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Evaluation of Pollution Parameters of Wastewater from Recycling of Waste Egg Cartons after Centrifugation

Atık Yumurta Kartonlarının Geri Dönüşümünden Kaynaklanan Atık Suyun Santrifüjleme Sonrası Kirlilik Parametrelerinin Değerlendirilmesi

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Abstract

This study investigates the effectiveness of centrifugation for the solid-liquid physical phase separation of wastewater generated during the recycling of waste egg cartons. The environmental impacts of wastewater discharge constitute a significant problem, particularly in the paper recycling sector. In this context, the pollution potential of wastewater obtained through centrifugation was examined by performing solid-liquid phase separation. In the study, wastewater obtained in a laboratory environment during the recycling of waste egg cartons was subjected to centrifugation at different operating speeds (1000 RPM and 3000 RPM) and durations (1-10 minutes). Water quality parameters such as pH, electrical conductivity, total dissolved solids, suspended solids, chemical oxygen demand, turbidity, oxidation-reduction potential, and dissolved oxygen were analyzed. In addition, analytical methods such as Fourier Transform Infrared (FT-IR) spectroscopy and UV-Vis spectrophotometry were used to evaluate the comprehensive impact of wastewater. When the experimental findings were examined, it was observed that as a result of separating the wastewater by centrifugation, the COD value decreased from 580 mg/L to 265 and 247 mg/L, the Suspended Solids (SS) value from 236 mg/L to 46 and 27 mg/L, and the turbidity value from 52 NTU to 17 and 9 NTU in the control samples. There was no significant change in pH values of 6.5-7.1 and 6.3-6.7. The results obtained were statistically evaluated and correlation analysis was performed. These results showed that the centrifugation process separated suspended solids in wastewater in phases and physically affected turbidity. It was understood that at higher centrifugation speeds (3000 RPM), more phase separation occurred and more stable performance was achieved compared to the processes carried out at 1000 RPM. In conclusion, the study showed that the centrifugation method for phase separation of wastewater obtained during paper recycling at various durations and speeds facilitated the determination of physical pollution parameters.

Özet

Bu çalışma, atık yumurta kartonu geri dönüşümünde oluşan atık suyun katı-sıvı fiziksel faz ayrıştırılması için santrifüjleme yönteminin etkinliğini araştırılmasıdır. Atık su deşarjının çevresel etkileri, özellikle kâğıt geri dönüşüm sektöründe önemli bir sorun teşkil etmektedir. Bu bağlamda, santrifüjleme işlemi ile elde edilen atıksularda katı-sıvı faz ayrıştırılması yapılarak atıksuyun kirlilik potansiyeli incelenmiştir. Çalışmada, atık yumurta kartonlarının geri dönüşümü sırasında labaratuvar ortamında elde edilen atıksu, farklı çalışma hızlarında (1000 RPM ve 3000 RPM) ve sürelerde (1-10 dakika) santrifüjleme işlemine tabi tutulmuştur. Çalışmada pH, elektriksel iletkenlik, toplam çözünmüş katı madde, askıda katı madde, kimyasal oksijen ihtiyacı, bulanıklık, oksidasyon-redüksiyon potansiyeli ve çözünmüş oksijen gibi su kalitesi parametreleri analiz edilmiştir. Ayrıca, atıksuların kapsamlı etkisini değerlendirmek için Fourier Dönüşümlü Kızılötesi (FT-IR) spektroskopisi ve UV-Vis spektrofotometri gibi analitik metotlar kullanılmıştır. Deneysel bulgular incelendiğinde, santrifüjleme işlemi ile atık suyun ayrıştırılması sonucunda kontrol örneklerinde 580 mg/L olan KOİ değeri 265 ve 247 mg/L'ye, 236 mg/L olan AKM değeri 46 ve 27 mg/L'ye, 52 NTU olan bulanıklık değeri ise 17 ve 9 NTU'ya düşürülmüştür. 6,5-7,1 ve 6,3-6,7 olan pH değerlerinde ise önemli bir değişiklik olmamıştır. Elde edilen sonuçlar, istatistik olarak değerlendirilmiş ve korelasyon analizi yapılmıştır. Bu sonuçlar santrifüjleme işlemi ile atıksudaki askıda katı maddeleri, faz olarak ayrıştırmış ve fiziksel olarak bulanıklığa etki ettiğini göstermiştir. Daha yüksek santrifüj hızlarında ise (3000 RPM) daha fazla faz ayrışımın olduğu ve 1000 RPM hızında yapılan işlemlere kıyasla daha stabil performans oluştuğu anlaşılmıştır. Sonuç olarak, çalışmada kâğıt geridönüşüm esnasında elde edilen atıksuyun santrifüjleme yöntemi ile çeşitli sürelerde ve hızlarda faz ayrıştırılmasında, fiziksel olarak kirlilik parametrelerini belirlemede kolaylık sağlamıştır.

