Research Article

Influence of Polyvinyl Alcohols on Paper Straw Adhesives and Effect on Straw Resilience

Özge ALPTOĞA[1*], Ali ÖNEN[2], Cansu AKARSU DÜLGAR[3]

[1] Organik Kimya San. Ve Tic. A.Ş., Turkey, Orcid ID: 0009-0001-3393-5596, E-mail: o_alptoga@organikkimya.com
[2] Organik Kimya San. Ve Tic. A.Ş., Turkey, Orcid ID: 0000-0001-8574-6327, E-mail: a_onen@organikkimya.com
[3] Organik Kimya San. Ve Tic. A.Ş., Turkey, Orcid ID: 0000-0001-7777-2656, E-mail: c_akarsu@organikkimya.com
* Correspondence: o_alptoga@organikkimya.com

(First received September 18, 2023 and in final form December 24, 2023)

Reference: Alptoğa, Ö., Önen, A., Dülgar, C., A. A. Influence of Polyvinyl Alcohols on Paper Straw Adhesives and Effect on Straw Resilience. The European Journal of Research and Development, 3(4), 34-41.

Abstract

Paper straws are gaining popularity worldwide due to the increasing demand for sustainability and government policies that aim to curb the use of single-use plastics. However, there have been concerns about the long-term quality and durability of paper straws when used with liquids. Paper straw adhesives are specially formulated adhesives used to bond the various layers of paper straws together and play a crucial role in maintaining the strength and functionality of paper straws by offering strong bonding and resistance against moisture. Typically, these adhesives are formulated using vinyl ester homopolymers or copolymers, and they can incorporate polyvinyl alcohol as an additive to adjust properties like tackiness, setting time, open time, and drying time. In this study, the water resistance performance of different paper straw adhesives was evaluated, which were prepared using various types of polyvinyl alcohols based on their molecular weight and hydrolysis degree.

Keywords: *Paper straw, water resistance, polyvinyl alcohol, tackiness*

1. Introduction

The global shift from single-use plastics to sustainable alternatives is evident, driven by environmental concerns and regulatory measures. Paper straws have emerged as a popular choice, addressing the need for eco-friendly alternatives (Banyi and Hassett, 2020). According to a European Commission publication (2021), 50% of EU marine litter consists of single-use plastic items. Consequently, as of July 3, 2021, single-use plastic plates, cutlery, straws, balloon sticks, and cotton buds are banned in the markets of EU Member States. While metal, glass, or silicon are excellent alternatives for reusable straws, there is also a resurgence of paper-made single-use straws (Gutierrez et al. 2019). In contrast to plastic straws, paper offers the advantage of being naturally degradable and recyclable, often repulped into newspaper or booklet paper. Moreover, paper straws boast a longer shelf life at a lower cost; while PLA straws can be stored for approximately one year, paper straws can be stored for two to three years (N. Qiu et. al. 2022). However, paper straws continue to face challenges in terms of durability. When exposed to typical beverages, they tend to lose mechanical integrity, and straws from specific brands may even impact the taste of the drink (Gutierrez et al. 2019), (N. Qiu et. al. 2022).

Producing paper straws involves a distinct process compared to the manufacturing of plastic straws. Typically, three layers of paper are utilized, and these layers are bonded together using a minimal amount of water-based adhesive with the assistance of a core-winding machine. The selection of both the paper and adhesive quality plays a crucial role in determining the performance of the paper straw, influencing the efficiency of the manufacturing process, and affecting the durability of paper straws.

The objective of this study is the evaluation of the water resistance performance of different adhesives for paper straws. These adhesives were prepared using various polyvinyl alcohols (PVOH) with distinct molecular weights and hydrolysis degrees.

2. Materials and Methods

2.1. Materials

In present study, different types of polyvinyl alcohols were supplied from multiple suppliers. PVOH is commonly available in bead or solution form in the market, it can be industrially produced through the hydrolysis of polyvinyl acetate, followed by partial or complete catalyzed hydrolysis. The degree of hydrolysis and molecular weight significantly influence the physical properties, with molecular weight affecting solution viscosity. An increase in viscosity corresponds to an increase in molecular weight.

Polyvinyl alcohol is categorized into grades of partially and fully hydrolyzed polymers. Fully or super hydrolyzed PVOH exhibits improved water resistance compared to lower hydrolysis PVOH. Additionally, the viscosity of the 4% aqueous solution at 20°C serves as a relative measure for the molar mass of the PVOH grade. The hydrolysis degree and 4% solution viscosity information can be inferred from the name of the polyvinyl alcohol. For example, the 5-88 grade is approximately 88% hydrolyzed, and its 4% solution in water at room temperature shows a viscosity of approximately 5 mPa.s. The properties of the polyvinyl alcohols utilized in this study are summarized in Table 1.

