HUNGARIAN JOURNAL OF
INDUSTRY AND CHEMISTRY
Vol. 54(2) pp. 95–103 (2026)
hjic.mk.uni-pannon.hu
DOI: 10.33927/hjic-2026-32

CHARACTERISTICS OF WHITE INK FOR A GARMENT IDENTIFICATION NUMBERING PRINTER USING MIXED SURFACTANTS

CHOLHUN CHOE[1], YUNSONG PAEK[1]*, GYONGMIN HWANG[2], ILGYONG PAK[1], KYONGNAM KANG[1] JUN HYOK HWANG[3], UI SONG JU[4], GANG CHOL PAK[5], CHOL JIN PAK[5] AND GYONG SONG CHOE[6]

1 Department of Material Science and Engineering, Pyongyang Han Dok Su University of Light Industry, Pyongyang, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
2 Department of Life Science, University of Science, Pyongyang, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
3 Department of Life Science, Kim Hyong Jik University of Education, Pyongyang, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
4 Department of Land and Environment Science, Sariwon Kye Ung Sang University of Agriculture, Sariwon, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
5 Department of Public Catering, Pyongyang Jang Chol Gu University of Commerce, Pyongyang, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA
6 Department of Distance Education, Pyongyang Agricultural University, Pyongyang, DEMOCRATIC PEOPLE'S REPUBLIC OF KOREA

This study was conducted to manufacture white ink for a numbering printer used for garment identification in the production of clothing products using mixed surfactants and to improve its characteristics. The ink used titanium dioxide as a colorant and paraffin oil as a vehicle. The ratio of colorant to vehicle was 1:3. Among the lipophilic surfactants Span-40, Span-60, Span-80, and Span-85 and the hydrophilic surfactants Tween-80 and OP-10, the most suitable lipophilic and hydrophilic surfactants for ink manufacture were selected, and experiments were conducted to determine the contents that best improved the ink characteristics. Span-60 (sorbitan monostearate) was found to be the most suitable lipophilic surfactant, and Tween-80 (polyoxyethylene sorbitan monooleate) was the most suitable hydrophilic surfactant. When the content of Span-60 was 0.2%, the dispersion stability was the highest at 192 h, and when the content of Tween-80 was around 0.4%, washability was the highest. To improve the number identification performance of the ink, rosin was used, and when the content was 0.9% or more, numbers could be identified even on light-colored fabrics. The characteristics of the finally manufactured ink were as follows: the average particle size was 0.603 μm, the viscosity was 631.4 mPa·s, and the structural recovery time was 1.5 to 1.7 s.

Keywords: mixed surfactants, numbering printer, cut piece, identification number, white ink

1. Introduction

In sewing processes in which dozens to hundreds of pieces of the same product are processed, cut pieces from the same spread/lay must be assembled together to prevent color variation in the final product. To ensure that cut pieces from the same product are correctly matched during sewing, a numbering process is carried out according to the layering sequence of the spread.

The numbering machine is designed to be low-effort, easy to operate, and capable of continuous numbering. By using it, production efficiency can be significantly improved with less labor. The numbering part of the machine features a convex plate with six digits, and with each press, it automatically rotates to imprint sequential numbers from 000001 to 999999.

Titanium dioxide is used in the manufacture of white ink for this cut-piece identification numbering machine.

Generally, printing ink is a stable suspension – a complex dispersion system in which fine colloidal particles (the dispersed phase) are uniformly distributed within a liquid (the dispersion medium). The composition of printing ink influences properties such as print quality, fastness, color strength, and ink penetration [1]. The fundamental components of printing ink are the vehicle and the colorant. The vehicle consists of solvents, binders, and additives, while the colorant is the pigment or, more generally, the coloring agent [2]. Coloring agents are divided into inorganic and organic pigments. Among inorganic pigments, titanium white (titanium dioxide) is the most widely used white pigment. Titanium dioxide is extensively utilized in pigments, inks,

Received: 14 Feb 2026; Revised: 31 March 2026;
Accepted: 1 Apr 2026
*Correspondence: pys18846835015@163.com

cosmetics, and the pharmaceutical industry because of its high whiteness, gloss, refractive index, and excellent dispersion stability [3].

An important characteristic of printing ink is its flow behavior. The flow properties of printing ink encompass viscosity, yield value, thixotropy, and flow degree [4]. Ink is a complex dispersion system based on pigments and a vehicle, containing various auxiliary materials. The stability of dispersion systems like emulsions or suspensions is enhanced by the electrostatic and steric-hindrance effects of ionic or nonionic surfactants [5]. Surfactants can be used individually or as mixtures of several surfactants. Recent research indicates that mixed surfactant systems exhibit superior properties compared to single surfactants and improve product performance [6],[7]. Most industries use mixed surfactants rather than pure ones. When mixing water and oil, using a blend of nonionic surfactants with significantly different hydrophilic-lipophilic balance (HLB) values leads to better solubility **Hiba! A hivatkozási forrás nem található.**,[9]. Commercially available surfactants are often mixtures of various types with different hydrocarbon chain lengths [10]. For example, detergents also use mixed surfactants composed of two or more surfactants rather than a single one. Mixed surfactants are employed for emulsification, wetting, and dispersion in pharmaceuticals, enhanced oil recovery, and water-based paint production, and there are instances of their use in printing ink manufacturing by blending two or more surfactants [11],[12]. Due to its specific requirements, the white ink for cut-piece identification numbering machines must allow the printed numbers to be discernible even on light-colored fabrics and be easily removable immediately if contamination occurs during the work process.