INTRODUCTION

Environmental pollution has emerged as one of the most pressing global issues of our time. However, industrialization and increasing production activities are among the primary factors contributing to the contamination of water resources. These activities have exacerbated their impact on natural ecosystems, particularly through wastewater discharge, posing significant threats to aquatic systems, soil health and human well-being (Huang and Logan 2008, Kamali and Khodaparast 2015, Izadi et al. 2018). It has already well documented by numerous researchers that wastewater generated from industrial processes may contain heavy metals, organic pollutants, suspended solids, and various chemical components, which, when directly discharged into the environment, can have severe adverse effects on ecosystems (Pokhrel and Viraraghavan 2004, Toczyłowska-Mamińska 2017). In particular, toxic compounds reaching water bodies endanger aquatic life and deteriorate the quality of drinking water reserves (Huang and Logan 2008, Kamali and Khodaparast 2015). Therefore, wastewater treatment is of paramount importance for environmental sustainability.

The paper recycling industry is one of the sectors characterized by high water consumption and significant wastewater generation (Čabalová et al. 2011, Kardeş et al. 2024). Typically wastewater produced during the paper recycling process contains fine cellulose fibers, fillers, adhesives, ink residues, and various chemicals (Hubbe et al. 2016, Han et al. 2021). However, the high organic load, turbidity properties, and biological oxygen demand of these wastewaters make treatment processes more complex (Pokhrel and Viraraghavan 2004). Conventional biological treatment systems may be insufficient for removing certain pollutants present in paper recycling wastewater while the use of physicochemical treatment methods is becoming increasingly significant (Nasser et al. 2013, Bayram et al. 2025). Peşman (2010) applied deinking and bleaching processes during the recycling of waste newspapers and magazines. He used sulfinic acid (FAS), peroxide, sodium borohydride and sodium dithionite compounds in the bleaching process and comparatively investigated the brightness values of the regenerated papers. Wong et al. (2006) investigated the effect of various polyacrylamide materials on the efficiency of pulp and paper mill wastewater treatment and determined the most suitable material for flocculation. Chaudhari et al. (2010) investigated the effect of pH on COD and color removal, the effect of coagulant concentration on COD, and pH by performing coagulation on paper mill wastewater, which reduces chemical oxygen demand and improved color.

Given the complex nature and pollutant diversity of wastewater from paper recycling, there is a need to investigate alternative, complementary or facilitating treatment techniques beyond traditional chemical and biological treatment methods. In this context, physical treatment methods such as centrifugation have attracted attention due to their potential to efficiently remove particulate matter and reduce turbidity without the use of additional chemicals. Integrating to the conventional treatment process may provide significant advantages in terms of environmental sustainability and compliance with discharge standards. As is known, the centrifugation process works by treatment the wastewater at high rotational speeds to precipitate solid particles and to provide solid-liquid separation. Studies have shown that centrifugation significantly reduces the amount of suspended solids and significantly improves turbidity levels (Özkan and Şahin 2023, Kardeş et al. 2024). It could be important to determine the efficiency of the centrifugation technique during seperation paper recycling wastewater can be crucial for reducing environmental impacts and preserving water resources.

