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Research Article

Impact of Phase Inversion and Process Parameters on Alkyd Emulsion Properties

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Abstract

In conventional alkyd coatings, the alkyd resin is dissolved in organic solvents, such as mineral spirits. However, due to growing health and environmental concerns, there is a rising interest in waterborne alkyd coatings. Alkyd emulsions, therefore, represent a viable alternative. Waterborne alkyd resins significantly reduce VOC emissions by using water as the dispersion medium, making them highly important for research in this area. The main objective of this study is to synthesize emulsified alkyd resins by replacing solvents with water, using nonionic and anionic surfactants, for the alkyd resins widely used in the paint industry for many years. Soybean oil/sunflower oil alkyd resins were emulsified with the anionic surfactant MAXEMUL 7201 and the nonionic MAXEMUL 7101. This paper investigates the effect of emulsification temperature, mixer model and rotation speed on the formation of alkyd emulsion The synthesized alkyd resins were evaluated based on acid value, viscosity, gloss, Fourier transform infrared spectroscopy (FTIR), gel permeation chromatography (GPC), and particle size analysis.

Keywords: *Water-borne, Emulsion formation, Alkyd resins, Emulsification, Coating*

1. Introduction

The term alkyd resin was initially introduced by Kienle in the United States, describing a polyester resin synthesized through the condensation polymerization of polyols, polyacids, and fatty acids as the key raw materials. Its raw materials are readily available and do not depend on non-renewable resources such as petroleum [1]. Alkyd resins are frequently utilized as binders in surface coatings due to their distinctive properties, such as excellent color and gloss retention, film flexibility, durability, and strong adhesion [2, 3]. Today, there is an increasing need to protect the environment from degradation to ensure sustainable development, addressing the needs and aspirations of both current and future generations. With the expansion of the world economy, there has been a gradual increase in public awareness of environmental protection. Governments have introduced numerous regulations to control volatile organic compounds (VOCs) emissions in the coatings industry, leading to restrictions on solvent-based coatings. As a result, researchers have begun to explore alkyd systems with low or zero VOCs [4-6].

The challenge faced by paint chemists and technologists is how to reduce the VOC content in coatings. As a result, coating chemists and technologists are transitioning to more environmentally friendly technologies that offer performance similar to solvent-based coatings. These technologies have led to the development of water-based, high-solids, powder, and radiation-cured coatings, which combine excellent coating properties with improved environmental sustainability [2, 7-9]. The targeted alkyd emulsion is designed to comply with the European Union Directive 2004/42/EC and achieve performance values comparable to solvent-based alkyd resin equivalents. The developed products will be evaluated in glossy, satin, and matte paints to ensure they meet the required performance characteristics. Currently, several firms in Europe produce alkyd emulsions, whereas domestic production remains limited, with only a few companies manufacturing unspecified formulations. These international manufacturers synthesize alkyd emulsions using conventional long, medium, and short oil alkyds, as well as modified alkyds, and introduce them to the market [10].