Based on this, we propose a method for manufacturing white ink for cut-piece identification numbering machines by using a blend of lipophilic (hydrophobic) and hydrophilic surfactants. The purpose of this research is to study the manufacturing method and the characteristics of the white ink for cut-piece identification numbering machines utilizing mixed surfactants.

2. Experimental

2.1. Materials

Paraffin oil (density: 0.87 g/cm³, viscosity: 84 mPa·s, pour point: –17.5°C) was used as the vehicle. Titanium dioxide (density: 3.9 g/cm³, refractive index: 2.52, hiding power: 0.012 g/cm²) was selected as the white pigment because it is non-toxic and possesses excellent properties, including high whiteness and hiding power **Hiba! A hivatkozási forrás nem található.**,**Hiba! A hivatkozási forrás nem található.**. *Table 1* lists the characteristics of several white pigments.

As surfactants, Span-40, Span-60, Span-80, Span-85, Tween-80, and OP-10 (analytical grade) were used. Rosin was employed as the binder.

Table 1: Properties of white pigments

Pigment type	Specific gravity	Refractive index	Hiding power (g·m⁻²)	Melting point (°C)
Titanium dioxide (1111-2), Anatase	3.9	2.52	120–150	1858
Titanium dioxide (1111-2), Rutile	4.2	2.71	200	—
Zinc oxide (46)	5.47–5.61	—	—	1800
Basic lead carbonate (1107)	6.14	1.99–2.04	—	—
Lithopone (1116)	4.3 (ZnS 29.1%)	1.7–2.3	Greater than that of ZnO and basic lead carbonate	—

For the ink color-characteristic tests, black Dacron fabric (plain weave, warp density: 508 threads/10 cm, weft density: 428 threads/10 cm, size: 5 cm × 5 cm) and blue Dacron fabric (plain weave, warp density: 468 threads/10 cm, weft density: 276 threads/10 cm) were utilized.

2.2. Methods

2.2.1. *Manufacturing method of ink*

Span-60 (sorbitan monostearate, a lipophilic surfactant) and Tween-80 (polyoxyethylene sorbitan monooleate, a hydrophilic surfactant) were added to the oil phase in an amount corresponding to 1/5 of the total paraffin quantity required for the ink formulation. This mixture was heated to approximately 60 °C and stirred continuously until the surfactants were completely dissolved and a uniform oil phase was formed. Subsequently, rosin resin was added, and the temperature was raised to about 80 °C to ensure complete dissolution of the resin in the surfactant-modified paraffin oil. Concurrently, the remaining 4/5 of the paraffin was premixed with titanium dioxide (TiO_2) pigment powder to obtain a pigment-containing oil phase. Both the surfactant-containing oil phase and the TiO_2-containing oil phase were transferred to a high-speed shear dispersion device. The mixture was then subjected to high-speed dispersion at 2,500 rpm for 10 minutes [15].

2.2.2. *Measurement of surface morphology and particle size of the ink*

The surface morphology of the samples was analyzed using scanning electron microscopy (SEM) in secondary electron (SE) mode at an acceleration voltage of 20 kV, a working distance (WD) of 10 mm, and a magnification of ×5,000.

The particle size of the ink was measured using a Nano Laser Particle Size Analyzer BT-90 **Hiba! A hivatkozási forrás nem található.**.

2.2.3. Measurement of ink dispersion stability

The dispersion stability of the ink was assessed by filling a test tube with 10 cm of ink. The time required for complete separation of the pigment layer and the oil layer at room temperature was measured over a specified period by visual observation. A longer separation time indicates greater dispersion stability [17].

2.2.4. Measurement of ink color characteristics

The ink was stamped onto Dacron fabric to create a spot approximately 2 cm in diameter. Using a spectrophotometer and the direct tristimulus-value measurement method, the CIELAB (1976) color-space coordinates were recorded: lightness (L*), chromaticity (a, b), chroma (C^*_{ab}), and hue angle (H^*_{ab}). Color differences were calculated using the following equations [18],[19].

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1),$$

$$\Delta L^* = L^*_2 - L^*_1 \quad (2),$$

$$\Delta C^*_{ab} = C^*_{ab2} - C^*_{ab1} \quad (3),$$

$$\Delta H^*_{ab} = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2} \quad (4),$$

where ΔE^*_{ab} is a total color difference, ΔL^* is a brightness difference, ΔC^*_{ab} is a chroma difference and ΔH^*_{ab} is a hue difference.

2.2.5. Measurement of ink washability

To quantify ink washability, a cleaning process was performed. The contaminated substrate (Dacron fabric) was scrubbed with a clean, damp cloth of the same material using a consistent physical force. Cleaning efficiency (D) was calculated based on the lightness index (L^*) of the substrate measured with a spectrophotometer, using the following formula [20].

$$D = \frac{L^*_2 - L^*_1}{L^*_0 - L^*_1} \times 100 \quad (5),$$

where D is a washability, L^*_0 is a lightness of base cloth, L^*_1 is a lightness of the contaminated area and L^*_2 is a lightness of contaminated area after washing.

