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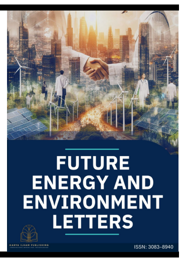

Synthesis of Eco-Friendly Inks from Waste Cooking Oil: Evaluating the Properties of Charcoal and Butterfly Pea Flower Formulations

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ABSTRACT

The development of eco-ink offers a sustainable alternative to conventional inks that often contain harmful substances. In this study, an ink formulation from waste cooking oil by combining a binder, raw materials, natural pigment, and additives. Physical properties were evaluated through viscosity, ink flow and adhesion to determine the suitability of the eco-ink formulation for practical use. The results demonstrated the broad absorption band in the range of 3000–3600 cm^{-1} corresponds to the O-H stretching mode, which indicates that the -OH group which may originate from distilled water, ethanol or glycerine and is present in both the charcoal and butterfly pea flower (BPF) inks during FTIR analysis. The viscosity was found to be 4-5 mPa.s. Since the ink flow time is shorter, it indicates a lower viscosity value. The adhesion for charcoal ink was 44.44% and for BPF was 100%. Overall, the finding highlight the potential of waste cooking oil as a viable raw material for new development of sustainable products like eco-ink.

1. Introduction

Industrial inks commonly contain toxic petroleum-based materials, which are non-renewable and harmful to the environment. It contains volatile organic compounds (VOCs) such as toluene (C7H8), benzene (C6H6), and xylene (C8H10), which are organic chemicals with a high vapor pressure at ordinary room temperatures [1]. These substances may affect the environment and human health [2]. In addition, a survey conducted by the Malaysia Palm Oil Board (MPOB) found that, 77% of the population dispose waste cooking oil (WCO) improperly, causing pollution to the environment and blockage of waterways. Therefore, converting WCO into ink offers a practical alternative for waste utilization, as it has strong potential to be transformed into useful products [3].

Previous studies have shown that palm oil is the most widely used vegetable oil in the world, surpassing soybean, rapeseed, and sunflower oil [4]. It contributes 39.6 % of global vegetable oils, is about four times more productive than other oil seeds and has the highest yield per hectare among edible oils. It is also the most widely used and cheapest type of vegetable oil [5]. However, when WCO from food preparation is disposed of improperly, it creates serious environmental issues. These

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environmental problems include things like unpleasant odors and the accumulation of oil on the surface of the water, which increases biological oxygen demand in water system [6]. On the other hand, WCO has great ability where recent oil chemistry research has shown that refined unsaturated vegetable oils can be used to produce high-quality printing inks for newspapers and magazines, such as lithographic, typographic, and offset ink [7]. However, limited studies have explored the use of WCO as a base material for ink production, especially when combined with natural pigments. This research gap creates an opportunity to develop safer, biodegradable ink using easily available materials while reducing pollution caused by waste cooking oil.

Recent research has also explored bio-based ink formulations made from other vegetable oils. For instance, [8] successfully formulated plant-based ink using waste soybean oil with natural pigments demonstrating the potential of food industry waste as a sustainable ink ingredient. In another study, researchers developed offset printing inks using Karanja oil as a sustainable substitute for linseed oil, which showed satisfactory printing performance and environmental advantages [9]. These innovations reflect the growing interest in using vegetable oils for eco-friendly ink production. Nevertheless, research involving waste palm cooking oil and natural pigments for general purpose ink is still very limited.

The eco-friendly ink is composed of only organic material, making it safer to use compared to conventional ink, which often contain chemicals, heavy metals and VOCs that can harm the environment, to ensure compatibility and cost effectiveness, two natural pigments were selected which are butterfly pea flower (BPF) and charcoal. These pigments were chosen due to their availability, low in cost, and environmentally beneficial, making them suitable for eco-ink development. Gum Arabic was used as the natural binder to improve ink adhesion to paper. Linseed oil acted as a fast-drying agent to enhance absorption and reduce smudging. Glycerin served as a humectant to retain moisture and smooth ink flow, while ethanol functioned as a preservative to prevent any microbial growth. Tween-80 was added as an emulsifier to ensure a homogenous mixture. It was specifically selected because of its biosafety, biocompatibility, and biodegradability. In addition, it has been proven to be effective in forming stable microemulsions with oils like coconut and olive oil [10].

The ink production process involved five phases. The first phase was raw material preparation, followed by binder preparation, ink formulation, chemical and physical characterization, and finally ink application. In this study, only physical parameters used to evaluate the ink formulation and drawing paper was selected as the standard substrate for the ink application.

Therefore, this research aimed to formulate an eco-friendly ink using WCO. It also aims to characterize its physical properties like viscosity, ink flow and adhesion. In addition, the study evaluated the performance of WCO-based eco-friendly ink when applied on drawing paper.

2. Methodology

2.1 Materials

Waste Cooking Oil (WCO) was collected from households in Batu Pahat. Glycerin, Tween-80 emulsifier, Arabic gum, triethanolamine, linseed oil, Butterfly Pea Flower powder (BPF), charcoal powder, activated charcoal powder, cheesecloth, bleaching earth, filter paper, and empty brush pen were purchased online. Distilled water and ethanol were provided in the laboratory.

