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A Novel Water-Based Ink Varnish System for High-Speed Flexographic Paper Printing: Low Misting Colloid-Based Systems

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Abstract: In this study, ink misting performance and print resistance properties were obtained and were related to varying ink formulations using combinations of special acrylic emulsions, colloidal, and water-soluble resins. The misting and tackness performance of the two different colloids were investigated using an IGT TackOScope 3 SC. It was observed that acrylic colloids significantly affect the ink misting performance. After choosing the right colloidal resin and the optimum balance with the emulsion and water-soluble acrylic resin has yielded an excellent varnish that can be used in high-speed flexographic machines up to 700 m/min without misting. In industrial trials, 111,600 m of printing was carried out without misting and resolubility problems. In this paper, in addition to developing an ink that can run on high-speed machines, problems such as low print quality, resolubility, dry rub resistance, and tackness were solved and confirmed using industrial tests. From a sustainability perspective, process efficiency increased, and ink and paper waste minimized.

Keywords: water-based ink, printing ink, flexography, colloidal resin, misting, paper packaging.

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1. INTRODUCTION

Flexographic printing is a common printing technique in the packaging industry. This printing method is characterized primarily by the flexible printing plate and low viscosity inks, which allows it to be used on almost any surface (Johnson, 2008). Flexography has a number of advantages including high throughput, superior line edge definition, and reduced printing plate costs (Mariappan, Kim & Hart, 2020). Flexographic printing, which uses molded rubber stamps to print graphics, is now turning into a next-generation electronics manufacturing technique for large-area displays and smart packaging at high speeds (Bhagya, Sunil, Shetty *et al*., 2021).

Acrylic resins are the most successful of all waterborne technologies available and can be classified into four categories, which are alkali soluble resins, acrylic emulsions, colloidal emulsions and solutions and acrylic specialty polymers. Colloidal emulsions are perfect for creating low-cost inks due to their high viscosity efficiency. Recent developments in colloidal emulsion technology have produced goods with outstanding print quality, superior economics for ink formulation, and the ability to disperse organic pigments (Laden, 1997). The water-soluble resin is used as the water-based ink's binder, and has a significant impact on the viscosity, adhesion, gloss, drying speed, printing adaptability, and preferred conditions (Mingzhi & Oluju, 2019).

The flexographic printing water-based varnish is simple to use, saves production costs, and is ideal for industrial use. Although solvent varnish has a long history of use, it can be toxic, irritating, and volatile, polluting the environment and putting the operator's health at risk. Water-based varnish is colorless, odorless, and free of organic volatiles, and it offers environmental protection, safety, low cost, and a diverse range of materials. Water-based varnish is gradually replacing solvent-based varnish as a new green printing material. However, the current water-based varnish has a poor drying speed and is prone to process failures such as unstable product size (Ito & Suwa-Shi, 2018). However, today, the drying speed of water-based resin systems have improved to perform similar drying as solvent-based inks on absorbent surfaces.

Flexographic printing water-based varnish can be prepared by adding a pure acrylic emulsion, a styrene-acrylic emulsion and auxiliary agents such as defoaming agents, waterborne wetting agents, wax additives, waterborne rheological aid, and other additives (Liu, Xie, Zhong, Fan & Qv, 2021). While stirring, a thickener and deionized water is also added to adjust the viscosity of the flexographic printing water-based varnish (Chen, 2011).

In water-based ink formulations, choosing the suitable mix of polymers is very important to obtain the desired properties. In the long print jobs, the resolubility property of the ink is required to obtain clean images. A resin solution can be added to the emulsion polymer in order to enhance resolubility. While choosing the acrylic emulsion resins, glass transition temperature (Tg) is a very important parameter. When the Tg is low, it provides better film formation, water resistance, flexibility, and adhesion, whereas, when the Tg is high, gloss, hardness, heat resistance, and drying speed will be better (Rentzhog & Fogden, 2006).

Jašúrek et. al tested the misting, which is the propensity of the ink splashing from the machine rollers. This ink splashing can cause color contamination and servicing problems. Tack and misting of unemulsified inks and their emulsions were measured using the Kershaw Tackmaster-92. They found that, at the same temperature, unemulsified inks resulted in higher misting and bigger mist drops when compared to the emulsified inks (Jašúrek, Vališ, Syrový & Jablonovský, 2010).

