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Performance of water-based functional inks and their application in packaging printing

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Abstract: This study is concerned with the preparation, performance testing and application of aqueous functional inks in packaging printing. The preparation process of aqueous functional inks is firstly introduced, focusing on the rheological and color properties. A comprehensive understanding of the fluidity and deformation behavior of the ink in printing is provided, which provides important process parameters for practical application. Attention is also paid to the color reproduction and stability of aqueous functional inks to ensure that the printed products have excellent visual effects in the packaging field. Finally, the wide application of aqueous functional inks in packaging printing is outlined. The correlation coefficients of red, green and blue are 0.961, 0.985 and 0.950. It provides a scientific basis for the optimization of the performance of aqueous functional inks, and at the same time provides an environmentally friendly and efficient choice for the packaging printing industry.

1. Introduction

With the increasing awareness of environmental protection, traditional organic solvent-based inks release volatile organic compounds (VOCs) during use, which are potentially harmful to the environment and human health [1]. Therefore, the search for more environmentally friendly, low VOC-emitting alternatives has become an urgent need, and water-based functional inks are gradually gaining attention in research and application due to their environmental friendliness [2]. In packaging printing, it is often necessary to print on a variety of different materials, such as paper, plastic, metal and so on. Water-based functional inks have a wide range of printing adaptability and can cope with diverse packaging materials, making them widely used in the printing industry [3]. The continuous development of printing technology, the superior performance of water-based functional inks in the printing process has been further highlighted [4]. Its application in a variety of printing processes, such as flexographic printing, gravure printing, screen printing, etc., has promoted the progress of related process technology [5].

Literature [6] studied the latest situation of water-based ink synthesis technology, analyzed the current status of water-based ink application in China, and summarized the research progress of water-based ink. The application of water-based ink in flexographic printing is emerging, but it is still in its infancy in gravure plastic film printing. The printing substrate for water-based inks consists of a single corrugated paper or paper, and a change to various non-absorbent materials, such as plastic films, should be encouraged. Literature [7] water-based inks are used in flexographic printing and, more importantly, in packaging printing. Packaging must have a good commercial appearance, which is generally obtained by the transfer of ink to its substrate. It is important that the inks used in packaging printing are produced from environmentally friendly and sustainable raw materials and are suitable for the printing system. The growing demand in the printing and packaging sector and the scarcity of resources to meet this demand has accelerated the search for new sources of inks. Literature [8] designed water-in-oil emulsion binder by adding toluene diisocyanate to modify the water-in-oil emulsion binder in order to solve the drawback of short stabilization time of binder system by using aqueous solution of polyvinyl alcohol as aqueous phase and ethyl acetate solution of fluorocarbon resin as oil phase. Literature [9] The surface energy of printed materials can be increased to the desired level by utilizing different chemicals or methods. The surface properties of matte and glossy coated papers were improved by an argon-containing atmospheric pressure plasma device because the plasma treatment method does not cause surface damage to the paper.

In this paper, through the detailed experimental analysis of the rheological properties of aqueous functional inks at different shear rates, systematically reveals the trend of the fluidity of the ink in the printing process. It provides a scientific basis for the rational setting of printing process parameters, and the conclusions supported by the data make the research results more credible and practical.

2. Method

2.1 Preparation of water-based functional ink

Water-based ink production includes modified water-based polyurethane, diol ether, epoxy alcohol, sodium hydroxypropyl cellulose, polyvinyl alcohol, pigments, surfactants, dimethylethanolamine, inorganic fillers, silicone oil, sodium alginate grafted cyclodextrin, and deionized water [10]. Water-based inks have excellent performance, excellent rubbing fastness and good waterproof performance, modified water-based polyurethane molecular chain contains more active groups and high surface tension. Therefore, after introduced into the ink, the prepared ink is more suitable for planar printing use, and the printing quality is substantially improved [11]. At the same time, through the introduction of sodium alginate grafted cyclodextrin, it can effectively regulate the cohesive strength of the ink, and further improve the friction fastness of the ink. Its chemical equation is $A+B\rightarrow C$. The production method is as follows:

(1) Collect the required raw materials, including resin, pigment, additives and so on. The resin of water-based functional ink usually chooses water-based emulsion resin, the pigment chooses the corresponding color according to the specific application, and the additives are used to adjust the rheological properties of the ink.

(2) According to the application needs and performance requirements of the ink, design a suitable formula. Ensure the proportion of various components is coordinated to obtain the required color, viscosity and printing performance.

(3) Add the pigment into the water-based emulsion resin, and make the pigment evenly suspended in the resin by means of stirring and dispersant to form a stable pigment dispersion system.