Preparation of Raw Materials

WCO was filtered using a cheesecloth to remove large impurities particles. Then, 25 g WCO was poured into a 100 ml beaker. The 25 g WCO was heated at 100°C using a hot plate. Next, 0.5 g activated charcoal powder and 1.75 g bleaching earth were added to the 25 g WCO and mixed. The temperature was maintained at 100°C for 30 minutes. After that, the mixture was filtered through filter paper.

Preparation of Binder

1.5 grams of Arabic gum were weighed using an analytical balance and dissolved in a 100 ml beaker using 14 ml of distilled water. Arabic gum was stirred using a glass rod. After it had fully dissolved, 6 ml of Linseed oil, 6 ml of glycerin and 2 ml of Tween-80 were measured using a measuring cylinder and added into the dissolved gum Arabic. The mixture was mixed well.

Ink Formulation

The prepared binder was slowly added to the purified oil while stirring it continuously. Then the mixture was divided evenly into two 100 ml beakers, one for charcoal ink and another for BPF ink. Each beaker contained 45 mL of binder. Next, for the charcoal ink, 3.8 g of charcoal powder was gradually added to the beaker while stirring it. Add 10 ml of distilled water, 4.5 ml of Tween-80 and 3 ml of ethanol, each added one by one while continuously stirring to ensure even dispersion. For the BPF ink, 5.5 g of butterfly pea flower powder was added in the same manner, followed by 15 ml of distilled water, 5.5 ml of Tween-80 and 3 ml of ethanol. Each composition was added gradually while stirring to ensure a uniform and homogeneous mixture. Both mixtures were mixed until homogeneous, and pH was checked. Triethanolamine was added dropwise until the range of 8.5-9.5 *pH was reached.*

2.5 Physical Characterization

Physical characterization evaluated the usability of the ink through various tests. The viscosity of the ink was measured using the flow time method. A pipette was filled with 10 ml of ink, and the time taken for the ink to flow out completely was measured. Next, the same step was repeated for distilled water. Then, the viscosity of the ink was calculated using Eq. (1) below:

$$\eta \text{ ink} = \eta \text{ distilled water } \times \frac{t\ ink}{t\ distilled\ water} \tag{1}$$

Where η ink is the viscosity value of the ink, η distilled water is the viscosity value of distilled water (1 mPa.s), time taken (t) ink is the time taken for the ink to flow out completely, and t distilled water is the time taken for the distilled water to flow out completely. Based on the viscosity test, the ink flow could also be determined. The suitable viscosity for this ink was in the range of 2–5 mPa·s. A higher viscosity of the ink indicated longer flow times, while a lower viscosity indicated shorter flow times.

The adhesion of the ink was measured using a tape test. The ink was applied to the paper and allowed to dry for 1 minute. After 1 minute, a grid line was drawn, and a piece of adhesive tape was pressed onto the surface of the paper. The tape was then quickly peeled off at an angle of 180 degrees. Next, the tape was examined to determine how much ink had come off with it. The adhesion was measured by using the formula for the percentage of ink remaining on the paper as in Eq. (2) below:

$$\text{Percentage of ink remaining (\%)} = \frac{amount\ of\ the\ remaining\ area}{total\ ink\ area\ applied} \times 100\% \quad \textbf{(2)}$$

The last test used to analyze the physical characterization of the ink was the water resistance test. The ink was applied to the paper by drawing a grid line and allowed to dry for 1 minute. Two drops of distilled water were applied to the surface of the cross-cut line and spread using a ruler. After that, the sample was left to dry for 30 seconds, and the distilled water was gently removed using tissue. The ink was then visually inspected for any changes such as smudging. Equation 2 was used to determine whether the ink had good water resistance based on the percentage of ink remaining after water exposure.

3. Results

3.1 Viscosity Test

Table 1 shows the time taken for both charcoal ink and BPF ink to flow out compared by distilled water as a reference.

Table 1
Time taken for ink flow

Ink Type	Reading 1 (s)	Reading 2 (s)	Reading 3 (s)	Average (s)
Charcoal	58.30	53.38	54.83	55.50
Butterfly Pea Flower	65.62	58.50	57.68	60.60

The time it took for the distilled water to flow out completely was 12.7 seconds. The viscosity value for both inks was determined using Equation 1 with the average for each ink being the value for t ink. The viscosity for charcoal ink was 4.37 mPa.s, and for the BPF ink was 4.77 mPa.s. This shows that the charcoal ink has a lower viscosity than the BPF ink. Both ink viscosities are between the range 2-5 mPa [19], which is a suitable viscosity for a regular ink. It helps to indicate each ink flow time since a lower viscosity of the ink indicates shorter flow times.

3.2 Ink Flow Test

Since the viscosity test is done using the flow time method, the time taken for the ink to flow out is the result for this test. Both ink shows a decrease in seconds the more trial is run, with the Charcoal shortest time to be 53.38 seconds and the BPF 57.68 seconds, with distilled water as the blank sample (12.70 seconds). This test is required to know the time required by a fluid to flow. It shows that the inks are denser than distilled water, making it take more time to flow through.