The printing sector mostly generates paper and cardboard wastes, which are among the oldest and most widely used packaging materials. Most of these wastes can be recycled and used as secondary fibres in the manufacturing processes after being sorted, washed, and deinked. Ink is the second most waste-producing printing material. Ink wastes form during the post-printing phase, but solvent-based inks are also hazardous during the printing and post-printing phases due to the solvents they contain by evaporating and polluting the air. The safest ways to handle ink waste are either recycling the inks or burning the solvent they contain. A method for avoiding waste however, is to modify the manufacturing process to prevent waste, which can be accomplished by using water-based inks in production (Hayta & Oktay, 2019).

The average speed of the industrial bag printing machines in Turkey is almost half of the new generation printing machine speed, and high-speed technologies are just emerging. The technologies of the ink companies producing in Turkey are suitable for working at traditional printing machine operating conditions. At higher speeds such as 700 m/min, ink misting occurs which prevents efficient operation. Water-based varnish technology that can work at 700 m/min speed is not available in Turkey.

The aim of the study is to develop a water-based technology varnish that can efficiently work at high printing speed (700 m/min) with a continuous printing length of 10 reels/100,000 m, by providing an optimum ink transfer, drying speed, and preventing ink misting. Recently developed varnish systems will not only contain the quality features obtained in existing systems, but also prevent machine downtimes and ink contamination that affects print quality because of ink misting at high printing speed. In this way, printing companies might be able to increase their process efficiency, minimize ink and paper waste, and work time loss.

2. MATERIALS AND METHODS

2.1. Chemicals

The chemical names and the manufacturer names of the components used in this study are given in Table 1.

Table 1. Components of water-based technology varnish.

Ingredients	Manufacturer
Styrene Acrylic Emulsion Resin	BASF
Styrene Acrylic Emulsion Resin	BASF
Polyether Siloxane Emulsion Defoamer A	Evonik
Polyether Siloxane Defoamer B	Evonik
HDPE wax emulsion	Keim Additec
Ethylene diamine	Croda
Ammonia	Coldgaz
Monoethanolamine (MEA)	Ineos
Blue Color Base	Sun Chemical
Water	–

2.2. Materials

The brown and white kraft sack papers used in this study were supplied by Mondi Group. The kraft sack paper, with an advantage speed of 90 g/m², is an extensible high porosity paper combining high tensile energy absorption (TEA), excellent runnability, and very good printability. The main reason for choosing this paper was the paper features such as, a smooth paper surface, uniform paper formation, strength, and stiffness; and achieving a high-quality print result and allowing an effective operation of the high-speed machinery (Mondi Group, 2023).

2.3. Experimental

For the preparation of the varnish samples, an acrylic solid resin was dissolved in water and MEA. Meanwhile, in a separate beaker, water, acrylic colloidal resin, ethylene diamine, and defoamer A and B were mixed at 3900 rpm for 5 min and then the ammonia and MEA were added slowly and mixed for 15 min to neutralize the colloidal resin. A solution of the acrylic resin, acrylic emulsion resin, and HDPE wax were added and mixed for 10 min as the final stage. Four different varnish samples (Sample A, Sample B, Sample C, and Sample D) were prepared by using different component combinations and amounts.

For the ink preparation, varnish, water, and blue color base were weighed in a beaker and stirred for 1 min for homogenization. Four ink samples were then prepared from each varnish sample.

Misting performance of the ink samples were compared using an IGT TackOScope 3 SC, at 350 m/min, at 20℃ for 1 min, based on ASTM D 4361-97. Other tests were conducted using two samples with a low tendency to misting.

Ink samples were drawn down by depositing a layer of the ink and transferring to the surface of the substrate using the Harper QD Flexo Proofer, 200-lpc anilox.

Viscosity measurements of two samples were made with an ink viscosity in the range of 18 – 22 sec, under flexo printing conditions. Viscosity of the varnish and ink samples were measured with a DIN 53211-flow cup 4 mm, at 25℃. The optimum pH value of the water-based inks is between 8.2 – 9.5. The pH values were measured with a Mettler Toledo SevenCompact S220. The friction test result value must be greater than 4, so that the ink applied to the bags does not contaminate with friction during transportation and use. Rub resistance of the ink drawdowns were checked with a Sutherland 2000 rub tester with regards to ASTM D5264.