2.2.6. Measurement of ink viscosity

First, the shear stress corresponding to the shear rate was measured using a rotational viscometer, the "RHEOTEST-2."

A 25 mL sample of ink was placed into the sample container (S1/S) of the viscometer. The container was then secured within the fixed frame, which had been pre-fitted with the rotor. Using the viscometer with the installed sample container, the shear stress corresponding to the shear rate was measured.

The shear rate was gradually increased from 1.5 s^{-1} to 1312 s^{-1}. At each stage, the dial reading (α) indicating the shear stress was recorded.

As the shear rate was increased, the α value was measured. This value was multiplied by the container constant to calculate the shear stress (σ) at the corresponding shear rate.

$$\sigma = \alpha \cdot z \quad (6),$$

where σ is the shear stress (Pa), α is the instrument reading (μA), and z is the constant of the sample container. Subsequently, a curve depicting the change in the ink's shear stress as a function of shear rate was plotted. The viscosity was determined from the function obtained by extrapolating the linear portion (Newtonian region II) of the graph to the shear-stress axis [21].

$$y = \eta x + \sigma_0 \quad (7),$$

where η (Pa·s) denotes the apparent viscosity and σ_0 denotes the yield stress (Pa).

2.2.7. Measurement of structural recovery time

A 25 mL sample was taken and placed into the sample container (S1/S) of the rotational viscometer. The sample container was then fixed into the holder, which had been pre-fitted with the rotor. Subsequently, the viscosity value was measured at the maximum point (shear rate, 72.9 s^{-1}). The shear rate was then decreased until it reached a stop point, where it was held for 5 minutes. After this hold, the shear rate was increased again from the minimum point (shear rate, 1.5 s^{-1}). The time required for the viscosity to recover to the viscosity value at the maximum point was measured to determine the structural recovery time [3],[22] (*Figure 1*).

The viscosity was calculated using the following equation:

$$\eta = \sigma_r \cdot 100/D_r \quad (8),$$

where η is the viscosity, σ_r is the shear stress, and D_r is the shear rate.

3. Results and analysis

3.1. Effect of dispersants on the dispersion Stability of the pigment

3.1.1. Selection of the dispersant

As the vehicle is an oil, a sorbitan fatty acid ester, a lipophilic surfactant, was used as the dispersant. To select the dispersant, the dispersion stability of the pigment

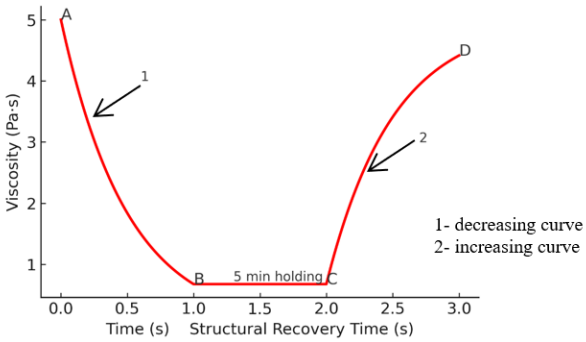


Figure 1: Recovery of the structure over time

Table 2: Dispersion stability as affected by different types of dispersants

Dispersant type	Span-40	Span-60	Span-80	Span-85
Dispersion stability (h)	78	127	114	105

according to the type of dispersant was investigated; the results are presented in *Table 2*.

As shown in *Table 2*, among the lipophilic surfactants, Span-60 exhibited the highest dispersion stability, at 127 h.

This can be attributed to the better compatibility of Span-60 with the paraffin oil-based vehicle, likely because its hydrocarbon chain length and lipophilicity are more closely matched to those of the oil than those of the other Span surfactants. Nonionic sorbitan fatty acid esters are known to adsorb onto pigment particle surfaces, thereby reducing van der Waals attraction forces between particles and imparting steric stabilization that inhibits agglomeration. In particular, Span-60 possesses a saturated C18 chain, which strengthens its interaction with paraffin oil. Consequently, it can form a more stable adsorption layer on the TiO_2 particle surface. This trend is consistent with previous research findings that the chain structure and lipophilicity of nonionic surfactants govern pigment dispersion stability [23],[24].

Therefore, in this study, Span-60, which demonstrated the highest dispersion stability, was selected as the lipophilic surfactant.

3.1.2. Effect of Span-60 content on the dispersion stability of the pigment

Inks were prepared by varying the Span-60 content within a range of 0.10–0.25% of the total formulation, and their dispersion stability was evaluated. The results are presented in *Figure 2*.

As shown in *Figure 2*, dispersion stability increased significantly with increasing Span-60 content, reaching 192 h at a concentration of 0.20%, while no further increase in dispersion stability was observed above 0.20%.

