Asian Journal of
Science, Technology, Engineering, and Art

e-ISSN: 3025-4507
p-ISSN: 3025-5287
Index: Harvard, Boston, Sydney University, Dimensions, Lens, Scilit, Semantic, Google, etc

https://doi.org/10.58578/AJSTEA.v3i5.7210

Effect of pH on Microbial Growth and Performance of Paint Produced Using Gum Arabic as a Binder

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Jul 23, 2025	Aug 18, 2025	Aug 30, 2025	Sep 5, 2025

Abstract

This study investigates the use of gum Arabic as a natural binder in emulsion paint, with particular focus on the influence of pH levels on its physical properties and microbial resistance. Paint formulations were adjusted to pH values ranging from 7.11 to 11.16. Results showed that increasing pH reduced paint density and viscosity, while drying time, scrub resistance, and coverage remained largely unaffected. Microbiological analysis revealed significant bacterial growth, including *Bacillus*, *Pseudomonas*, and *Staphylococcus* species at pH 7.11, whereas no microbial activity was observed at higher pH levels, indicating that pH regulation plays a critical role in minimizing microbial contamination. These findings highlight gum Arabic's potential as an eco-friendly and sustainable alternative to synthetic binders in paint production. However, the study also emphasizes the importance of incorporating complementary preservation strategies, as long-term microbial resistance under varying environmental conditions may require the addition of natural or synthetic preservatives or synergistic use of other natural compounds. Overall, gum Arabic offers promise for greener industrial applications when coupled with optimized pH control and preservation measures.

Keywords: Gum Arabic; Paint Binder; pH Effect; Physical Properties; Microbial Resistance

INTRODUCTION

Paint can be defined as a mixture of pigments, binders, and solvents that form a continuous film that can be decorative or protective (Abdulsalam, 2015). Paint products are commonplace commodities that are used for aesthetic purposes and protection purposes. Paint has been in production since prehistoric times. It is one of the earliest on record for the early man producing some form of synthetic substance for personal use (Abdulsalam & Maiwada, 2016). On the other hand, emulsion paints "water-based paints", were not as frequently used at the time. The water-based paints became more frequent during the twentieth century (Malshe, 2019; Zhao, 2017). The waterborne paints had advantages to the oil-based paints, they were safer and more environmentally friendly. Mainly because the paints possessed low flammability and contained few or zero volatile organic compounds (VOCs) and hazardous air pollutants (HAP) emissions (Abu et al., 2022). Emulsion paint is water-based paint that coats the internal and external surfaces of a building. The quality and performance of emulsion paints are highly dependent on their constituent components, such as binders, pigment solvents, and additives. In the constituents for the production of emulsion house paints, prime pigment (titanium dioxide) and binder (PVA) usually takes between 50 to 70% total cost of production depending on paint type and this raw material are not available locally, therefore imported. Hence, high cost of these materials (PVA and Titanium dioxide) and consequently high cost of production due to the use of expensive binder and prime pigment (Malshe, 2019).

The binder in paint plays an important role in attaching the pigment to the surface of the object being painted and becoming a continuous film. The type and amount of binder used in paint affects performance factors such as durability, stain resistance, adhesion, and crack resistance. In general, the higher the ratio of binder to pigment, the higher the paint quality. Commonly used binders in emulsion paints are water-dispersed binders such as polyvinyl acetate (PVA) and styrene acrylic, known in the paint industry as synthetic latex (Afolabi et al., 2019). Poly (vinyl acetate) (PVA), is one of such binders commonly used for emulsion paint formulation. Contrariwise, paints derived from PVA are characterized by poor water, chemical and water resistances, flexibility, gloss and durability etc. (Akpoguma, 2018). Therefore, if these properties are to be improved, the PVA must be modified with a locally sourced material whose property can make the needed correction. Hence, the purpose of choosing gum Arabic as that optimizer. In the study by Billstein, 2022, emulsion paints were produced by partially replacing the synthetic binders with a locally sourced sustainable material; gum Arabic (Acacia Senegal). Their study showed that the emulsion paints produced resulted in high quality paint products (Dauqan & Abdullah, 2013) noted that at 100%replacement of the synthetic binder (PVA), the paint failed to meet the required standard.