3.3 Adhesion Test

The visual grid consists of 108 small boxes drawn on the ink surface. The percentage of ink remaining on the paper was calculated using Equation 2. For charcoal ink, 48 boxes contained some ink remaining after the tape test as shown in Figure 1 (a). This indicated a calculated adhesion percentage of approximately 44.44%. As shown in Figure 1 (b) for the butterfly pea flower ink, visual inspection suggested that nearly all boxes contain their ink after tape test. Out of 108 boxes nearly 108 boxes contained intact ink, representing a very strong adhesion with 100 % percentage.

A lot of black residues were transferred to the tape. The charcoal ink applied in this study contains undissolved charcoal powder. Solid particles are loose at the physical level, and the tape can easily lift the charcoal particles. Consequently, the amount of residue on the tape may not represent only poor adhesion but also show the physical property of charcoal powder wanting to release [22]. For butterfly pea flower ink, there was no ink transfer and tape appeared clear.

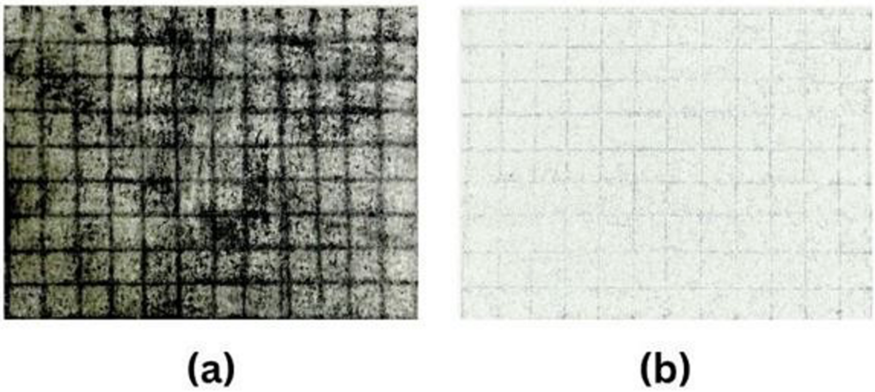

Fig. 1. (a) Tape test after removal from the charcoal ink, (b) Tape test after removal from the surface Butterfly Pea Flower 3.4

3.4 Application of Ink

The formulated ink applied with a 4.5 mm brush pen demonstrated good spread ability and initial appearance on paper as shown in Figure 2 (a) charcoal ink application and 2 (b) BPF ink application. After two weeks, there were sporadic and broken lines during application due to the irregular ink flow. There are probably several causes for this problem. First, clogging in the pen's feed system may result from an increase in ink viscosity brought on by solvent evaporation over time [23]. The smooth flow of ink may also be disrupted by phase separation, in which pigments sink to the bottom and the binder gets more concentrated. Additionally, eco-friendly ink formulations are vulnerable to microbial growth in the absence of suitable antimicrobial agents, which can result in the formation of biofilms and additional blockages inside the pen. It is interesting to note that the ink performed flawlessly with no indications of drying or flow disruption when applied using different application techniques like a paintbrush and stamping.

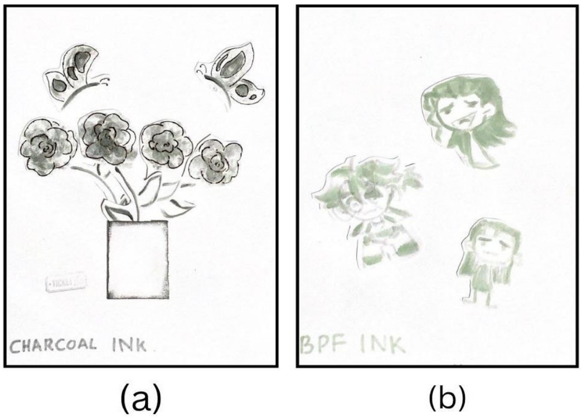

Figure 2 (a) Charcoal ink application, (b) BPF ink application

4. Conclusions

The experimental results revealed several important differences between Butterfly Pea Flower (BPF) ink and charcoal ink. BPF ink recorded a viscosity of 4.77 mPa·s with a flow time of 60.60 seconds, while charcoal ink had a slightly lower viscosity of 4.37 mPa·s and a faster flow time of 55.50 seconds. The adhesion test showed that BPF ink demonstrated excellent bonding with 100% ink retention, while charcoal ink achieved only 44.44% adhesion due to the presence of undissolved particles.

The development of this ink has shown strong potential in addressing both performance and environmental concerns. Laboratory evaluations confirmed important properties such as adhesion test indicating its suitability for further development. However, However, the formulation is still in the early stage of development and requires more detailed studies and testing before reaching full commercial potential. Future improvements should focus color consistency, drying time, and spreading quality. With continued refinement, this ink could contribute to sustainable practices and offer a safer, eco-friendly alternative suitable for commercialization.

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