The friction coefficient value should be in the range of 0.2 – 0.3, in order to avoid slipping over each other and to prevent tipping during the transportation and storage of the printed bags. The Lloyd LRX friction tester described in ISO 8295:1995 determined the kinetic coefficient of friction. The water resistance must be at the minimum level of four against the moisture that may come from the product placed in the bag and the effect of water that may accumulate on the surface of the bag from the outside environment. The water resistance of the printed samples was controlled according to DIN EN 646. The water-based inks tend to foam during printing due to air pressure in the pneumatic pumps and the friction of the machine parts. The foaming tendency of the inks were tested by placing a 60 cc of sample into a beaker, stirring for 30 min at 3900 rpm, and then pouring the sample into 100 cc graduated cylinder immediately, checking the initial foam rise and foam level after 10 min, 20 min, and 30 min

3. RESULTS AND DISCUSSION

Initially, four different recipes were developed during the study and are shown in Table 2. In this study, two different acrylic colloidal resins and two different defoamers were used. The other ingredients are the same for all recipes, but the amounts differ. Samples were prepared as 250 g for all recipes and several tests were performed.

Table 2. Details of the Recipe.

Ingredients	Sample A (g)	Sample B (g)	Sample C (g)	Sample D (g)
Water	153.50	141.00	141.50	118.75
Surface active agent	2.50	2.50	2.50	2.50
Colloidal resin 1	43.75	43.75	37.50	-
Colloidal resin 2	-	-	-	62.50
Defoamer 1	0.25	0.25	0.25	1.25
Defoamer 2	1.00	1.00	1.00	1.25
Neutralization agent	4.00	4.00	3.50	6.25
Emulsion resin	25.00	37.50	43.75	37.50
Acrylic solution	12.50	12.50	12.50	12.50
Polyethylene wax	7.50	7.50	7.50	7.50
Total	250	250	250	250

Since misting is one of the most important parameters, a comparative analysis of the recipes was carried out in terms of misting parameters using the IGT TackOScope 3 SC at 350 m/min, at 20℃ for 1 min A4 size copy paper was then placed under the cylinders of the machine and at the end of the test, the ink stains were controlled on the paper. Results of the misting test were crucial to determine the final recipe. Figure 1 shows how much ink was splashed onto the A4 size copy paper. Sample A has the highest misting, followed by Sample C, the Reference sample, Sample B, and lastly Sample D. Based on these results, Sample A and Sample C were eliminated.

The tack tests of Sample B and Sample D were performed using the IGT TackOScope 3 SC at 50 m/min for 225 sec. According to the results shown in Figure 2, the Reference Sample and Sample D have similar tack profiles, whereas, Sample B has a lower tack profile. The maximum tack of the Reference Sample, Sample B and Sample D were measured as 80.39, 61.91, and 73.00 with the average tack of the samples measured as 40.34, 27.51, and 37.57 respectively. Since the emulsion resin amount is the same for Sample B and Sample D, it is seen that colloidal resin 1 has a lower tackness tendency than colloidal resin 2.

The foaming test was conducted as described in the experimental part of this study. The initial foam rise levels from 60 cc were observed as: 63 cc for the Reference Sample, 83 cc for Sample B, and 70 cc for Sample D. The recovery times to 60 cc were: 8 min for the Reference Sample, and 14 min for Sample B, and 12 min for Sample D. Recovery time, up to 25 min, generally does not cause problems while printing. However, longer than 25 min may cause printing problems especially when pneumatic pumps are used.

The coefficient of friction (COF) of the Reference Sample was 0.287, Sample B was 0.237, and Sample D was 0.278. The coefficient of friction is important for stacking printed bags. All samples have a convenient coefficient of friction that is in the range of 0.2 – 0.3. The friction coefficient value should be in the range of 0.2 – 0.3, in order to prevent slipping over each other on the stack.