Water-based coatings are becoming increasingly economically attractive due to the low cost of water and the limited application scope of other coating types. Therefore, studying the waterborne properties of alkyd resin is crucial. However, waterborne alkyd resins face several challenges, including slow drying of the paint film, poor water resistance, and limited storage stability of the resin [11, 12]. As a result, research on the technical modification of waterborne alkyd resins holds significant practical importance. A summary of the benefits and drawbacks of the waterborne system is presented in Figure 1 [13]. The choice of alkyd resin plays a crucial role in the emulsification process. Unlike solvent-based air-drying alkyds, emulsification requires specifically formulated alkyd resins with well-selected raw materials. The use of fatty acids instead of oils is essential, as oils contain glycerides that can undergo hydrolysis in water-based alkyd emulsion systems. Similarly, glycerin, a common component in alkyd synthesis, is unsuitable for emulsification due to its susceptibility to hydrolysis. Research suggests that using isophthalic acid instead of phthalic anhydride results in hydrolysis-resistant alkyd resins, contributing to a more stable and high-performance alkyd emulsion [14, 15]. Waterborne alkyds are of two types: one based on alkyd oils with high acid values that become water-soluble after neutralization, and the other where the alkyd oil is dispersed in water and stabilized by a surfactant or built-in stabilizing groups [16, 17]. Alkyd resin emulsions are formed by dispersing the alkyd resin in water. At the start, alkyd emulsion paints form films similarly to other coatings. However, due to their low molecular weight and glass transition temperature, the viscosity of alkyd particles is much lower than that of acrylic latex paints. The transition from oil-in-water to water-in-oil emulsion occurs easily, often passing through a metastable state. Once water evaporates, the binder droplets merge, forming a continuous alkyd film, similar to that of conventional solvent-based alkyd paints [4, 18]. Alkyds used for industrial coatings have significantly higher viscosity compared to those used in consumer paints, requiring a specialized emulsification technique to produce finely dispersed emulsions. Alkyd resins are synthesized through a polycondensation reaction of vegetable oils or fatty acids with polyfunctional carboxylic acids and polyhydric alcohols. The oil percentage, raw material selection, and molar ratios significantly affect alkyd resin performance. This study aims to investigate the effects of phase inversion and process parameters on alkyd emulsion properties. By systematically analyzing the impact of surfactant selection, emulsification temperature, and mixing conditions, we seek to enhance the stability and performance of alkyd emulsions. The findings will contribute to the development of eco-friendly alkyd-based coatings with properties comparable to solvent-based counterparts, ensuring a balance between sustainability and high performance.

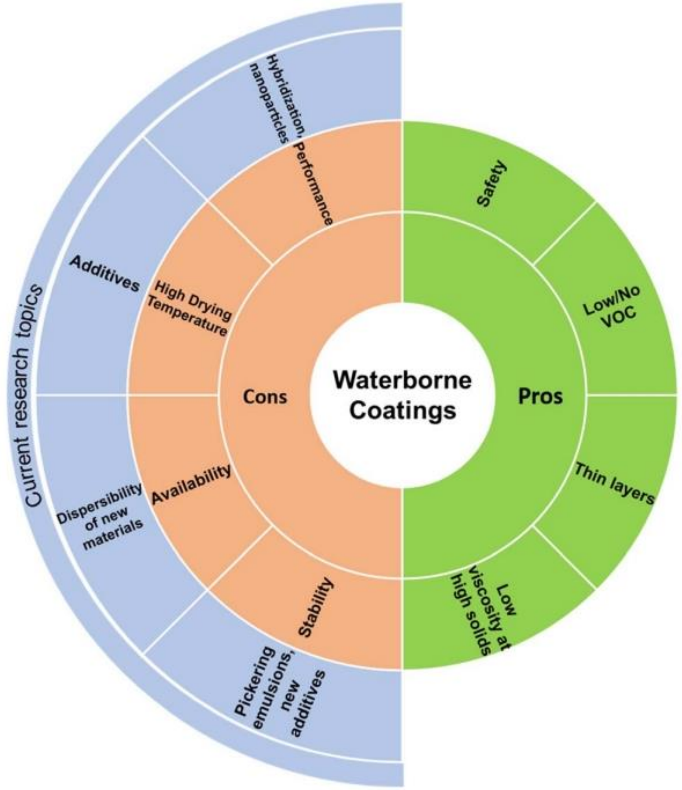

Figure 1: Advantages and Disadvantages of Waterborne Coating Systems Compared to Alternative Technologies [13]

2. Materials and Methods

In this study, laboratory grade pentaerythritol, glycerol, phthalic anhydride, benzoic acid, soybean /sunflower oil, potassium hydroxide (KOH) in water solution at 40 % weight ratio was used for the synthesis of alkyd emulsion. MAXEMUL 7201 was used as anionic surfactant and MAXEMUL 7101 was used as nonionic polymeric emulsifier.

2.1. Synthesis of Alkyd Resins:

Alkyd resins are synthesized through a polycondensation reaction of vegetable oils or fatty acids with polyfunctional carboxylic acids and polyhydric alcohols. The oil percentage, raw material selection, and molar ratios significantly impact alkyd resin performance. This project proposes emulsifying traditionally solvent-based alkyd resins using nonionic and anionic surfactants, replacing the solvent with water. For synthesis Process: Fatty acids, polyhydric alcohols, and polycarboxylic acids are loaded into a 5-liter reaction flask equipped with a stirrer, condenser, and water separation system. Esterification is conducted at 200-250 °C, with water removal facilitated by azeotropic distillation using xylene. Once the desired acid and viscosity values are achieved, the mixture is cooled.