In this study, the effects of centrifugation at various RPM levels and durations on pollution parameters in paper recycling wastewater were evaluated. The primary objective of the study is to examine the impact of the centrifugation process on key water quality parameters, including; pH, electrical conductivity (EC), total dissolved solids (TDS), suspended solids (SS), chemical oxygen demand (COD) and turbidity (NTU). Additionally, the study investigates the effects of centrifugation using FT-IR and UV-Vis analytical techniques to scientifically validate the efficiency of this method, in terms of paper recyling wastepaper. A statistical assessment was conducted using correlation analysis to compare the obtained results. The reliability of the study and the interrelationships among the analyzed parameters were also examined.

MATERIAL AND METHODS

Material

In this study, waste egg cartons were used as the raw material. Initially, the egg cartons were shredded into small pieces and soaked in water for 24 hours to facilitate the recycling process. During the recycling, the resulting paper pulp was separated, and the wastewater generated in this process was collected for further analysis. The collected wastewater was filtered through a 200-mesh sieve to remove fibrous and non-fibrous particles. Subsequently, the filtered wastewater was transferred into standard centrifuge tubes, with each tube containing 20 mL of sample (6 × 20 mL = 120 mL per centrifugation process) (Özkan and Şahin 2023). The centrifugation process was conducted at two different rotational speeds (A: 1000 RPM, B: 3000 RPM) and at varying durations (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10 minutes for each speed). The experimental design graph of the study is given in Figure 1.