This result is attributed to surfactant adsorption saturation. As the Span-60 concentration increased, the adsorption layer covering the TiO_2 particle surfaces

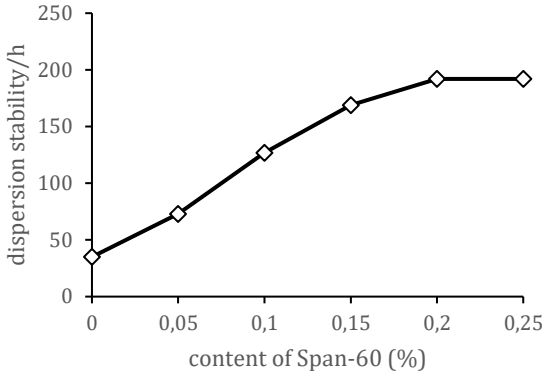


Figure 2: Dispersion stability according to the content of Span-60

became progressively more complete, effectively inhibiting direct contact between particles. However, beyond a certain critical concentration, the particle surfaces became saturated with surfactant molecules, limiting any additional stabilizing effect. This concentration-dependent stabilization behavior, leading to a plateau, is a commonly reported phenomenon in pigment dispersion systems using nonionic surfactants [25],[26].

Based on these results, the optimum Span-60 content was determined to be 0.20%.

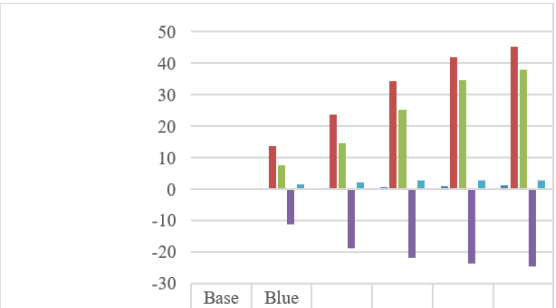
3.2. Effect of rosin on the color characteristics of the ink

Rosin is a natural resin secreted by trees of the genus Pinus. It is soluble in organic solvents and is an effective material for imparting good adhesion to fibers and promoting drying. Its primary component is abietic acid, whose molecular structure contains both nonpolar and polar moieties. The polar carboxylic acid group of abietic acid forms hydrogen bonds with polar functional groups on the fiber surface, orienting the molecule's nonpolar portion outward. This oriented nonpolar portion then interacts with the nonpolar paraffin oil. Consequently, the use of rosin enhances the ink's adhesion to the fabric [27].

Based on this, the color characteristics of the ink were measured while varying the rosin content (*Table 3*).

Table 3: Effect of rosin content on the color characteristics

Sample	Rosin content (%)	Brightness index (L*)	Clarity a*	Clarity b*	Clarity (C^*_{ab})	Hue angle ($H^*_{ab}/^\circ$)
Base color	0	41.59	-7.67	-41.67	42.37	259.57
Blue fabric	0	49.1	-7.05	-30.31	31.12	256.91
	0.3	55.14	-5.95	-22.94	23.7	255.46
	0.6	67.83	-5.61	-19.89	20.67	254.25
	0.9	76.25	-5.22	-18.11	18.85	253.92
	1.2	79.69	-5.01	-17.27	17.98	253.82



	Base color	Blue fabric				
Rosin Content (%)	0	0	0.3	0.6	0.9	1.2
ΔE^*_{ab}	0	13.63	23.78	34.4	41.98	45.32
ΔL^*	0	7.51	14.55	25.24	34.66	38.1
ΔC^*_{ab}	0	-11.25	-18.67	-21.7	-23.52	-24.39
ΔH^*_{ab}	0	1.69	2.28	2.78	2.81	2.75

Figure 3: Color change according to rosin content

As shown in *Table 3*, increasing the rosin content in the white ink results in a hue that is nearly identical to that of the blue base fabric. However, the clarity decreases to less than half that of the base fabric, while the lightness almost doubles compared with that of the base fabric. These relationships, when evaluated as color change (color difference) relative to rosin content, are presented in *Figure 3*.

As evident from the table data, the color difference in the white ink relative to rosin content is substantial. Specifically, at a rosin content of 1.2%, the hue difference is the smallest, at approximately 2.8. The clarity difference is about −24.4, reduced to roughly 0.6 times the base value, while the lightness difference is about 45.3, increased by about 1.9 times. Furthermore, when rosin is not added or is added in small amounts (around 0.3%), the clarity difference is larger relative to the lightness difference. In contrast, when the rosin content is higher (around 0.6%), the lightness difference becomes larger relative to the clarity difference.

Additionally, as seen in *Figure 3*, lightness increases significantly when more than 0.3% rosin is added. The rate of increase in lightness begins to level off at a content of 0.9% and above. Regarding number identification, a 0.9% rosin addition was visually sufficient, whereas with a 0.6% addition, identifying the numbers tended to be slightly difficult [28]. This phenomenon is attributed to the decrease in paraffin oil fluidity caused by rosin, which prevents the ink from penetrating deeply into the fabric structure and causes more of it to adhere to the surface. It is considered that at a rosin content of about 0.9%, this effect is sufficient for clear number identification.

Therefore, it can be concluded that a suitable rosin content for number identification, even on light-colored base fabrics, is 0.9%.

3.3. Effect of hydrophilic surfactants on the washability of the ink

3.3.1. Selection of the hydrophilic surfactant

Washability tests were conducted on black Dacron fabric using Tween-80 and OP-10, both nonionic surfactants with hydrophilic properties. The results are shown in *Figure 4*. As shown by the data in *Figure 4*, the lightness of the white ink was almost unaffected by the presence or absence of Span-60 or by its concentration, and Span-60 did not influence post-wash lightness either. This indicates that Span-60 does not affect the washability of the ink.