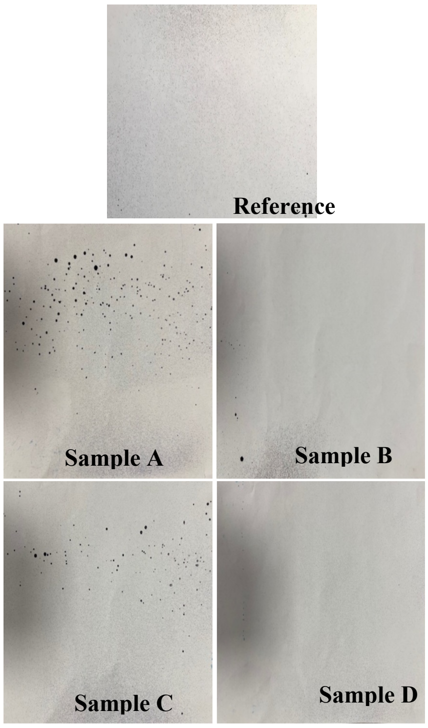

Figure 1. Misting result of the inks.

The rub resistance test results are shown in Figure 3. The results are evaluated on a scale of one to five, one being for a bad rub resistance and five is for a perfect rub resistance. Since there is no ink stain on the blank substrate, the rub resistance of the Reference Sample was evaluated as 4 and Sample B and Sample D as 5, respectively. A rub resistance value greater than 4 is convenient for the ink where it does not contaminate other surfaces during transportation and use.

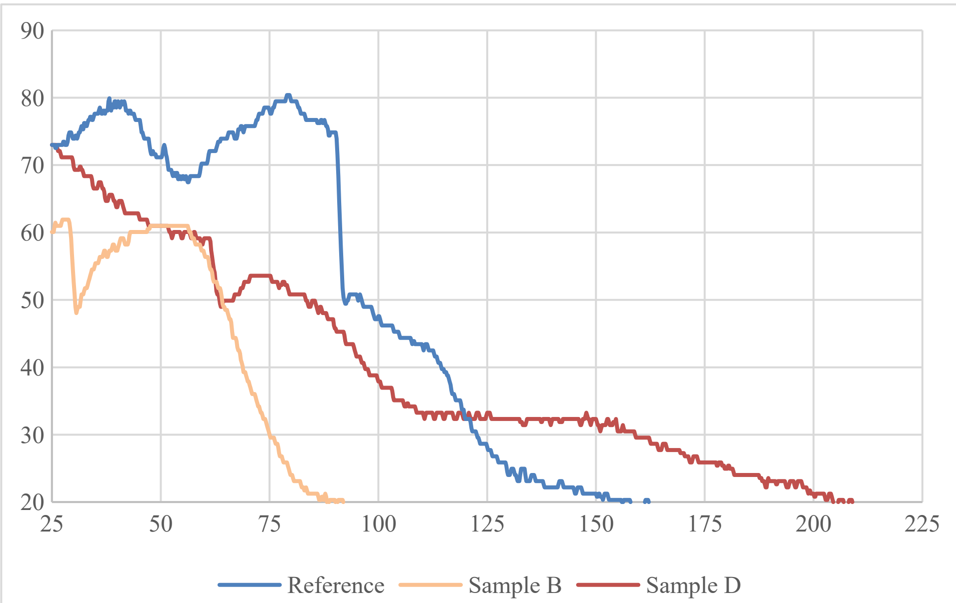

Figure 2. Tackness curves of reference, Sample B and Sample D.