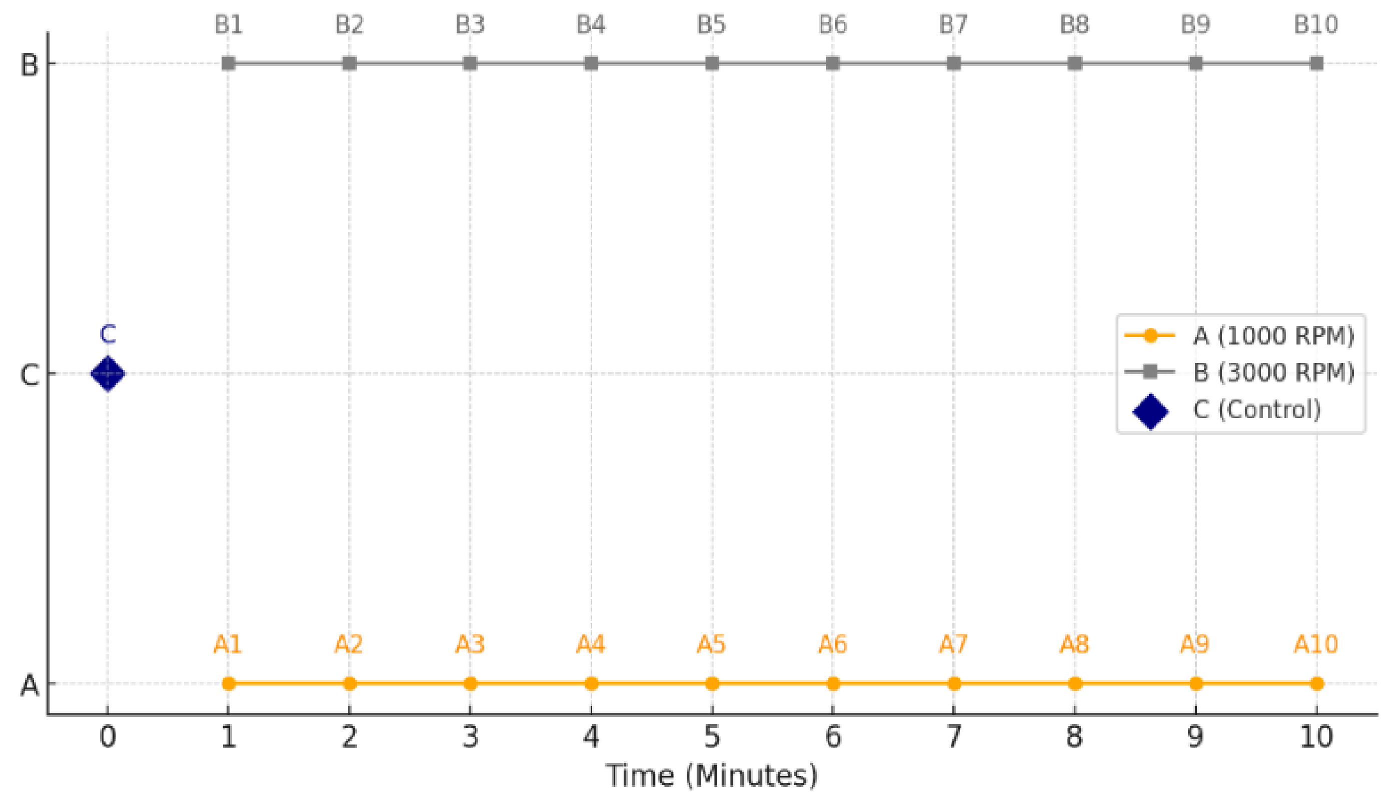


Figure 1. Experimental design graph

Methods

Various tests and analyzes of the obtained wastewaters from the recycling process of waste egg cartons were performed and interpreted comparatively. Important analysis methods such as pH, Electrical Conductivity (EC), Suspended Solids (SS), Turbidity, Oxidation Reduction Potential (ORP), Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Dissolved Oxygen Content (DO), UV/Visible Spectrophotometer, Fourier Transform Infrared (FT-IR) and Correlation Analysis were performed and the relationships between the parameters were examined.

Measurement and Analysis

The pH, EC and TDS analyses were conducted in accordance with standard measurement methods using a multiparameter water analysis device, Apera PC5 (Wuppertal, Germany), which was calibrated before each measurement. Turbidity measurements were performed using the Hanna HI 93703 turbidity meter (Woonsocket, USA). ORP measurements were carried out in compliance with standard procedures using a multiparameter measurement device (Jinan Huiquan Electronic Co. Ltd, China). The dissolved oxygen (DO) concentration was automatically measured using a HACH Pocket Colorimeter. Suspended solids (SS) were determined according to the standard method (APHA 2005) using the 2540 D method.

Chemical Oxygen Demand (COD) was measured using a HACH colorimetric test kit following the APHA 2005 standard, utilizing COD test kits ranging from 100 to 2000 mg/L. The UV/Visible Spectrophotometer analysis was conducted using a Peak USA c-7100 UV/Visible single-beam spectrophotometer (Houston, TX 77084) with a spectral bandwidth of 2 nm.

FTIR measurements were performed using the FT/IR-4700 Type A instrument, covering a wavelength range of 400–4000 cm^{-1}, with spectra obtained at a resolution of 4 cm^{-1}. Statistical analysis of the findings was carried out using the "R" software, applying correlation analysis. Based on the results obtained from the analyzed parameters, correlation matrices were conducted for comparative evaluation.

RESULT AND DISCUSSION

It has been widely documented in the literature that pH is a critical control parameter in various physical, chemical, and biological treatment processes aimed at preserving water quality and enhancing its potential for reuse. For these processes to function effectively, pH levels must be maintained within an optimal range (Han et al. 2021).

One of the commonly used indicators in wastewater quality monitoring is Total Dissolved Solids (TDS), which is important for assessing the environmental impact of chemical constituents such as minerals, salts, and metals. Particularly in recycled paper production facilities, it has been reported that a significant portion of dissolved organic compounds can be removed through secondary treatment stages within a three-step purification process (Remya and Lin 2011).

Another key water quality parameter is the oxidation-reduction potential (ORP), a numerical index used to measure electron transfer processes occurring in the aquatic environment (Račys et al. 2010). Similarly, dissolved oxygen (DO), which is essential for sustaining aquatic life, is a major parameter used in the classification of surface water resources under the Turkish Surface Water Quality Regulation.

Moreover, turbidity results from both dissolved and suspended organic and inorganic matter in water and serves as an indirect indicator of cleanliness or contamination by influencing light transmittance. It is well established that physical and chemical treatment methods such as coagulation, sedimentation, and filtration can significantly reduce turbidity (Sawyer et al. 2003).