Similar to Span-60, Tween-80 and OP-10 also did not affect the lightness of the white ink. However, post-wash lightness changed depending on the concentration of these surfactants. The degree of change was greater for Tween-80 than for OP-10 (*Figure 5*). As can be seen from *Figure 5*, Span-60 had no effect on improving the washability of the ink. In contrast, Tween-80 and OP-10 significantly enhanced washability. At a 0.5% addition, Tween-80 achieved a washability of 96.9%, indicating almost complete removal of white ink contamination, while OP-10 also exhibited washability above 90%. As shown in *Figure 5*, both Tween-80 and OP-10 greatly improved the ink's washability, but Tween-80 showed higher washability than OP-10 at the same concentration.

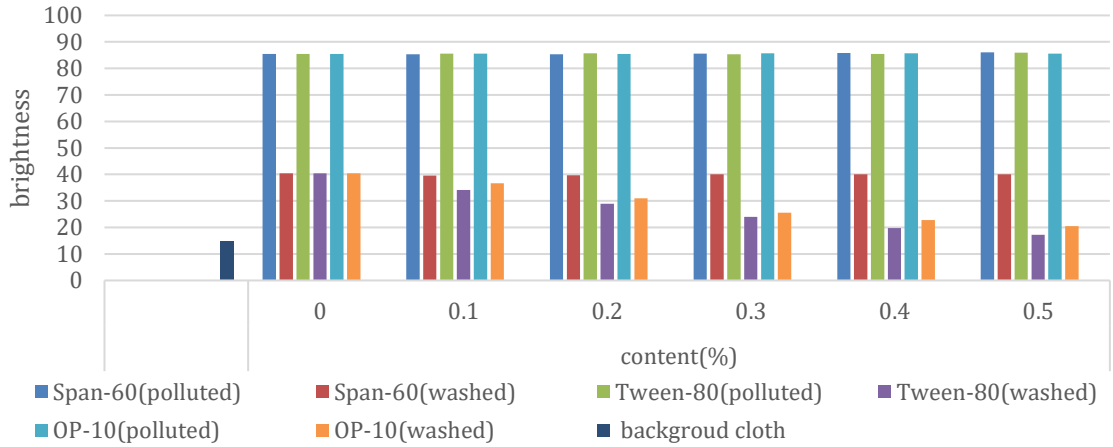


Figure 4: Brightness change according to the type and content of surfactants

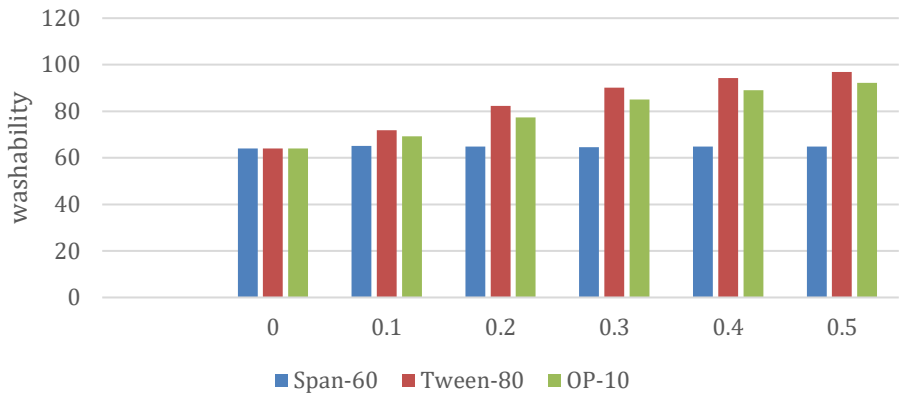


Figure 5: Washability change according to the type and content of surfactants

This may be because Tween-80, a nonionic surfactant with a high HLB value, is more effective at converting the paraffin oil-based ink into an O/W (oil-in-water) emulsion system.

In nonionic surfactant systems, washability is governed by the emulsification capability of the hydrophilic component, and a higher HLB value facilitates easier removal by water. This result is consistent with previous research indicating that, in mixed surfactant systems, the hydrophilic surfactant dominates the washing effect [29].

Based on the experimental results, Tween-80, which demonstrated higher washability, was selected as the additive to improve the ink's washability. Furthermore, using Span and Tween together is particularly effective for emulsifying vegetable oils, mineral oils, and fatty acids, making Tween-80 a suitable choice for this application.

3.3.2. *Effect of Tween-80 content on the washability of the ink*

A washability evaluation test was conducted while keeping the Span-60 content constant at 0.2% and varying the Tween-80 content from 0% to 0.5% in increments of 0.1%. The results are presented in *Figures 6 and 7*.

The results shown in *Figures 6 and 7* can be attributed to the fact that, at a Tween-80 content of approximately 0.3–0.4%, the HLB value of the mixed surfactant system relatively closely matches the HLB value required for O/W (oil-in-water) emulsification of paraffin oil. Consequently, the emulsification (and thus cleaning) efficiency of water is significantly enhanced for the white ink based on paraffin oil as the primary vehicle. Based on these results, the Tween-80 content was determined to be 0.4%.