2.1.1. Long-oil Alkyd Resin

The alkyds were synthesized using various types of drying fatty acids, polyhydric alcohols, and mono- and dicarboxylic acids. The alkyd resins are designated as T62 D70 and F65 W70, both formulated with a solid content ranging from 95-100 %. These resins have been specifically developed for use in construction coatings, offering versatile applications in glossy, semi-matte, and matte satin wall paints.

2.2.2. Medium- Oil Alkyd Resin

This alkyd resin is named F49 WX55 and was prepared with a solid content of 95-100 %. A key characteristic of this alkyd is its significantly higher viscosity compared to long-oil alkyds, as well as its faster drying time. This resin was specifically developed for use in construction paints where rapid drying is required. It is suitable for applications such as topcoats for metal parts, garden gates, as well as for use in glossy, semi-matte, and matte satin wall paints. Its ability to provide both fast drying and versatile finish options makes it an excellent choice for a range of coating applications, especially in environments where speed and efficiency are essential.

2.2.3. Surfactant Selection

Nonionic surfactants consist of a hydrophilic polymerized alkene oxide (typically 10-100 units long) and a lipophilic segment. Since this work focuses on oil-in-water (O/W) emulsions, surfactants with a hydrophilic-lipophilic balance (HLB) of 17 will be used.

2.3. Determination of Emulsification Temperature

The viscosity values of alkyds are particularly important for emulsification. Alkyds with very high viscosity need to be heated in order to be emulsified more easily and successfully. As shown in the graph below, the temperature at which heating is required is determined by plotting the Temperature-Viscosity change curves, which were generated using the Cap 2000+ Cone & Plate Viscosity device. The viscosity as a function of the temperature is shown in Figure 2.

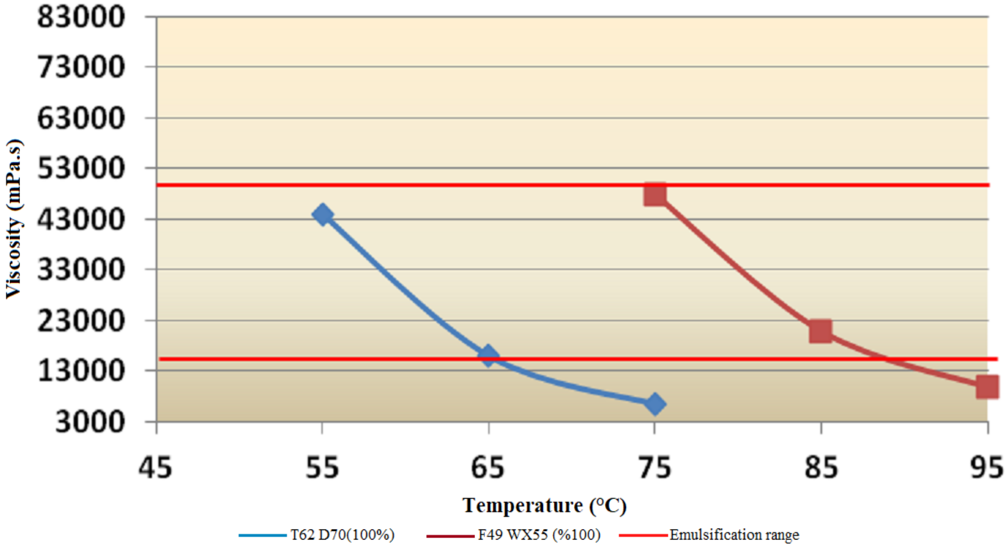

Figure 2. Temperature-Viscosity Change Curve of Long and Medium-Oil Alkyd Resins

2.4. Preparation of Alkyd Emulsion

Approximately 250 grams of alkyd resin were weighed and placed in a 500 ml jacketed glass reactor, heated to around 60 °C (or the specified temperature). The system was stirred at 175 rpm (~0.8 m/s) (or the specified speed). A KOH solution was added to neutralize at least 40 % of the alkyd's acid groups, and the mixture was stirred for 30 minutes. Nonionic and anionic surfactants were added and stirred for 30 minutes. Demineralized water, pre-heated to the emulsification temperature, was added to the reactor at a specified flow rate while stirring. After water addition, stirring continued for 10 more minutes. The mixture was then cooled, filtered, and discharged. The phase inversion methodology for an alkyd resin is schematically represented in Figure 3.