ORP, which reflects the tendency of substances in water to undergo oxidation (electron loss) or reduction (electron gain), is also commonly used to monitor the effectiveness of disinfection processes (Kim et al. 2000). In this context, the experimental investigation of these key parameters highlighted in the literature as critical for assessing water quality offers a comparative perspective on the effectiveness of different applications. Accordingly, this study monitored the temporal variations of these parameters in wastewater samples collected from Group A and Group B, revealing significant differences between the two groups.

The main parameters include pH, ORP, EC, TDS DO and Turbidity. The variation of these parameters is important for determining the chemical and physical properties of water. Figure 2 shows the comparison of different water quality parameters (pH, ORP, EC, TDS, DO and Turbidity) for Group A and Group B. The pH values for Group B range between 6.5 and 7.1, whereas Group A exhibits values between 6.3 and 6.7. In Group B, a noticeable upward trend is observed in the later stages of the samples, while Group A demonstrates more irregular fluctuations. Regarding the oxidation-reduction potential (ORP) values, Group B fluctuates within the range of 200–280 mV, whereas Group A varies between 170 and 265 mV.

ORP levels in Group B exhibit an increasing trend over time, while Group A maintains relatively lower values with a more variable pattern. In terms of electrical conductivity (EC), Group B generally remains within the range of 1360–1410 µS/cm, while Group A fluctuates between 1330 and 1420 µS/cm. The EC levels of Group B follow a more stable trajectory, whereas Group A exhibits more pronounced variations. With respect to total dissolved solids (TDS), Group B maintains a higher and more stable profile, ranging from 680 to 710 ppm, whereas Group A varies between 660 and 690 ppm. Group B starts at a relatively higher level and exhibits minimal change over time. In terms of dissolved oxygen (DO), Group B demonstrates values ranging from 2.2 to 3.4 mg/L, whereas Group A fluctuates between 2 and 3 mg/L. Group B generally maintains higher DO levels, whereas Group A displays lower and more variable trends. When analyzing turbidity levels, Group A exhibits values ranging from 12 to 21 NTU, whereas Group B remains at significantly lower levels (8–12 NTU) with a stable trend. Turbidity in Group A decreases over time, while Group B maintains a nearly constant pattern. The control sample, on the other hand, presents a considerably high initial value of approximately 52 NTU.