(4) Emulsify the suspended and dispersed pigment with the water-based emulsion resin to form the basic system of water-based ink. In the process of emulsification, it is necessary to control the temperature, stirring speed and other conditions to ensure that the emulsification is sufficient and stable.

(5) Add some additives, such as stabilizers, rheological agents, etc., to adjust the performance of

the ink according to the needs. These additives can improve the stability of the ink, reduce viscosity, improve printing performance and so on.

(6) Use acid-base adjusting agent to adjust the pH value of the ink to ensure that it has the best performance in the appropriate acid-base environment.

(7) Filter the prepared water-based functional ink to remove the impurities and particles in it to ensure the quality of the ink. Finally, the filtered ink is packed for storage and transportation.

2.2 Performance Tests

2.2.1 Rheological performance test

Determination of the flow properties of printing inks is carried out through the use of rotational viscometers and parallel plate compression viscometers [12]. For the study of non-Newtonian flow and thixotropy, the rotational viscometer is particularly suitable. Whereas for the study of plastic flow, parallel plate compression viscometers were used. Capillary and falling ball type viscometers are not suitable for materials that exhibit complex flow such as printing inks due to the complexity of the flow conditions in the study of materials involving complex flow. These viscometers, particularly the co-axial double cylinder viscometer, are suitable for use at low rotational velocities. Regardless of the type of viscometer used, the relationship between the apparent shear velocity D and the shear stress T obtained with a co-axial double-layer cylinder type viscometer during testing is given by the following equation:

$$D = 2Q / 1 - \left(R_1 / R_2\right)2 \tag{1}$$

$$T = M / 2\pi R_1^2 h \tag{2}$$

Where Q is the relative angular velocity of the inner and outer cylinders M is the rotating torque R_1, R_2 is the radius of the inner and outer cylinders h is the height of the liquid layer and the depth of the inner cylinder immersed in the liquid, and the apparent viscosity N is obtained from the following equation:

$$N = T / D \tag{3}$$

These rheological performance test methods provide an effective means to study the performance of aqueous functional inks and help to understand the rheological behavior of inks under practical application conditions in packaging printing.

2.2.2 Color performance test

Hue coloring power is a basic item of ink testing, which has a great influence on the color of ink [13]. Hue is a specific feature of the ink color, and coloring power refers to the size of the degree to which one ink affects the color change of another ink. When mixing spot-color ink, when the hue of one of the original ink changes, the color of the spot-color ink will change. Therefore, to ensure the correctness of the printing ink hue, the stability of the tinting force leitung, the control of the color of the printed matter is very important.

The performance characteristics of water-based functional inks are as follows:

(1) Water-based Functional Ink adopts water-based resin substrate, low volatility and low VOC emission, environmental friendly.

(2) It can adhere well on all kinds of packaging materials and guarantee the printing quality.

(3) It has good color reproducibility, ensuring accurate reproduction of the colors expected by designers.

(4) Suitable for flexographic printing, gravure printing, screen printing, etc., widely used in packaging printing.

(5) Strong abrasion resistance, the print is not easy to wear and maintain a long and clear pattern.

Use the colorimeter to measure the color difference between the print and the standard color to evaluate the color accuracy. The formula is as follows:

$$Aberration = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{4}$$

Where ΔL、Δa、Δb indicates the difference between the brightness, red-greenness, and yellow-blueness of the sample and standard colors, respectively. The smaller the color difference value, the closer the color is to the standard color. The color depth is calculated by measuring the intensity of absorbed and transmitted light. A higher color depth indicates a more intense color. Glossiness is calculated by comparing the intensity of reflected and incident light. A higher value of gloss indicates a smooth surface and better luster.

2.3 Application in packaging printing

The application of water-based functional inks in packaging printing usually involves a series of steps, and the application process, as shown in Figure 1, includes the selection of printing equipment and the setting of printing process parameters. The following are the general application steps:

(1) Select the printing equipment suitable for water-based functional inks. Common printing equipment includes flexographic printing presses, gravure printing presses, screen printing presses and so on. We need to ensure that the equipment can adapt to the characteristics of water-based inks, such as adhesion and drying time, to optimize printing results.

(2) Prepare packaging materials suitable for water-based functional inks. Surface treatment is involved to ensure that the printing surface has good adhesion and adaptability to water-based inks.

(3) Stir the aqueous functional ink before printing begins. We need to ensure that the pigments and resins in the ink are fully mixed to maintain printing stability and color consistency throughout the printing process.