This work investigated emulsion paint formulated with gum Arabic as a binder, revealing the significant influence of pH on the paint's physical and microbial properties. Specifically, higher pH resulted in lower paint density and viscosity, while drying time, scrub resistance, and coverage remained relatively stable. Notably, a pH of 7.11 exhibited heightened susceptibility to bacterial contamination, with varying growth patterns observed for Bacillus, Pseudomonas, and Staphylococcus species. Thus, while gum Arabic offers a viable, eco-friendly binder, maintaining appropriate pH levels is crucial for both optimizing physical characteristics and effectively controlling microbial growth, necessitating tailored antimicrobial strategies based on anticipated environmental conditions.

MATERIALS AND METHODS

Materials

The materials used for producing emulsion paint met laboratory standards, with Gum Arabic serving as the binder. Tap water was sourced from the Chemical Engineering Laboratory at the University of Maiduguri, while distilled water was procured from the Maiduguri Water Treatment Plant in Borno State.

Sample Collection and Preparation

Samples of Gum Arabic were purchased from the Maiduguri Monday Market in Maiduguri, Borno State. The crude Gum Arabic was sorted to remove impurities. The sample was then ground into a fine powder and passed through a 212 µm mesh screen. The prepared sample was placed in containers and stored at room temperature. To produce a 65% wt/v solution, 1.2 kg of the ground Gum Arabic powder was dissolved in 1L of distilled water for 24 hours (Malshe, 2019).

Reagents Used

The reagents and chemicals used were analytical grade purchased from Monday market, Maiduguri, Borno State. The reagents are as follows; calcium carbonate ($CaCO_3$), titanium dioxide (TiO_2), Ammonia (NH_3), formalin, and natrosol.

Experimental procedure

0.5L of water was measured into a reaction pot, the stirrer was then switched on. 75g of calcium carbonate ($CaCO_3$) was added and mixed thoroughly at 300rpm for 5 minutes. After mixing, 125g of titanium dioxide (TiO_2) was added and mixed at 300rpm for 5 minutes. 22.5g of natrosol was then gradually added to the mixture and thoroughly mixed. 0.625g of Calgon was added to the mixture. Formalin 12.5g was then added into the mixture and was mixed thoroughly. Processed gum Arabic sample was added and mixed thoroughly at 300rpm. Three separate aliquots of ammonia were added to the base mixture. The resulting three paint formulations contained varying concentrations of ammonia. The pH of each sample was adjusted to 7, 9, and 11 using formalin and ammonia (Malshe, 2019).

Microbial Colony Growth Test

The microbial colony growth test for paint made with Gum Arabic as a binder involves a systematic procedure to detect and quantify microbial contamination. To begin, the paint sample is diluted with 90 mL of sterile water to achieve a manageable concentration, allowing for accurate counting and colony formation. Nutrient agar, prepared with 20 grams of agar powder per liter of distilled water, is sterilized via autoclaving at 121°C for 15 minutes to ensure a sterile medium. After cooling, the agar is poured into sterile Petri dishes (approximately 20 mL per dish) and allowed to solidify. Following dilution, 1 mL of the prepared paint sample is inoculated onto the agar surface using sterile swabs or pipettes, ensuring even distribution across the medium. These inoculated plates are then incubated at an optimal temperature of 27°C for 24 hours. After incubation, plates are examined for microbial growth, with colonies counted and characterized based on morphology. Results are recorded as colony-forming units (CFUs) per milliliter of the paint sample, providing a clear measure of microbial contamination levels. Process is repeated for all three samples (Malshe, 2019).

RESULTS

Table 1 shows the result comparison of the physical properties of formulated emulsion paint with different pH values.

Table 1: physical properties of formulated emulsion paint with pH of 7.11, 9.30 and 11.16

Properties	$pH_{7.11}$	$pH_{9.3}$	$pH_{11.16}$
Density (g/cm3)	1.31	1.27	1.21
Viscosity (poise)	5.54	5.32	5.02
Drying time(min)	36	34	35
Scrub resistance (cycles)	47	46	46
Coverage Area (m^2/L)	5.89	5.85	6.02
Block resistance	6	6	5

