of a continuous film on the surface **[7].** The binder molecules are dispersed throughout the solution.
2. Pigments*:* Pigments are the substances that impart colour to the paint solution. It is dispersed thoroughly in the coating. It has protective nature that protects the surface film from UV light. These are of various types; namely, organic, inorganic, synthetic, and natural.
3. Solvent: The solvent is a medium in which all the particles get dispersed. The particles include, binders, pigment, and additives. The solvent can be water or any other organic solvent. The main purpose of the solvent is to alter the viscosity of the mixture for proper application. The solvent has evaporating properties, which help in the formation of a solid coating.
4. Additives: These are small substances added in a very small quantities that help in modifying paint properties. These are added in 0.001% to < 5% and have a great impact on physical and chemical properties.

Formulation of Polymer-Based Paints

Polymer-Based paints are formulated by combining binders, solvent, pigment and additives in a desired proportion. Proper formulation leads to uniform dispersion of particles in the mixture and a smooth, homogeneous paint system. The ratio of these components plays an important role in the formation of paint. Any change in this ratio can lead to a change in expected behaviour and properties of the paint.**[8]**

COMPONENT	FUNCTION
Binder	Film formation
Pigment	Colour and opacity
Solvent	Viscosity adjustment
Additives	Improving paint performance

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Emulsion Polymerization and Paint Evaluation

Emulsion Polymerization: It is a widely used technique for preparing water-based polymer paints **[9]**. Emulsion polymerization is a process in which small units, called monomers are polymerized in an aqueous medium in the presence of surfactants and initiators.

This technique helps in the formation of stable emulsions which have controlled particle size, and high molecular weight **[10]**. It is environmentally friendly and efficient as compared to other systems.

Principle of Emulsion Polymerization: It is a free-radical polymerization technique that involves water as the continuous phase and monomers are dispersed as tiny droplets in it. This dispersion takes place with the help of an emulsifying agent or surfactant.

As the reaction proceeds, stable polymer latex particles are formed. These latex particles can be used directly in water-based paints.

Mechanism: Emulsion Polymerization takes place in various steps:

- Initiation
- Particle nucleation
- Propagation
- Termination

For example, acrylic emulsions are prepared by the emulsion polymerization technique, using methyl methacrylate as monomer, butyl acrylate as surfactant in the presence of water, and an initiator.

Application: This process results in the formation of stable polymer latex which acts as a binder in water-based systems and is hence used widely in the paint industry. Emulsion Polymerization helps in the formation of the following paints:

- Acrylic emulsion paints
- Water-based paints
- Industrial coatings
- Protective coatings
- Roof coatings
- Low VOC and eco-friendly paints.

Evaluation of Polymer-based paints: Evaluation parameters help in determining the suitability of paints for different applications.

- **Viscosity:** Determines flow of paint and application properties
- **Drying time:** It is the time required for the formation of film

- **pH:** It affects stability and shelf life
- **Adhesion:** Measures strength of bond between paint and substrate molecules
- **Water resistance:** Evaluates resistance against moisture
- **Gloss:** Evaluates shine of the surface

PARAMETER	IMPORTANCE
Viscosity	Flow behaviour
Drying time	Film formation
pH	Stability
Adhesion	Surface bonding
Water resistance	Moisture protection
Gloss	Smooth, shiny surface

Recent Advances in Polymer-Based Paints

Recent researchers have focused on the development of nanotechnology in polymer-based paints **[11]**. Nanoparticles such as silica, zinc oxide and titanium dioxide are added to improve the strength of paint. These types of coatings show better scratch resistance. Various smart coatings are also developed. These respond to different environmental factors. Smart coatings such as, self-healing coatings can repair small cracks themselves; self-cleaning coatings and antimicrobial coatings clean themselves and avoid formation of microparticles **[12]**.