(4) Set the printing process parameters and set the appropriate printing speed according to the performance of the printing equipment and packaging requirements. Adjusting the printing pressure of the printing machine ensures that the ink can be evenly transferred to the substrate. Similarly, adjusting the squeegee pressure controls the thickness of the ink. Setting the temperature and time of the drying system ensures that the water-based ink dries quickly, thereby enhancing productivity. Print tests are conducted to verify print quality and color accuracy. Subsequently, process parameters are adjusted based on the test results to achieve the expected printing results. Mass production printing commences after confirming satisfactory test results. Continuous monitoring of print quality and adjustment of process parameters maintain consistency throughout production. Quality checks on printed products are conducted to ensure compliance with product standards. Packaging is performed upon completion, ready for shipment. At the end of printing, it is important to perform equipment cleaning, especially focusing on cleaning the parts that come into contact with water-based inks, to prevent the adverse effects of ink residue on the equipment [14].

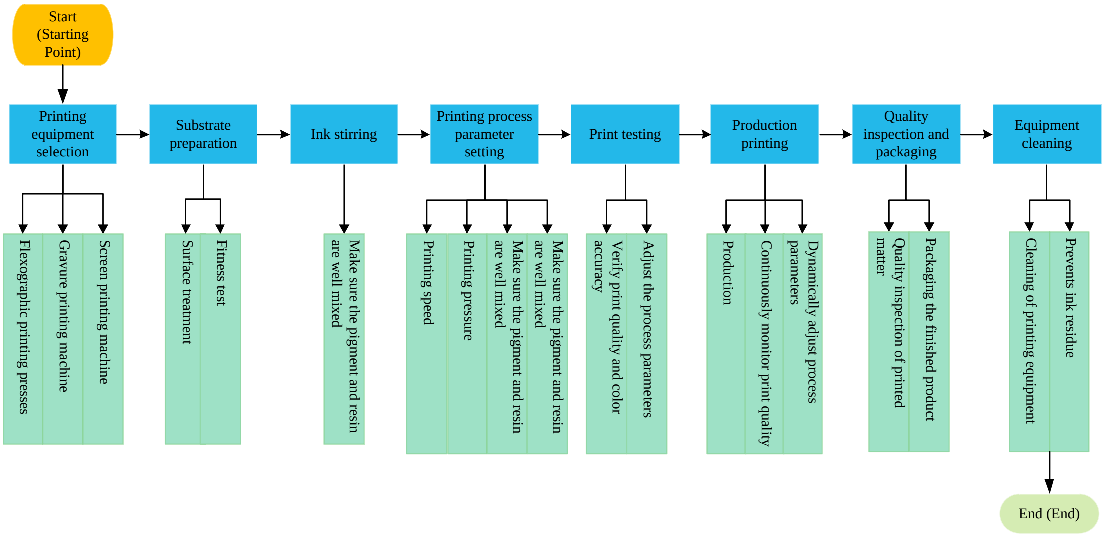

Figure 1: The application process of water-based functional inks in packaging printing

3. Results and Discussion

3.1 Rheological properties

The rheological performance of aqueous functional inks is one of the key performance indicators in packaging printing, Table 1 shows the viscosity of aqueous functional inks at different shear rates to gain insight into their rheological behavior. The viscosity decreases from 150 mPa-s to 120 mPa-s in the range of shear rates from 1 to 5, which is about 20%. This indicates that the ink is relatively viscous at low shear rates. The viscosity gradually decreases from 120 mPa-s to 80 mPa-s over the range of shear rates from 5 to 20. The viscosity decreases by about 33% during this process, showing that the ink flows better at moderate shear rates. In the range of shear rates from 20 to 50, the viscosity continued to decrease from 80 mPa-s to 50 mPa-s with a decrease of about 37.5%. This indicates that at high shear rates, the inks exhibit better flow, which is favorable for transfer and coverage during the printing process. The viscosity change of the aqueous functional inks at different shear rates shows moderate rheological properties, and the moderate viscosity ensures stability at low shear rates and better fluidity at high shear rates. This rheological performance helps to improve printability and efficiency, providing a good printing experience for packaging printing.

Table 1: Flow performance analysis

Shear rate	Viscosity
1	150
5	120
10	100
15	90
20	80
25	75
30	70
35	65
40	60
45	55
50	50

3.2 Color performance

The data from the homochromatic and heterospectral experiments and the experiment to determine the parameters of the density law equation were processed using the correlation coefficient method and the nonlinear regression method. Through the processing, the function describing the relationship between hue and main wavelength and the parameters in the density law equation were obtained. The colors of the formulations obtained in the color matching experiments were evaluated by means of the integrated evaluation method and the homochromatic index. It was observed that there were two dot percentages corresponding to the dominant wavelengths of the colors and that the dot percentages of the different types of inks in each set of colors were proportional to each other in a ratio of 1:1. In order to simplify the problem, the dot percentages of the inks of any of the sets of primary inks in each of the intervals were chosen in place of the color hue. In this way, the success of the color hue and the main wavelength data, making it more suitable for subsequent analysis and calculation. Finally, the absolute value of the correlation coefficient between each inter-color hue and the main wavelength is obtained, and the specific calculation results are shown in Table 2. The coefficient of red is 0.961, the coefficient of green is 0.985, and the coefficient of blue is 0.950. Combined with the performance of aqueous functional inks and their application in packaging printing, these coefficients may represent some characteristics or properties of the colors in the printing process. In the application of water-based functional inks, the coefficients of the colors may be correlated with the ink's properties such as adhesion and drying time. Higher coefficients may indicate better printing performance, while lower coefficients may suggest some problems that need attention.