Three samples underwent a microbial colony growth test to assess bacterial contamination. Among them, only the sample with a pH of 7.11 exhibited bacterial growth. Growth rates and data collected for this sample, which displayed colonies of Bacillus, Pseudomonas, and Staphylococcus over a four-month period, are detailed in the table below. This assessment highlights the sample's unique susceptibility to bacterial contamination due to its optimal pH conditions. This finding is consistent with reports that near-neutral pH values generally provide favorable conditions for microbial proliferation, as most bacteria thrive between pH 6.5 and 7.5 (Prescott et al., 2008). Comparable observations were made by Madigan et al. (2015), who highlighted that deviations toward acidic or alkaline conditions often restrict bacterial growth due to enzyme inactivation and disruption of cell membrane integrity. Similarly, a study by Oyetayo and Akinyosoye (2004) found that bacterial contaminants in food and environmental samples exhibited optimal growth in samples with neutral to slightly alkaline pH values. Furthermore, the observation that samples outside this pH range did not show bacterial growth aligns with findings by

Nascimento et al. (2017), who demonstrated that microbial survival and colony formation are significantly reduced under acidic or basic conditions.

These results suggest that maintaining pH outside the neutral zone may serve as a natural barrier to microbial contamination, supporting earlier studies by Lambert and Stratford (1999), which reported that acidification and alkalinization are effective preservation strategies against bacterial growth.

Table 2: Growth Rate Test (Bacillus) Of Formulated Emulsion Paint With pH of 7.11

Weeks	Colony Count	Dilution Factor	CFU/mL	Growth Phase
3	0	0	0	No Activity
6	20	10^{-3}	$3.6 * 10^{4}$	Initial Growth Phase (lag)
9	40	10^{-4}	$4.2 * 10^{4}$	Initial Growth Phase (lag)
12	85	10^{-4}	$8.5 * 10^{5}$	Exponential Growth Phase

Table 3: Growth Rate Analysis (Pseudomonas) Of Formulated Emulsion Paint With pH of 7.11

Weeks	Colony Count	Dilution Factor	CFU/mL	Growth Phase
3	0	0	0	No Activity
6	30	10^{-3}	$3.0 * 10^{4}$	Initial Growth Phase (lag)
9	55	10^{-4}	$8.2 * 10^{4}$	Exponential Growth Phase
12	90	10^{-4}	$9.0 * 10^{5}$	Continued Exponential Growth

Table 4: Growth Rate Analysis (Staphylococcus) Of Formulated Emulsion Paint With pH of 7.11

Weeks	Colony Count	Dilution Factor	CFU/mL	Growth Phase
3	0	0	0	No Activity
6	20	10^{-3}	$2.0 * 10^4$	Initial Growth Phase (lag)
9	40	10^{-4}	$7.2 * 10^4$	Moderate Growth Phase
12	65	10^{-4}	$6.0 * 10^5$	Exponential Growth Phase