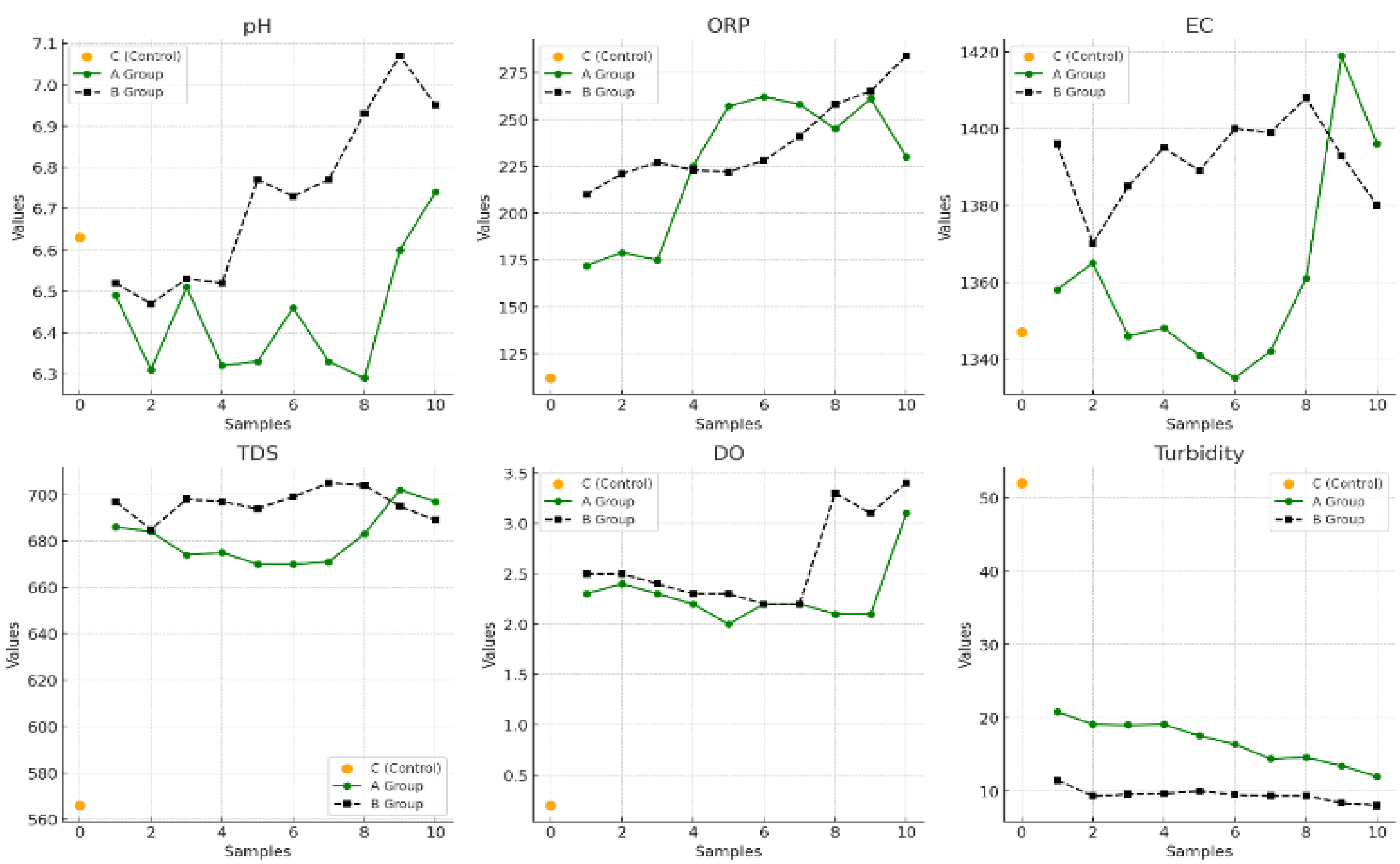


Figure 2. Comparison of groups A and B in various parameters

Suspended Solids (SS) Results

Figure 3 shows the comparison of suspended solids (SS) concentrations in wastewater samples. The data are categorized into two distinct groups: Group A (1000 RPM) and Group B (3000 RPM). Overall, the SS values in Group A were found to be higher than those in Group B, highlighting the difference in separation efficiency between the two centrifugation speeds. A decreasing trend in SS concentrations was observed across the samples. Notably, the first and second samples exhibited elevated SS values, followed by a significant decline in the subsequent samples. The control sample was measured to have an SS concentration of 236 mg/L.