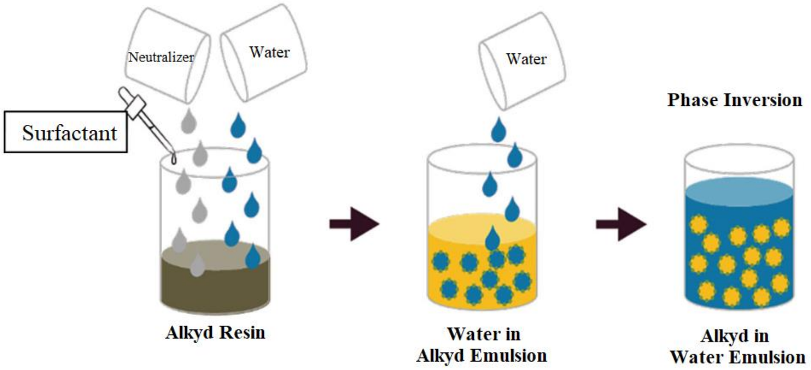

Figure 3. Schematic of alkyd resin phase inversion methodology

2.5. Preparation of Water Based Paint

2.5.1. Mill-Base-Disperse Stage (Paste Preparation)

In this study, foam breaker and disperser agents were added to the paint mixing process. Initially, the required amount of foam breaker and disperser agent was weighed and added to the mixing container. Then, the mixture was stirred in a disperser at 800 rpm using a 4 cm diameter dissolver disk. During the mixing process, titanium dioxide was added. After the additions were completed, the rotation speed was increased to 2000 rpm. Subsequently, the rheology agent was added and stirring speed was raised to 2400 rpm. The mixing process was continued until the crushing (Hegman) value decreased below 10 microns.

2.5.2. Let Down (Sub-Additions)

The mixer speed was reduced to 1000-1500 rpm and the alkyd emulsion was added. Some more defoamer and spreading agent were added and mixed for ~10 minutes and filtered.

2.6. Characterization

Determination of acid number:

Acid values were determined according to ASTM D -1639 standard. Approximately 1 gram of the sample was weighed into a 300 mL Erlenmeyer flask. A 100 mL mixture of neutral ethanol/toluene was added and heated to dissolve the sample. After cooling, a few drops of phenolphthalein were added, and the solution was titrated with 0.1 N KOH to a pink endpoint. The acid value is calculated using the following equation [19]:

$$AV = \frac{V_{KOH} \times M_{KOH} \times C_{KOH}}{m \times N.V.C}$$

AV: Acid value; V_{KOH}: volume of KOH solution introduced to neutralize the alkyd resin (mL); M_{KOH}: molar mass of KOH (g⁄mol); C_{KOH}: concentration of KOH (mol⁄mL); m: mass of alkyd resin with draw (g); N.V. C.: nonvolatile Content.

Viscosity Determination:

The final viscosities of the alkyds were measured using a Brookfield DV-1 Viscometer and Gardner viscosity tubes in accordance with ASTM D-1545.

Gloss Measurement:

The gloss of the coatings was determined using a Micro Tri Gloss. A smooth, dry film of the paint was applied to a substrate, and the gloss was measured at a 20°, 60° or 85°, depending on the desired level of gloss. The device records the amount of light reflected from the surface, providing a quantitative value of the surface gloss.

Particle size analysis:

The particle size of the materials was measured using a laser based particle size analyzer, namely a Malvern MSS Mastersizer 2000 Ver. 5.54 [20].

Molecular weight determination:

The molecular weight of the formulated alkyd resins was determined using a Waters gel permeation chromatography (GPC) system. The analysis was conducted at ambient temperature with tetrahydrofuran serving as the eluent. Linear polystyrene was utilized for calibration, and the data was analyzed using Waters Empower software.