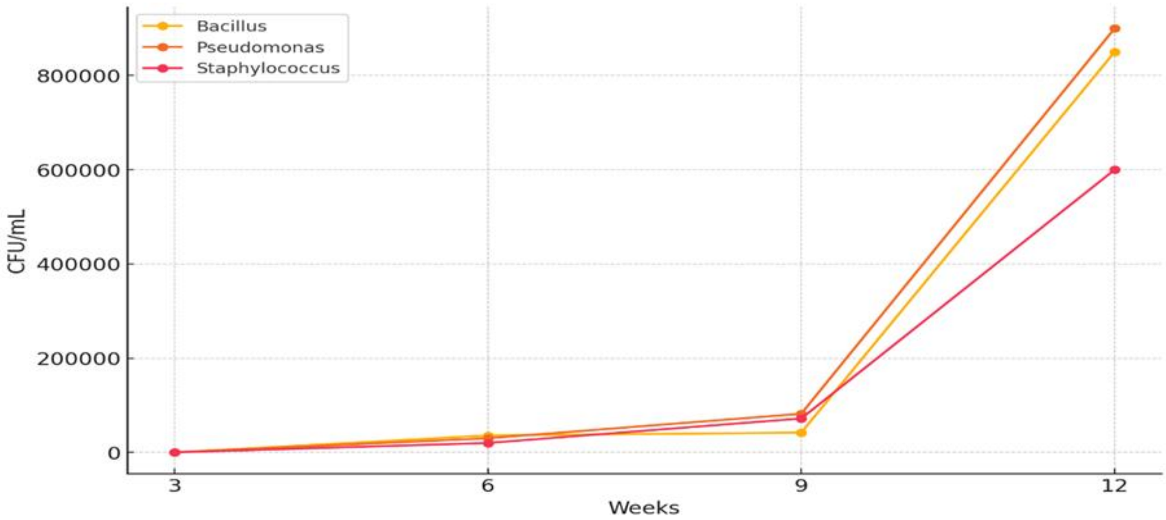

Figure 1: Rate of Microbial Growth in Base Samples with pH of 7.11

DISCUSSION

Physical Properties

The results from Table 1 indicate that pH significantly affects the density and viscosity of the formulated emulsion paint. As the pH increases from 7.11 to 11.16, both density and viscosity decrease, which aligns with the trend observed in the literature where higher pH leads to reduced molecular interactions in emulsion systems, thereby lowering viscosity and density. For instance, studies have shown that in water-based formulations, an increase in pH can disrupt hydrogen bonding, leading to a decrease in viscosity (Osemeahon et al., 2013). However, the drying time, scrub resistance, and coverage area showed minimal variation across the pH range, suggesting that these properties are less sensitive to pH changes. This finding contrasts with some research where pH was found to affect the drying rate due to changes in the rate of water evaporation or film formation (Ibrahim et al., 2022), but our results indicate consistency, possibly due to the specific composition of our paint formulation.

Microbial Growth

The microbial growth analysis in Tables 2, 3, and 4 for Bacillus, Pseudomonas, and Staphylococcus in the paint at pH 7.11 shows a clear pattern of exponential growth after an initial lag phase, which is consistent with microbial growth dynamics in nutrient-rich environments. The pH of 7.11, being near neutral, provides an optimal environment for microbial proliferation, as noted in various studies which highlight that most bacteria prefer near-neutral pH for optimal growth (Ibrahim et al., 2022; Idris, 2017; Allen et al., 2004). The growth patterns observed differ among the species, with Bacillus and Pseudomonas showing a more pronounced lag phase before entering exponential growth, while Staphylococcus had a more gradual increase, indicating different adaptation speeds to the paint environment.

Comparatively, research on similar systems has shown that microbial degradation in paints is not only pH-dependent but also influenced by the presence of nutrients from the paint components (Lawal et al., 2019). Our findings are in line with these studies, showing that at a pH closer to neutral, microbial growth is significantly enhanced. However, in contrast to some reports where higher pH environments (alkaline) were effective in inhibiting bacterial growth (Rodrigues et al., 2022; Lelon et al., 2010), our paint formulation at pH 7.11 did not exhibit such inhibition, suggesting that the specific formulation or the presence of other components might counteract the expected antimicrobial effect of pH.

The uniqueness of our results compared to others might be due to the specific composition of the emulsion paint used, which could offer different nutrients or conditions for microbial growth, or perhaps the bacteria strains used in our study are particularly adapted or resistant to typical biocidal conditions in paints. Future studies could explore the interaction between pH, paint composition, and microbial resistance more deeply, perhaps by altering the formulation or testing with a broader range of microbial species.

This discussion of results underlines the complexity of paint formulation where physical properties and microbial resistance must be balanced to ensure product quality and longevity. The findings suggest that for paints formulated at lower pH values, additional preservatives or alternative strategies might be necessary to control microbial growth effectively.

CONCLUSION

This study explored the formulation of emulsion paint using gum arabic as a binder, with a specific focus on how pH affects the paint's physical properties and microbial resistance. Gum arabic was chosen for its local availability, cost-effectiveness, and environmental benefits. The results demonstrated that pH significantly impacts the paint's density and viscosity, with higher pH values leading to less dense and less viscous paint. However, the drying time, scrub resistance, and coverage were relatively consistent across different pH levels, suggesting these properties are less sensitive to pH variations.

Microbial growth tests indicated that at a pH of 7.11, the paint was particularly susceptible to bacterial contamination, showing growth of Bacillus, Pseudomonas, and Staphylococcus after an initial lag phase. This highlights that while gum arabic serves as an effective, natural binder, the pH of the paint formulation plays a crucial role in microbial control. The growth patterns varied among bacterial species, with Bacillus and Pseudomonas exhibiting a more pronounced lag phase before exponential growth, while Staphylococcus showed a moderate, steady increase, underscoring the need for tailored microbial strategies based on expected environmental conditions.

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