Table 1: Properties of the polyvinyl alcohols

Grade	Viscosity (1) (mPa.s)	Hydrolysis (mole %)	Type
PVOH 4-98	3.5-4.5	98.0-98.8	Fully hydrolyzed
PVOH 30-92	27.0-33.0	90.0-93.0	Medium hydrolyzed
PVOH 27-98	25.0-30.0	97.5-99.0	Fully hydrolyzed

(1) of a 4 % aqueous solution at 20°C

2.2. Formulation of paper straw adhesives

2.2.1. Preparation of PVOH solution

Polyvinyl Alcohol (PVOH) is readily soluble in both hot and cold water. To prepare a solution, the powder is gradually introduced to cold deionized water to prevent lump formation, given that the material tends to become sticky, and the likelihood of lump formation increases with rising temperatures. After achieving complete dispersion of the powder, the mixture is heated to the temperature at which the polymer becomes solubilized (90-95°C). Mixing persists at this temperature until the Polyvinyl Alcohol is entirely dissolved. The duration of this process can vary depending on the material grade and the effectiveness of the agitation system. All PVOH solutions used in this study have been prepared at a concentration of 14%.

2.2.2. Preparation of water based adhesive mixture

The water-based adhesives were prepared by blending, in order, Polymer A and the PVOH solution at a certain weight percentage for all the Blend samples. The polymer system employed was referred to as Polymer A cannot be revealed for proprietary reasons. Table 2 below provides the names and contents of the prepared blend samples.

Table 2: Water-based adhesive blends

Blend A	%95 Polymer A + %5 PVOH 4-98 solution
Blend B	%95 Polymer A+ %5 PVOH 30-92 solution
Blend C	%95 Polymer A + %5 PVOH 27-98 solution

2.3. Paper straw sample preparation

The paper straw manufacturing process exhibits similarities to other tube winding procedures. In this method, several slender paper reels pass through a bath of adhesive. Subsequently, these adhesive-coated reels are wound together to create an elongated paper cylinder. The extended cylinder tubes are later sliced into individual straw dimensions. To ensure the adhesive sets completely, the cut straws might undergo a drying phase before becoming ready for use. The final paper straws are then packaged and sent for distribution. The paper straws utilized in the research were fabricated at a speed of 100 m/min, corresponding to the maximum operational speed of the employed machinery.

2.4. Test and Analysis Methods

2.4.1. Contact angle

The water repellency of adhesive film was evaluated by determining the water contact angle measurement. The contact angle was measured by using a sessile drop method with an analyzer. The volume of drops was 1 μl, and the images of the droplet were taken with a CCD camera (Figure 1).

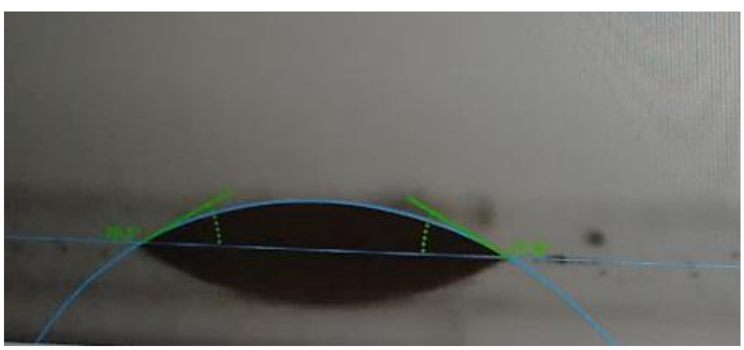

Figure 1: Contact angle measurement

2.4.2. Water resistance

To assess the durability of paper straws, three variations were created and designated as Straw A, Straw B, and Straw C, corresponding to Blend A, Blend B, and Blend C, respectively. Additionally, Straw D, composed solely of Polymer A adhesive (without PVOH), served as a reference material. Subsequently, the straws were submerged in water (20-25°C), utilizing common drinking (fountain) water for longevity testing. The time taken for delamination of the straws was recorded. Delamination, as illustrated in Figure 2, typically occurs at the ends where the cutting process is executed.

Figure 2: Delamination of paper straw after immersing to water.

3. Result

2.5. Contact angle measurements

In addition to the blends, Polymer A was utilized as a reference. All measured values are presented in Table 3.

Table 3: Contact angle measurements of adhesives

Adhesives	Water contact angle
Blend A adhesive	52.59±0.52
Blend B adhesive	59.24±1.77
Blend C adhesive	53.96±2.55
Polymer A	53.74±2.25

According to water contact angle measurements, it is expected that Blend B will show better results in terms of higher value of water contact angle. However, as we know from our previous experiences, in addition to the performance of the adhesive on its own; it is also important that it has good adhesion when combined with the straw paper.

It is well known that the aqueous solution of a partially hydrolyzed PVOH having a hydrophobic acetate group and a hydrophilic hydroxyl group exhibits lower surface tension than the aqueous solution of a fully hydrolyzed PVOH (Figure3).