Hardness Test was determined with Koenig SC1-L1 (TS 4317). The tests applied to resins were drying time (TS 11338/TS 4317), solid content (ASTM D-1259), gloss (TS 4318 EN ISO 2318).

3. Results

The results of FTIR analysis of modified alkyd resins (F49 WX55) are presented in Figure 4.

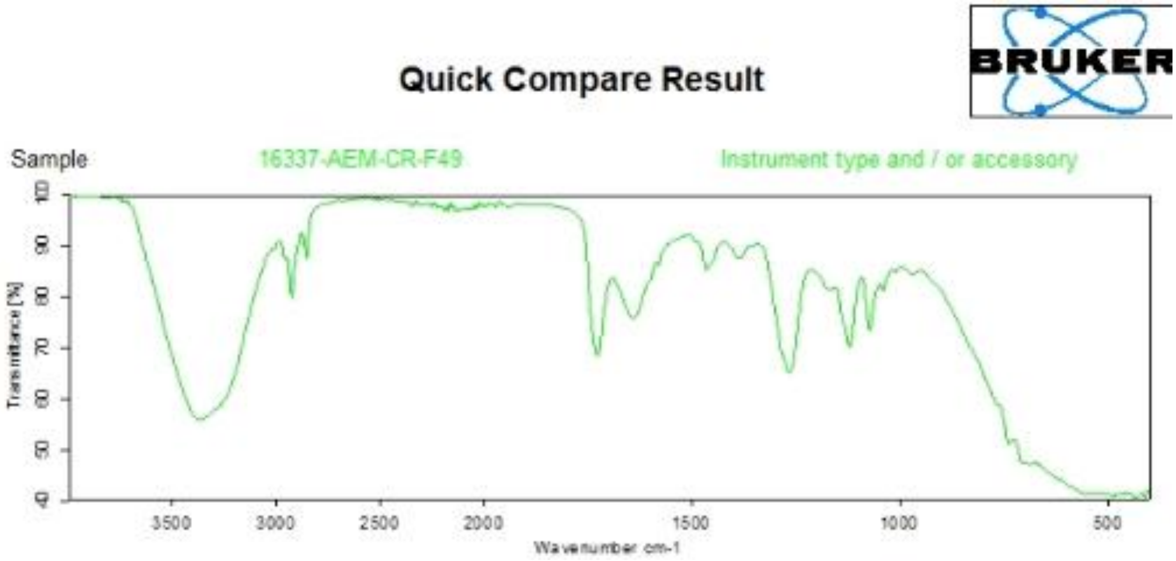

Figure 4. fourier transform infrared spectrum of F49 WX55 alkyd resin

The prominent absorption peak at 3455 cm^{-1} corresponds to the valence vibration of the free hydroxyl group (-OH) present in the pentaerythritol structure of unsaturated fatty acids in sunflower oil. The absorption band at 3010 cm^{-1} is attributed to the non-conjugated double bond of the -C=C- group found in linoleic acid from soybean oil. The strong absorption peak at 1732 cm^{-1} is indicative of the presence of the carbonyl (C=O) functional group. The absorption band at 1122 cm^{-1} is associated with the -CO group bonded to the phenyl radical. The peak observed at 1582 cm^{-1} is characteristic of the -C=C- bond in the aromatic ring of phthalic anhydride. Finally, the peak at 1270 cm^{-1} is related to the ester (-COO-) functional group. The aforementioned analyses collectively demonstrated that the synthetics of alkyd resin was successful.

Resin emulsification:

The characteristics of emulsions are influenced by numerous factors, including the properties of the dispersed resin and surfactants, as well as the method and conditions of emulsification. Emulsions are prone to alterations over time, and a key requirement for maintaining robust colloidal stability is the formation of fine droplets with a narrow particle size distribution [7, 12, 21]. Phase inversion refers to a process in which a dispersion of one liquid's droplets within another undergoes a morphological change, where the droplets coalesce to form the continuous phase, while the original continuous phase becomes dispersed as droplets [22]. This method enables the formation of fine emulsions with small particle sizes and is commonly employed for the emulsification of viscous resins, as the resin can be efficiently heated to the desired temperature [7, 23, 24]. During the emulsification process, several parameters (such as emulsification temperature, water addition time, mixer speed, blade type, water temperature, and surfactant concentration) were varied to observe their effect on the final outcome. The analysis results of F49 WX55, which was synthesized as a medium oil alkyd without adding solvent, are given in Table 1.