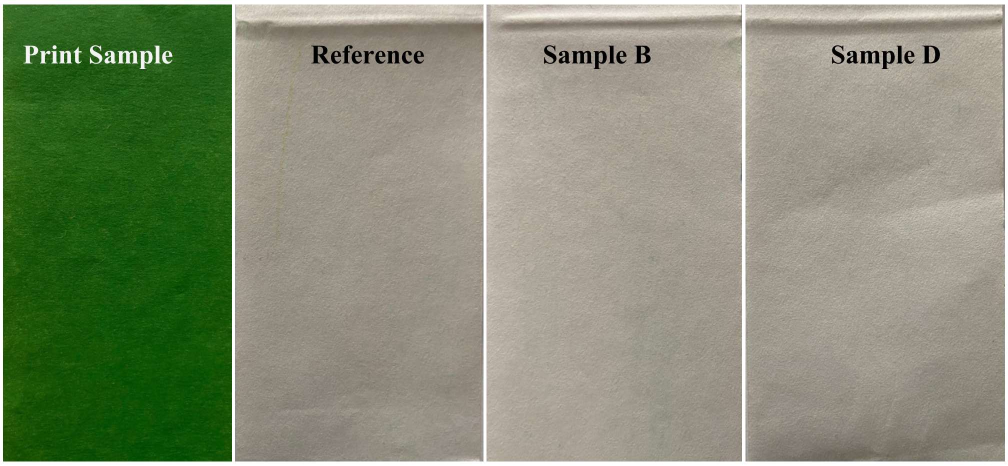

Figure 3. Rub resistance of Reference, Sample B and Sample D.

In a similar research about water-based flexographic ink with acrylic binders, Sonmez et. al found that the binder type influenced some print qualities, while the effect was not significant for others. One of the qualities that was not influenced by the acrylic type was the rub resistance (Sonmez, Alsaid, Pekarovicova *et al.*, 2023).

The first industrial print trial results of the Reference Sample, Sample B, and Sample D are shown in Figure 4. The printing machine speed was 700 m/min and a 10,000 m length printed for each formulation. Sample D has the lowest misting, followed by Sample B and the Reference Sample. At the end of printing with the Reference Sample ink and Sample B ink, the accumulation of ink occurred in the hollow areas of the plate and formed residues in the form of droplets and dust, causing the design on the paper bag to become stained. Since Sample D, ink has the lowest misting, insignificant residues formed on the plate and the printed bag was not contaminated.

Figure 4. (a) Plate of the reference ink, (b) plate of the Sample B ink, (c) plate of the Sample D ink.

In the second industrial print trial, the machine speed was 700 m/min and the print length was calculated at which the press stopped due to it reaching a level that could affect print quality.

Images of the clean photopolymer plate, dirty photopolymer plate after misting started and printed samples with the ink marks are shown in Figure 5. After the photopolymer plate shown in Figure 5(a) is used in the printing job, ink residues formed because of misting are collected in the hollow parts of the photopolymer plate as shown in Figure 5(b). When these formations accumulate more than the printing level of the photopolymer plate, they cause contamination in the final print. As seen in Figure 5(c), dot print impurities have formed in the white area that should be blank.

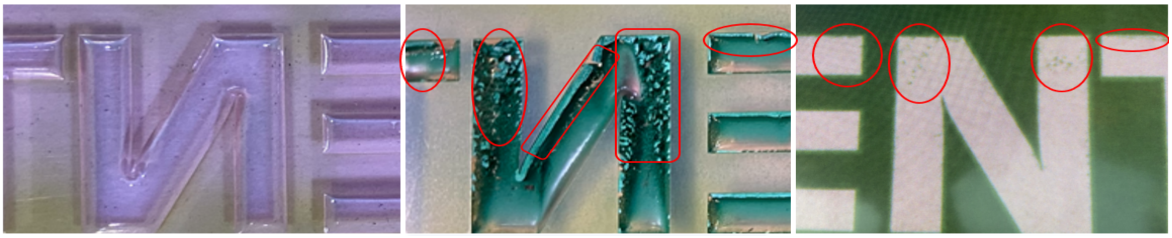

Figure 5. (Left) photopolymer plate before print, (middle) photopolymer plate after misting starts, (right) ink marks on the print after misting.

In Table 3, the approximate print length of the misting started, the total print length at which the print cannot be continued, and the number of printed reels are given. With the Reference Sample ink, 43,000 m printed; with Sample B ink, 75,000 m, and with Sample D ink 88,000 m printed without misting. Sample D has the highest total print length, whereas, the Reference Sample ink has the lowest.

Table 3. Industrial print trial results.