Table 2: Color performance analysis

Color	Ratio
Red	0.961
Green	0.985
Blue	0.950

4. Conclusion

The viscosity of aqueous functional inks showed a moderate decreasing trend with the gradual increase in shear rate. Specifically, the viscosity decreased from 150 mPa-s to 50 mPa-s for shear rates ranging from 1 to 50.This shows that the aqueous functional inks have good flowability in the printing process. The relatively high viscosity of 150 mPa-s at low shear rate helps to maintain the stability in the printing machine, whereas the viscosity decreases gradually with the increase in shear rate, which improves the fluidity of the ink. At a shear rate of 50, the viscosity drops to 50 mPa-s, providing better maneuverability for printing. The moderate rheological properties allow the ink flow to be controlled by adjusting the shear rate, resulting in better printing results, which has a positive impact on improving printing quality and efficiency.

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References

[1] Lee M H. Interpretable machine-learning for predicting power conversion efficiency of non-halogenated green solvent-processed organic solar cells based on Hansen solubility parameters and molecular weights of polymers[J].Solar Energy, 2023(Sep.):261.

[2] Bamane P B, Jagtap R N.Development of a water-based functional additive by using isobornyl acrylate copolymer to improve ink-adhesion on untreated polypropylene surfaces: A comparative approach [J].International Journal of Adhesion & Adhesives, 2023.
[3] Aini N, Sustriawan B, Muthmainah M M R, et al. Estimation of the Shelf-Life of Corn Yoghurt Packaged in Polyethene Terephthalate Using the Accelerated Shelf-Life Method[J]. International Journal on Advanced Science, Engineering and Information Technology, 2021, 11(1): 298-298.
[4] Li S, Zhang H, Han Y. (107593) Thermally assisted extrusion-based 3D printing of continuous carbon fiber-reinforced SiC composites [J].Composites, Part A. Applied science and manufacturing, 2023.
[5] Xiao P, Yan S, Long J,et al.An adaptive coarse-to-fine framework for automatic first article inspection of flexographic printing labels[J].Expert Systems with Application, 2023.
[6] Zhao C, Wang J, Lu L.Preparation and application of water-based nano-silver conductive ink in paper-based 3D printing [J].Rapid prototyping journal, 2022(4)
[7] Sonmez S, Salam A, Paul D. Fleming III, et al. Usability of cellulose-based binder in water-based flexographic ink[J].Coloration technology, 2023(3):139.
[8] Han K, Xie Z, Deng L, et al. Design of TDI modified oil-in-water emulsion and its application in explosive ink [J]. Propellants, Explosives, Pyrotechnics, 2023(8):48.
[9] Ozsoy S A, Acikel S M, Aydemir C. Effects of green technology plasma pre-treatment on the wett ability and ink adhesion of paper[J]. Pigment& Resin Technology, 2023.
[10] Fuensanta, Khoshnood, Rodr ǵuez-Llansola, et al. New Water borne Polyurethane-Urea Synthesized with Ether-Carbonate Copolymer and Amino-Alcohol Chain Extenders with Tailored Pressure-Sensitive Adhesion Properties [J]. Materials, 2020, 13(3):627.
[11] Verma S, Sharma A K, Shukla S K. Self-fuelled nickel oxide encapsulated sodium alginate-grafted-polypyrrole for potentiometric sensing of lead ions [J]. Materials Science and Engineering: B, 2023.
[12] Stanciu I.Rheology of Gums Used in the Food and Flour Industry for "Tortillas"[J].Oriental Journal of Chemistry, 2022.
[13] Radovan, Ban A, Željko. Prediction of HSV color model parameter values of cloud movement picture based on artificial neural networks [J].Zbornik radova 41. Meunarodnog skupa za informacijsku i komunikacijsku tehnologiju, elektroniku i mikroelektroniku[2024-01-16].
[14] Hosseini K, Hincal E, Mirzazadeh M, et al. A nonlinear Schrdinger equation including the parabolic law and its dark solitons [J]. Optik, 2023, 273:170363.