Table 1: Specifications of F49 WX55 alkyd resin

Tests	***Reference Method***	***Target***	***Result***
Solid content, %	IS0 3251 (15 min., 160 °C)	98-100	~98
Acid value (mgKOH/g)	ISO 2114	10 max	6.1
Viscosity (Gardner at 25 ˚C, 55 % WS/X)	ASTM D 1545	75-95	84
Color (Gardner- 50 %)	ISO 4630-2	Max 5	3.6
Through-drying	TS 4317, ASTM D-1640	1-2	1:45

Emulsification and paint studies were conducted, starting with experiments to evaluate the effect of surfactant concentration. The objective was to minimize surfactant usage while achieving stable, unimodal particle size distribution, as surfactants significantly impact resin costs. The emulsification of F49 WX55 (100 % solids) was tested at various temperatures, surfactant concentrations, and water addition rates. Five alkyd emulsion formulations were prepared, and successful emulsions were converted into paint. The following tests were performed: particle size analysis, emulsion stability (+50 °C for 1 month and freeze-thaw cycling), dynamic viscosity, pH measurement, König hardness, and gloss. Table 2 shows the alkyd emulsion test results using the same alkyd at different parameters.

Table 2. Overall evaluation of F49 WX55 formulation

	1	**2**	**3**	**4**	**5**
F49 WX55	50.0	50.0	50.0	50.0	50.0
Anionic surfactant	1.53	1.56	1.56	1.77	1.77
Nonionic surfactant	1.52	1.54	1.54	1.78	1.77
KOH	0.11	0.11	0.11	0.11	0.11
Pure water	46.9	46.8	46.9	46.4	46.4
Homogenization (°C)	85	80	85	85	85
Mixing time (hour)	0.5	0.5	0.5	0.5	0.5
Emulsification (°C)	85	80	85-75	85	85
Surfactant (wt % on resin)	6.1	6.2	6.1	7.1	7.1
Surfactant ratio (anionic/nonionic)	1:1	1:1	1:1	1:1	1:1
Watering time (ml/min)	1.6 Stable	0.4-1.6 Increasing	1.6 Intermittent	1.6 Stable	1.6 Stable
Particle size (nm)					
d (0,5)	536	428	416	328	299
d (0,9)	895	818	821	633	677
Width	1.23	1.66	1.72	1.46	1.87
Shape	Monomodal	Bimodal	Bimodal	Monomodal	Monomodal
Viscosity (mPa.s)	181	173	255	301	334
Spindle	RV1	RV1	RV1	RV1	RV1
Speed (rpm)	20	20	20	20	20
pH	5.06	5.14	5.02	4.93	5.51

Alkyd emulsions 2 and 3 contain the same amount of surfactant, but their water addition times are different. Alkyd emulsion 4 has the best particle size and shows a narrow distribution. Alkyd emulsion 5 is a repetition of emulsion 4. According to the test results, alkyd emulsion 4 yielded the best results. It has been determined that optimization occurred with a 7 % surfactant content (based on the resin). Next, alkyd emulsion 4 was used to prepare a paint formulation. The drying, gloss, and König hardness test results of the paint were analyzed. The results are shown in Table 3. Specifically, optimal emulsification temperatures around 70 °C, surfactant concentrations of approximately 7 %, and controlled water addition rates have been shown to improve phase stability and particle size distribution. The use of anionic and nonionic surfactants in a balanced ratio enhances the emulsion’s durability and resistance to phase separation.

Table 3. Test results of paint made with F49 WX55 100 % formulation

	Drying Time			***Gloss (6 day)***		***König hardness (day)***		
Sample	Touch	Hard	Through	20 °	60 °	10	20	30
F49 WX55	0:30	1:30	4:40	73.9	90.7	28	38	50

Long-oil alkyds were synthesized as 100 % solids using the phase inversion method for emulsification and subsequent paint studies. The analysis results of the T62 D70, synthesized without solvent, are presented in the Table 4.