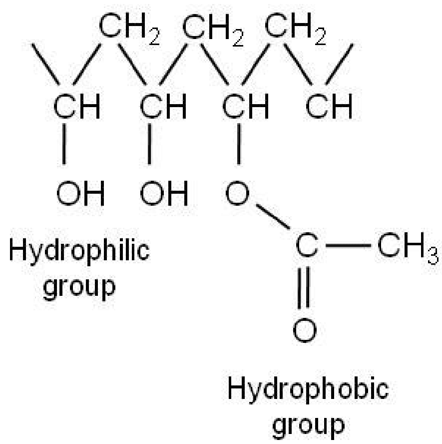

Figure 3: PVOH structure

The fully hydrolyzed PVOH has larger inclination and exhibits higher wetting power than the partially hydrolyzed PVOH. That is, from the viewpoint of adhesion it can be said that it is better to use the fully hydrolyzed PVOH for hydrophilic surfaces, such as paper or wood (Kuraray, 2023).

Having rheology sufficient to handle machine speeds cannot be directly simulated in the laboratory, so direct observation of the performance of pipettes on machine-produced paper straws provided a definitive insight.

2.6. Water resistance test results for paper straws

The delamination time in water were measured for all straws tested. The results shown in Table 4.

Table 4: Delamination time of paper straws in water

Straws	**Delamination** time
Straw A with Blend A adhesive	30 min-1 hour
Straw B with Blend B adhesive	2-3 hours
Straw C with Blend C adhesive	+8 hours
Straw D with only Polymer A	2-3 hours

4. Discussion and Conclusion

The contact angle measurements offer valuable insights into the water repellency of the adhesives used in the formulation of paper straws. As illustrated in Table 3, Blend B adhesive exhibits the highest water contact angle, indicating superior water repellency. This aligns with expectations based on the hydrophobic characteristics of the partially hydrolyzed PVOH component in Blend B. Nevertheless, it is crucial to emphasize that the evaluation of adhesive performance must consider its interaction with the paper straw, as this interaction plays a critical role in determining the adhesive's overall effectiveness.

The aqueous solution of partially hydrolyzed PVOH, characterized by a hydrophobic acetate group and a hydrophilic hydroxyl group, typically demonstrates lower surface tension than fully hydrolyzed PVOH solutions (Figure 3). This information underscores the significance of choosing fully hydrolyzed PVOH for hydrophilic surfaces, such as paper or wood. The larger inclination and higher wetting power of fully hydrolyzed PVOH contribute to enhanced adhesion, emphasizing its suitability for paper straw applications (Kuraray, 2023).

The water resistance assessments carried out on the paper straws indicate significant delamination durations, as outlined in Table 4. Notably, Blend C adhesive, which includes fully hydrolyzed PVOH and high molecular weight, exhibits outstanding performance with a delamination duration surpassing 8 hours. This outcome highlights the positive influence of opting for fully hydrolyzed PVOH on the resilience of paper straws when subjected to water. In contrast, Blend A and Blend B demonstrate delamination durations ranging from 30 minutes to 3 hours, while the reference Straw D, featuring only Polymer A adhesive, registers a delamination duration of 2-3 hours. The findings of this study have practical implications for the formulation of paper straw adhesives. By selecting the appropriate hydrolysis level and molecular weight of PVOH compatible with the main polymer, the water resistance and overall durability of paper straws can be enhanced.

In conclusion, this study sheds light on the critical role of fully hydrolyzed and high molecular weight PVOH in enhancing the water resistance of paper straw adhesives, contributing to the broader goal of developing sustainable and durable alternatives to single-use plastics. The combination of water repellency, adhesion, and durability is pivotal in ensuring the success of paper straws as a viable and eco-friendly option in the global shift away from single-use plastics.

5. Acknowledge

The authors would like to express their gratitude to Organik Kimya San. ve Tic. A.Ş. and technical teams for their technical and financial support.

References

[1] Banyi N. & Hassett J. (2020) Paper Straws: An Investigation into Surface Modification and Hydrophobization of Cellulose. STEM Fellowship Journal, vol. 6, no.1, pp. 1-10, doi: 10.17975/sfj-2020-007.

[2] European Commission, Directorate-General for Environment. (2021). Turning the tide on single-use plastics. Publications Office of the European Union, https://data.europa.eu/doi/10.2779/800074

[3] Gutierrez et al. (2019). Evaluation of Paper Straws versus Plastic Straws: Development of a Methodology for Testing and Understanding Challenges for Paper Straws. BioResources, vol. 14, no: 4, pp. 8345-8363, doi: 10.15376/biores.14.4.8345-8363.

[4] N. Qiu et. al. (2022) Evaluation and future development direction of paper straw and plastic straw. IOP Conference Series: Earth and Environmental Science, vol. 1011, no. 1, p. 012029, doi:10.1088/1755-1315/1011/1/012029.

[5] Kuraray. "Basic Physical Properties of PVOH Resin" https://www.kuraray.eu/fileadmin/product_groups/polyvinylalcohol/downloads/kuraray_poval_basic_physical_properties_web.pdf (accessed November. 30, 2023).