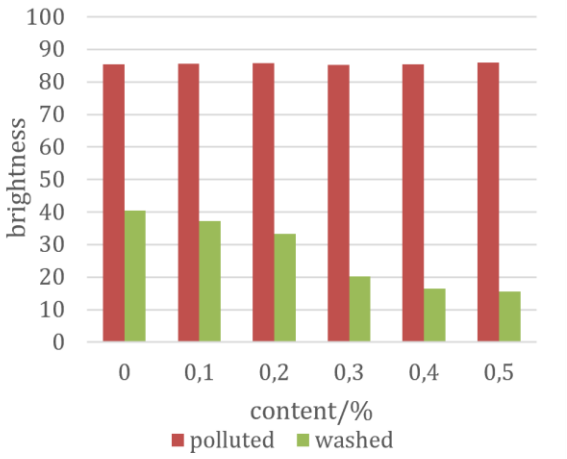


Figure 6: Brightness variation with Tween-80 concentration

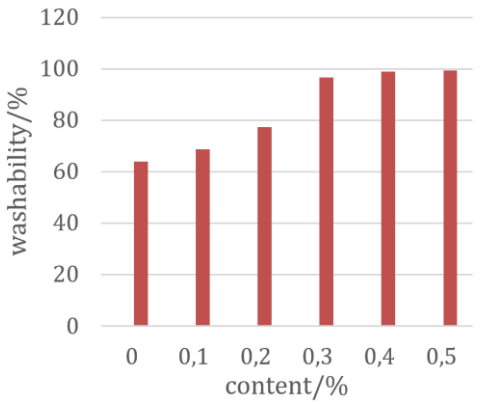


Figure 7: Variation of washability with Tween-80 concentration

3.4. Characteristics of the white ink

3.4.1. Surface morphology and ink particle size

The scanning electron microscopy (SEM) image (*Figure 8*) and the particle size measurement results obtained using the Nano Laser Particle Size Analyzer BT-90 for the white ink for cut-piece identification numbering machines, manufactured using a mixed surfactant system, are shown in *Figure 8* and *Table 4*, respectively.

As observed from the particle size distribution data in *Table 4*, after 10 minutes of dispersion, the titanium dioxide particles were mostly dispersed within a size range of 0.28–1.12 μm (280–1120 nm). Specifically, approximately 19% of the titanium dioxide particles were in the 0.519–0.605 μm range, about 53% were in the 0.445–0.705 μm range, and 80% of the particles fell within the 0.327–0.823 μm size range.

The number of particles larger than 1 μm was less than 3%. This particle size range represents a balance between optical hiding power and dispersion stability and is reported to be suitable for pigment systems in printing inks [30],[31].

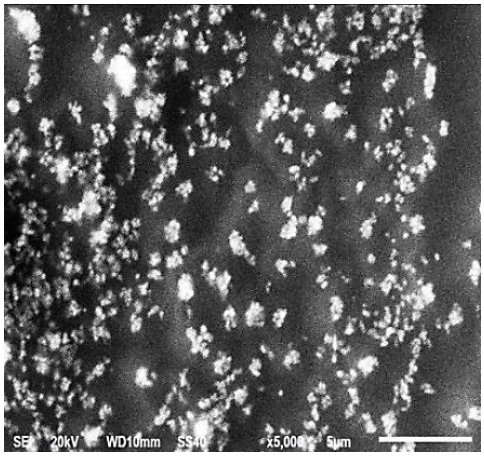


Figure 8: SEM image of the prepared ink for printing identification codes on cloth

Table 4: Titanium dioxide content according to particle size

Particle diameter (nm)	Content (%)	Particle diameter (nm)	Content (%)
281~327	1.48	605~705	17.48
327~382	6.25	705~823	14.13
382~445	12.45	823~959	9.27
445~519	17.2	959~1119	3.14
519~605	18.6		

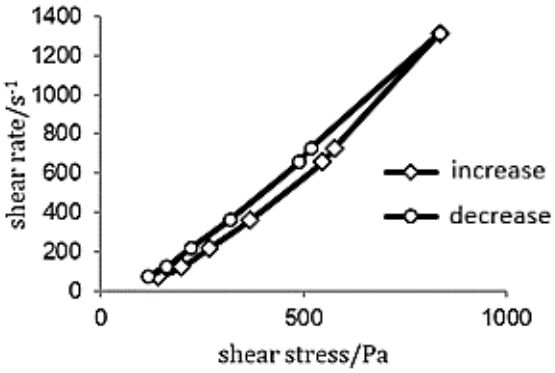


Figure 9: Flow curves of shear stress versus shear rate for the prepared white ink

3.4.2. Rheological characteristics of the ink

The results of shear stress measurements as a function of shear rate for the white ink prepared using the mixed surfactant system are presented in *Figure 9*.

From the graph, it is evident that the prepared ink exhibits pseudoplastic (shear-thinning) flow behavior.

According to the calculations, the viscosity of the ink is 631.4 mPa·s, and the structural recovery time is 1.5–1.7 s.

These rheological properties are advantageous for the printing process: during printing, the viscosity decreases under shear, which improves printability, while after printing, the structure recovers rapidly to suppress bleeding [32]. These properties are consistent with the rheological characteristics generally required for printing inks and are well aligned with previous reports.