Table 4. T62 D70 alkyd analysis results

Tests	***Reference Method***	***Target***	***Result***
Solid content ,%	IS0 3251 (15 min., 160 °C)	98-100	98.5
Acid value (mgKOH/g)	ISO 2114	10 max	7.8
Viscosity (Gardner at 25˚C, 70 % D40)	ASTM D 1545	80-110	85
Color (Gardner- 50 %)	ISO 4630-2	Max 7	5
Through-drying	TS 4317, ASTM D-1640	4-6	5:30

The aim of the experiments was to minimize the amount of surfactant used while achieving a stable and monomodal particle size distribution. The test results of the alkyd emulsions are given in Table 5. According to the test results, alkyd emulsions 1 and 2 have large particle sizes, which is due to the high emulsification temperature. The best result was obtained with an alkyd emulsion containing 7 % surfactant at 40 °C. Based on this, alkyd emulsion 3 was selected, and two different paints were prepared by creating paint formulations.

Table 5. Overall evaluation of T62 D70 formulation

	1	**2**	**3**	**4**	**5**	**6**
T62 D70	50.0 %	50.0 %	50.0 %	50.0 %	50.0 %	50.0 %
Anionic surfactant	1.64	1.52	1.76	1.51	1.51	1.76
Nonionic surfactant	1.58	1.51	1.75	1.51	1.51	1.81
KOH	0.18	0.18	0.18	0.18	0.18	0.18
Pure water	46.7	46.8	46.3	46.8	46.8	46.3

Homogenization (°C)	60	60	60	60	60	60
Mixing time (hour)	0.5	0.5	0.5	0.5	0.5	0.5
Emulsification (°C)	60	50	50-40	40	50-40	50-40
Surfactant (wt% on resin)	6.5	6.1	7.0	6.0	6.0	7.1
Surfactant ratio (anionic/nonionic)	1:1	1:1	1:1	1:1	1:1	1:1
Watering time (ml/min)	1.6 Stable	0.4-1.6 Increasing	1.6 Intermittent	1.6 Stable	1.6 Intermittent	1.6 Intermittent
Particle size (nm)						
d (0,5)	4293	3411	183	2225	441	173
d (0,9)	6539	5039	483	3382	1649	426
Width	0.88	0.81	2.18	0.83	3.52	1.99
Shape	Mono modal	Mono modal	Mono modal	Mono modal	Bio modal	Mono modal
Viscosity (mPa.s)	38660	55730	213	49060	550	321
Spindle	RV3	RV3	RV1	RV3	RV3	RV1
Speed (rpm)	1.5	1.5	20	1.5	20	20
pH	5.13	5.95	5.91	6.06	5.97	6.02

The drying, gloss, and König hardness test values of the resulting paints were examined. These results are given in Table 6.

Table 6. Test results of paint made with F49 WX55 100 % formulation

	Drying Time			***Gloss (6.day)***		***König hardness (day)***		
Sample	Touch	Hard	Through	20 °	60 °	10	20	30
15132 AEM-CR_T62 / paint (type 1 dryer O421A)	1:00	1:50	3:40	71.2	87.2	30	38	54
15132 AEM-CR_T62 / paint (type 2 dryer AVWX)	1:00	2:10	7:00	79.8	89.3	28	42	60

Additionally, the effects of temperature, mixer model and rotation speed on alkyd emulsion performance in the alkyd emulsion process were investigated. According to the results given in the Table 7, 70 °C has been determined as the optimal emulsification temperature due to the stability of the particle size and the unimodal shape of the peak.

The optimal mixer type was found to be Intermig. Additionally, a stable particle size distribution was achieved in the experiment conducted at a speed of 170 rpm.