Eco-friendly polymer-based paints:

Eco-friendly paints are developed to reduce environmental pollution. The paints that contain low volatile organic compounds (low VOCs) are promoted over other paints **[13]**. Water-based polymer paints are of this type. Acrylic latex paints are used widely in the formulation of eco-friendly paints. Studies include bio-based polymers formed from renewable sources like vegetable oil and natural polymers **[14]**. As a whole, eco-friendly paints provide good adhesion properties, high durability and low toxicity to make them suitable for use. Their protective nature, durability, moisture-resistance, heat-resistance, and aesthetic properties make them suitable for use in every field in modern coating technologies **[15].**

Environmental Impact

Paints play an important role in day-to-day life but their formulation and application properties affect the environment in both positive and negative ways. The environmental impact due to paint, depends on the raw materials used in their formulation; mainly, solvents, pigments, additives etc. **[16]**

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Environmental Concerns: The environmental concerns of paint include-

Solid waste generation

- Leftover containers and paint come under solid waste which is harmful to the environment.
- When disposal is not performed properly, it leads to soil contamination.

Water Pollution

- Washing of paint brushes and disposal of leftover paint may enter into water bodies and contaminate them.
- It can harm aquatic life due to the presence of harmful chemicals.
- Introduction of paint residues in water may increase the chemical content and disturb pH levels.

Emission of Volatile Organic Compounds (VOCs)

Traditional paints consist of organic solvents that release VOCs into the atmosphere during drying time. These compounds are very harmful to the atmosphere and have a negative impact on the environment **[16]**. They are responsible for-

- Air pollution
- Respiratory health issues
- Formation of smog in air
- Nasal irritation

Use of Toxic Pigments

Some paints contain heavy toxic elements such as, lead and chromium. These metals have a huge impact on both human health and the environment.

Measures to reduce Environmental Impact:

The list of measures to reduce this impact includes the following-

- Use of water-based paints instead of conventional paints.
- Proper disposal of paint leftovers.
- Disposal of solid waste in a proper way
- Replacing toxic chemicals with eco-friendly paints.
- Development of low VOCs or zero VOCs formulations.

Applications of Polymer-Based Paints

Polymer-based paints have a wide range of applications due to their durability, adhesion, chemical resistance, shorter drying time and environmental sustainability. These are used in industries **[17]**, automobiles, protective **[18]** & decorative purposes **[19]**, and advanced coatings **[20].**

S. No	Area of Application	Type of polymer paint	Description	Advantages
1.	Industrial coatings	Epoxy paint	Used in factory floors & machinery	Strong adhesion & High chemical bonding
2.	Automative Industry	Polyurethane paint	Used in car bodies & parts	Glossy finish
3.	Residential buildings	Acrylic Emulsion paint	Interior & exterior walls	Easy application & eco-friendly
4.	Metal protection	Epoxy coatings	Applied on pipelines, bridges	Prevents rusting
5.	Packaging industry	Polymer coatings	Food containers & packaging	Non-toxic, Moisture resistant
6.	Decorative applications	Emulsion paint	Aesthetic wall finishes	Variety of colours & textures
7.	Commercial Buildings	Latex Paint	Applied on offices, malls, etc.	Fast drying and durable

From the above table, it can be concluded that polymer-based paints play an important role in various sectors due to their properties **[21]**. Their protective nature, durability, moisture resistance, heat resistance, and aesthetic properties make them suitable for use in every field in modern coating technologies **[22].**

Future Scope

- Development of eco-friendly paints.
- Use of modern technologies, nanotechnology and smart coating techniques to improve the performance of paint.
- Usage of advanced materials for formulation.
- Increase resistance towards heat, light and moisture.
- Development of paints with low or zero VOCs.
- Weather testing & long-term durability tests should be included for better evaluation.
- Usage of self- cleaning coatings.

Conclusion

Polymer-based paints have become an important part of modern coating technology. Their properties like excellent adhesion, durability, flexibility and film formation make them versatile in nature. The formulation of paint involves the addition of binders, solvents, pigment and additives. Performance is evaluated by measuring viscosity, drying time, adhesion, gloss and water resistance. This paper

provides an idea about the Emulsion Polymerization technique and its contribution to the formation of polymer latex which is used in water-based paints. Recent advancements have taken place in nanotechnology and eco-friendly coatings, which have improved the performance of polymer-based paints. The Environmental impact of paints and preventive measures to reduce the impact are also explained in this paper. Future scope of this review is also mentioned and development of eco-friendly paints is promoted through this study. Hence, future developments should focus on green coatings and sustainable materials for the formation of paints.

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