4. Conclusion

We conducted a study to manufacture white ink for cut-piece identification numbering machines using a mixed surfactant system and to improve its characteristics. A lipophilic surfactant (Span-60) and a hydrophilic surfactant (Tween-80) were employed. Rosin was added to enhance number identification performance. Consequently, improvements were achieved in two of the ink's most critical properties: number identification performance and washability. The optimum concentrations were determined to be 0.2% Span-60, 0.4% Tween-80, and 0.9% rosin.

An examination of the characteristics of the ink manufactured using the mixed surfactants showed a viscosity of 631.4 mPa·s, a structural recovery time of 1.5–1.7 s, and a titanium dioxide pigment particle size predominantly within the range of 0.327–0.823 μm.

REFERENCES

[1] Xian, T. Z., Amran, F., Arsad, A., & Zaini, M. A. A. (2025). Potassium hydroxide-activated palm kernel shell carbon for methylene blue adsorption: reagent recovery and regeneration strategies. *Hungarian Journal of Industry and Chemistry*, *53*(2), 7–16. https://doi.org/10.33927/hjic-2025-12

[2] Liu, S., Han, Z., & Luo, X. (2025). A comprehensive review on inkjet-printed intelligent food packaging materials: principle, ink formulation, functional inks, and potential applications. *Food Frontiers*, *6*(4), 1715–1741. https://doi.org/10.1002/fft2.70034

[3] Dong, X., Sun, Z., Liu, Y., Jiang, L., & Zheng, S. (2018). Insights into effects and mechanisms of pre-dispersant on surface morphologies of silica or alumina coated rutile TiO_2 particles. *Chemical Physics Letters*, *699*, 55–63. https://doi.org/10.1016/j.cplett.2018.03.043

[4] Mahajan, M., & Arulmozhi, A. (2025). Rheological characterization of offset lithography inks and their impact on dot gain. *Multidisciplinary Science Journal*, *8*(5), Article e2026343. https://doi.org/10.31893/multiscience.2026343

[5] Jasinski, F., Zetterlund, P. B., Braun, A. M., & Chemtob, A. (2018). Photopolymerization in dispersed systems. *Progress in Polymer Science*, *84*, 47–88. https://doi.org/10.1016/j.progpolymsci.2018.06.006

[6] Du, X., Li, G., Zhu, X., Huang, B., Yang, H., Wang, X., Jiao, Y., Wang, K., & Fu, C. (2024). *Emulsion stability controlled by anionic nonionic and zwitterionic surfactants and its mechanism of EOR in high temperature, high salt and low permeability reservoirs* [Preprint]. Preprints.org. https://doi.org/10.20944/preprints202406.1942.v1

[7] Saw, R. K., Shinojiya, D., Pillai, P., Prakash, S., & Mandal, A. (2023). Experimental investigation of the synergistic effect of two nonionic surfactants on interfacial properties and their application in enhanced oil recovery. *ACS Omega*, *8*(13), 12445–12455. https://doi.org/10.1021/acsomega.3c00401

[8] Klier, J., Tucker, C. J., Kalantar, T. H., & Green, D. P. (2000). Properties and applications of microemulsions. *Advanced Materials*, *12*(23), 1751–1761, https://doi.org/10.1002/1521-4095(200012)12:23<1751::AID-ADMA1751>3.0.CO;2-I

[9] Tartaro, G., Mateos, H., Schirone, D., Angelico, R., & Palazzo, G. (2020). Microemulsion microstructure(s): A tutorial review. *Nanomaterials*, *10*(9), Article 1657. https://doi.org/10.3390/nano10091657

[10] Veeramanoharan, A., & Kim, S.-C. (2024). A comprehensive review on sustainable surfactants from CNSL: chemistry, key applications and research perspectives. *RSC Advances*, *14*(35), 25429–25471. https://doi.org/10.1039/D4RA04684F

[11] Schramm, L. L., Stasiuk, E. N., & Marangoni, D. G. (2003). Surfactants and their applications. *Annual Reports on the Progress of Chemistry, Section C: Physical Chemistry*, *99*, 3–48. https://doi.org/10.1039/B208499F

[12] Wu, H.-R., Tan, R., Hong, S.-P., Zhou, Q., Liu, B.-Y., Chang, J.-W., Luan, T.-F., Kang, N., & Hou, J.-R. (2024). Synergistic anionic/zwitterionic mixed surfactant system with high emulsification efficiency for enhanced oil recovery in low permeability reservoirs. *Petroleum Science*, *21*(2), 936–950. https://doi.org/10.1016/j.petsci.2023.12.023

[13] Gaikwad, K. K., & Hakim, L. (2022). Natural Dyes from Plants for Smart Packaging Printing and Applications. *Journal of Advanced Chemical Engineering, 12*, 1–8, https://doi.org/10.4172/2165-784X.1000196

[14] Breton, M., Moorlag, C., Lee, F. P.-H., Magdalinis, A. V., & Mayo, J. D. (2015). *White ink composition for ink-based digital printing* (2015/0077501). U.S. Patent Application

[15] Jiang, J., Wang, Z., Wang, C., Shi, L., Hou, J., & Zhang, L. (2022). Model emulsions stabilized with nonionic surfactants: Structure and rheology across catastrophic phase inversion. *ACS Omega*, *7*(48), 44012–44020. https://doi.org/10.1021/acsomega.2c05388