	Print length that ink misting started (m)	**Total print length (m)**	**Number of printed reels**
Reference	~43,000	62,000	5
Sample B	~75,000	99,200	8
Sample D	~88,000	111,600	9

The water resistance of the printed samples were tested in accordance with EN 646:2020 procedure C, short time contact. The test pieces were cut to a 50 mm x 20 mm dimension and the 60 mm x 90 mm glass fiber papers were immersed in deionized water. The glass fiber paper was then placed onto a 60 mm x 90 mm glass plate, and a test piece was put onto the fiber paper and covered with another glass fiber paper. A second glass plate was covered on a second glass fiber paper and loaded with a mass of 1 kg for 10 min at (23 ± 2)°C. After 10 min, the glass fiber filter papers were checked to see whether there were any ink stains stained on them. The evaluation scale is from one to five, one is for too bad water resistance and five is for perfect water resistance. All of the samples were graded as 5 since there is no ink stain on the papers (Figure 6).

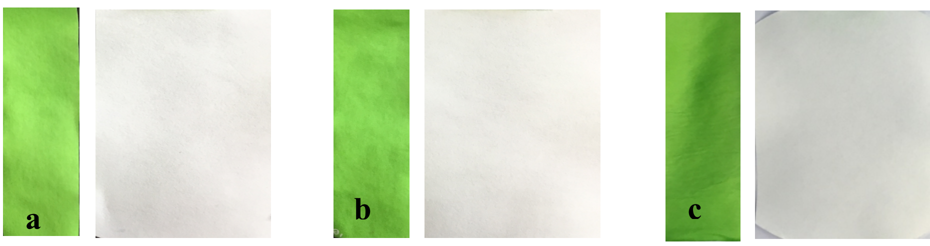

Figure 6. (a) Water resistance test results of the reference ink, (b) Sample B ink, (c) Sample D ink.

The wash up performances of the inks were tested after the application with an anilox roller side by side, allowing for 1-min drying. After 1 min, the anilox rollers were washed with water, and all of the inks were removed easily both on the anilox cylinder and rubber part (Figure 7). A good wash up performance is important for the cleaning of anilox rollers and plates on the printing machines.

If the wash up of the ink is not good, it causes clogging on the anilox rollers, and the amount of transferred ink is reduced.

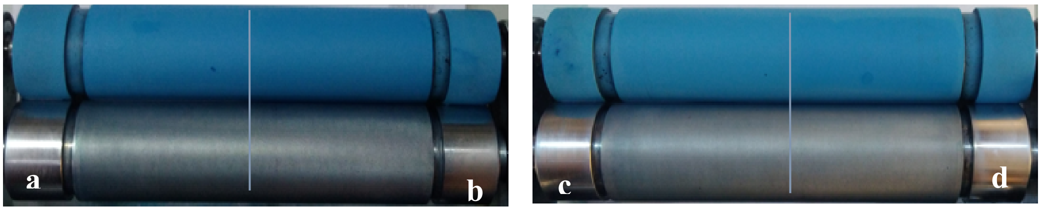

Figure 7. Wash-up control results of the anilox rollers, (a) reference and (b) Sample B are on the left-hand side, (c) reference and (d) Sample D are on the right-hand side.

3. CONCLUSION

In this work, a new generation of water-based technology varnish that can be run on high-speed printing machines, was designed using a combination of acrylic colloidal resin and acrylic emulsion resin. Sample B and Sample D showed low misting and Sample A and Sample C showed high misting, which was investigated using an IGT TackOScope 3 SC. In addition to the misting performance, the tests continued with the Sample B and D, whose tack level was close to the Reference Sample. In the foaming test, Sample B and D showed a higher foaming tendency than the Reference Sample, the foam disappeared below the 25 min recovery time. Sample B and Sample D showed good wash-up performance and did not cause any clogging on the rubbers and aniloxes rollers. The water resistance, rub resistance, and COF measurements were found to be similar to the Reference Sample. Two different industrial trials were made, one with a fixed print length and the second print length up to a high misting level. The accumulation on the photopolymer was controlled at the end of the first trial, Sample D showed minimal misting, while the Reference Sample and Sample B showed a similar misting tendency. The print length of the second trial was calculated, the Reference Sample ink was run for a 43,000 m print, and Sample B ink was run for a 75,000 m print. Sample D ink was run for an 88,000 m print without misting, in total 111,600 m was printed with minimal misting that did not affect the print quality. According to the results obtained from the tests, Sample D showed the best overall performance and it could be a guide to the design of inks to be used in machines capable of printing at speeds higher than 700 m/min in the future.

4. ACKNOWLEDGMENT

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