Table 7. Effect results of temperature, mixer model and rotation speed on alkyd emulsification process

Emulsification (°C)	***85***	***80***	***75***	***70***	***65***
d (0,5)	750	600	590	530	530
d (0,9)	1330	1030	1030	960	980
Width	1.25	1.32	1.46	1.37	1.43
Shape	Monomodal	Monomodal	Bimodal	Monomodal	Monomodal
Mixer model	***Intermig***	***Viscoprop***	***4 wing***	***Wingjet***	***Paravisc***
d (0,5)	650	580	420	300	480
d (0,9)	930	1020	950	1040	980
Width	0.77	1.36	1.91	2.99	1.68
Shape	Monomodal	Bimodal	Bimodal	Bimodal	Bimodal
Rotation speed	***175***	***170***	***150***	***-***	***-***
d (0,5)	590	570	520		
d (0,9)	1020	1050	1000		
Width	1.40	1.31	1.55		
Shape	Bimodal	Monomodal	Monomodal		

The alkyd emulsions obtained from different types of alkyd resins were stored at room temperature for one week and visually checked for phase separation. Samples without phase formation were selected, and their particle sizes were tested. These emulsions were then stored in a +50 °C oven for one month. After storage, phase formation and particle sizes were retested. The results, shown in the table 8, indicate no phase formation but some variations in particle size distribution. After storage in freeze-thaw tests at -10 °C, all samples were observed to degradation in different ways during the first cycle. To address this issue, it is recommended to add propylene glycol as an antifreeze.

Table 8. Particle size analysis of alkyd emulsions before and after stabilization

Sample	***1***	***2***	***3***	***4***	***5***
+50 ˚C Before Stability					
d (0,5)	748	602	587	532	526
d (0,9)	1327	1033	1017	962	978
Width	1.25	1.32	1.40	1.37	1.43
Shape	Monomodal	Monomodal	Bimodal	Monomodal	Monomodal

+50 ˚C After Stability					
d (0,5)	696	587	623	479	538
d (0,9)	1471	1082	142352	1490	1013
Width	1.63	1.29	228.210	2.65	1.55
Shape	Monomodal	Monomodal	Bimodal	Monomodal	Bimodal
-10 ˚C Stabilite:	Deterioration in the 1st cycle	Deterioration in the 1st cycle	Deterioration in the 1st cycle	Deterioration in the 1st cycle	Deterioration in the 1st cycle

Molecular weights of polymer resins are one of the important parameters affecting emulsification. The polydispersion index indicates the uniform molecular mass level of polymers. The molecular weights of emulsified F49 WX55 (Medium Oil) and F65 W70 (Long Oil) alkyds were determined by gel permeation chromatography (GPC) analysis. Typical narrow molecular weight distributions for alkyd resins were detected. According to the analysis results (Table 9), it is seen that F49 WX55 has a higher molecular weight and a higher polydispersity index value than F65 W70. Molecular weights affect the emulsion properties of alkyds (drying, hardness, impact resistance). Furthermore, molecular weight distribution and polydispersity index (PDI) have been identified as key factors affecting film formation and mechanical properties. Emulsions with a narrower molecular weight distribution exhibited improved gloss, adhesion, and hardness. GPC results confirmed that medium-oil alkyd resins provide better film properties due to their higher molecular weight and balanced hydrophilic-lipophilic properties.

Table 9. GPC analysis results of long oil and medium oil alkyd emulsions

Sample	**F49 WX55**	**F65 W70**
M_w (Weight Average Molecular Weight)	3412	2997
M_n (Number Average Molecular Weight)	1643	1535
PDI=M_w/M_n	2.08	1.95

Additionally, further investigations into crosslinking agents and drying accelerators could help mitigate the slow drying times associated with waterborne alkyd resins, leading to enhanced performance in various environmental conditions.

4. Discussion and Conclusion

Waterborne alkyd resins have emerged as a viable alternative to solvent-based coatings, driven by environmental regulations and the demand for sustainable materials. The findings of this study highlight the significance of optimizing emulsification parameters, surfactant selection, and formulation techniques to achieve stable and high-performance alkyd emulsions. Through phase inversion techniques and careful control of process parameters, it is possible to produce waterborne alkyd coatings with desirable properties, such as improved drying time, good film formation, and enhanced stability. The experimental results demonstrate that the choice of emulsification temperature, surfactant concentration, and water addition method play crucial roles in determining the final emulsion quality. The successful development of waterborne alkyd resins will contribute to reducing dependence on organic solvents, lowering VOC emissions, and promoting the use of sustainable coatings. Future studies should focus on further improving the mechanical properties and long-term durability of waterborne alkyd coatings to ensure their widespread adoption in industrial and consumer applications.

5. Acknowledge

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