[16] Bettersize Instruments Ltd. (2024). Particle size analysis of salt-formed active pharmaceutical ingredients (Application Note). https://www.bettersizeinstruments.com/learn/knowledge-center/particle-size-analysis-of-salt-formed-active-pharmaceutical-ingredients/

[17] Agbo, C., Jakpa, W., Sarkodie, B., Boakye, A., & Fu, S. (2018). A review on the mechanism of pigment dispersion. *Journal of Dispersion Science and Technology*, *39*(6), 874–889. https://doi.org/10.1080/01932691.2017.1406367

[18] Ewaznezhad Fard, D., Gorji Kandi, S., & Khatibzadeh, M. (2022). The effect of ink formulation on colorimetric properties of inkjet printing considering the impact of substrates. *Pigment & Resin Technology*, *51*(1), 60–68. https://doi.org/10.1108/PRT-09-2020-0103

[19] Kumar Samanta, A. (2022). Colorimetric evaluations and characterization of natural and synthetic dyes/pigments and dyed textiles and related products. In A. K. Samanta (Ed.), *Colorimetry*. IntechOpen. https://doi.org/10.5772/intechopen.104774

[20] Gao, C., Xing, T., Hou, X., Zhang, Y., & Chen, G. (2021). Clean production of polyester fabric inkjet printing process without fabric pretreatment and soaping. *Journal of Cleaner Production, 282*, Article 124315. https://doi.org/10.1016/j.jclepro.2020.124315

[21] Potanin, A., & Marron, G. (2021). Rheological characterization of yield-stress fluids with Brookfield viscometer. *Applied Rheology*, *31*(1), 1–9. https://doi.org/10.1515/arh-2021-0001

[22] Kornaeva, E. P., Stebakov, I. N., Kornaev, A. V., Dremin, V. V., Popov, S. G., & Vinokurov, A. Yu. (2023). A method to measure non-Newtonian fluids viscosity using inertial viscometer with a computer vision system. *International Journal of Mechanical Sciences*, *242*, Article 107967. https://doi.org/10.1016/j.ijmecsci.2022.107967

[23] Gaida, R., Dziubek, K., Król, K., Ostaszewska, M., & Wit, M. (2023). Influence of different dispersants on the quality and stability of aqueous quinacridone magenta pigment dispersion for ink-jet applications. *Coloration Technology*, *139*(6), 637–653. https://doi.org/10.1111/cote.12678

[24] Li, C., Geng, T., Huang, J., Zhang, C., Duan, M., Fang, S., Li, X., & Liu, S. (2024). Study on the dispersion stability of kaolin in oil phase. *Applied Clay Science*, *254*, Article 107396. https://doi.org/10.1016/j.clay.2024.107396

[25] Dário, B. S.; Pereira, R., & Petri, D. F. S. (2022). Tristyrylphenol based surfactants as efficient dispersants of TiO_2 particles in dilute and concentrated dispersions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *654*, Article 130170. https://doi.org/10.1016/j.colsurfa.2022.130170

[26] Hwangbo, S. A., Kwak, M., Kim, J., & Lee, T. G. (2021). Novel surfactant-free water dispersion technique of TiO_2 NPs using focused ultrasound system. *Nanomaterials*, *11*(2), Article 427. https://doi.org/10.3390/nano11020427

[27] Mahendra, V. (2019). Rosin product review. *Applied Mechanics and Materials*, *890*, 77–91. https://doi.org/10.4028/www.scientific.net/AMM.890.77

[28] Karademir, A., Aydemir, C., Yenidogan, S., Kandırmaz, E. A., & Kıter, R. G. (2020). The use of natural (*Pinus pinaster*) resin in the production of printing ink and the printability effect. *Color Research & Application, 45*(6), 1170–1178. https://doi.org/10.1002/col.22534

[29] Guo, J., Luo, C., Wittkowski, C., Fehr, I., Chong, Z., Kitzberger, M., Alassali, A., Zhao, X., Leineweber, R., Feng, Y., & Kuchta, K. (2023). Screening the impact of surfactants and reaction conditions on the de-inkability of different printing ink systems for plastic packaging. *Polymers*, *15*(9), Article 2220. https://doi.org/10.3390/polym15092220

[30] Theissmann, R., Drury, C., Rohe, M., Koch, T., Winkler, J., & Pikal, P. (2024). Comparative electron microscopy particle sizing of TiO_2 pigments: sample preparation and measurement. *Beilstein Journal of Nanotechnology, 15*, 317–332. https://doi.org/10.3762/bjnano.15.29

[31] Wang, L., Xie, G., Mi, X., Zhang, B., Du, Y., Zhu, Q., & Yu, Z. (2023). Surface-modified TiO_2@SiO_2 nanocomposites for enhanced dispersibility and optical performance to apply in the printing process as a pigment. *ACS Omega*, *8*(22), 20116–20124. https://doi.org/10.1021/acsomega.3c02679

[32] Paxton, N., Smolan, W., Böck, T., Melchels, F., Groll, J., & Jungst, T. (2017). Proposal to assess printability of bioinks for extrusion-based bioprinting and evaluation of rheological properties governing bioprintability. *Biofabrication*, *9*(4), Article 044107. https://doi.org/10.1088/1758-5090/aa8dd8