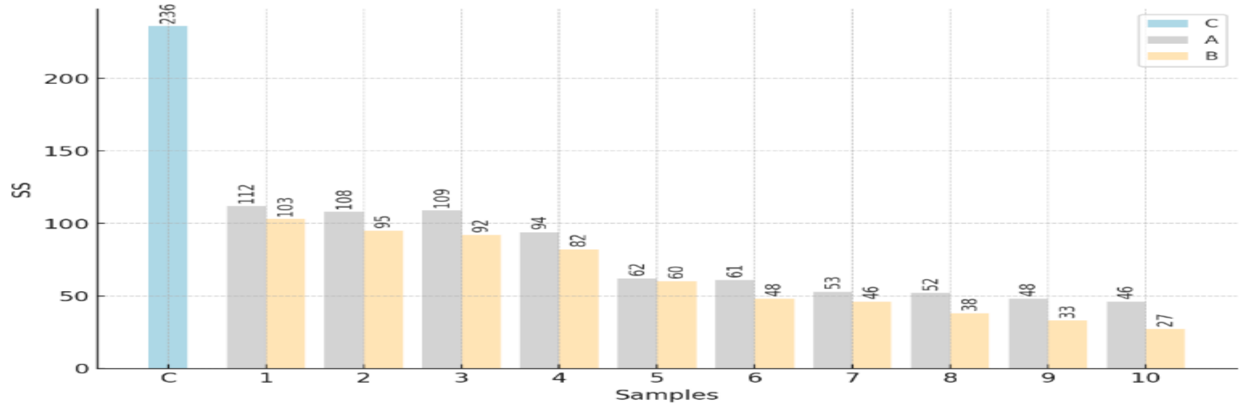


Figure 3. Suspended solids (SS) results

As the centrifugation time increased, a notable reduction in SS values was observed in both groups, indicating enhanced separation of particulate pollutants. The most effective results were obtained from the sample centrifuged for 10 minutes. At this point, the SS concentration was measured as 46 mg/L for Group A and 27 mg/L for Group B. These findings demonstrate that higher centrifugation speed and extended duration significantly improve solid-liquid separation efficiency. In conclusion, there are clear differences between Group A and Group B in terms of SS removal, and a general decreasing trend is evident across all samples.

Chemical Oxygen Demand (COD) Results

Figure 4 presents the comparison of Chemical Oxygen Demand (COD) values of the samples. COD is a crucial water quality parameter that indicates the amount of oxygen required to chemically oxidize organic matter present in the water. The graph displays COD values for two different data sets: group A (1000 RPM) and group B (3000 RPM). Overall, the COD values of group A were found to be higher than those of group B, and this trend was consistent across all samples. This suggests that group A may contain a higher amount of organic matter or a greater pollution load compared to group B.

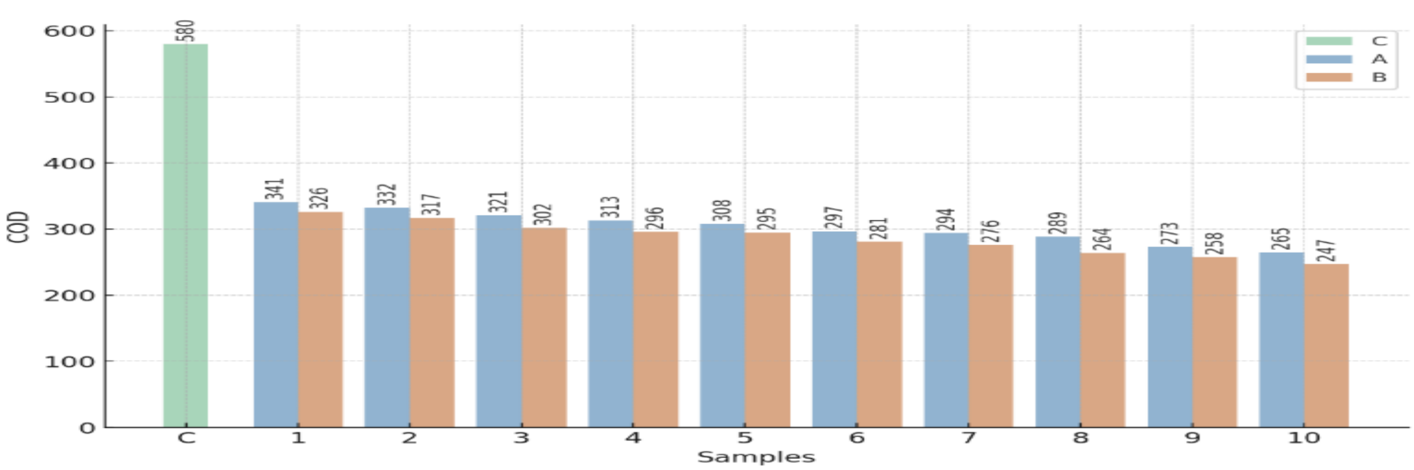


Figure 4. Chemical oxygen demand (COD) results

Upon examining the results, the COD value of the control sample was measured as 580 mg/L. As the centrifugation time increased, a noticeable decrease in COD levels was observed in both groups. This indicates that the organic load or pollutants in the system gradually decreased over time, leading to improved water quality. Specifically, by the end of the centrifugation process, COD values of 265 mg/L for group A and 247 mg/L for group B were obtained. This decline clearly demonstrates the effectiveness of the applied treatment in reducing organic pollution and highlights the impact of different centrifugation speeds on water purification efficiency.

Fourier Transform Infrared (FT-IR) Results

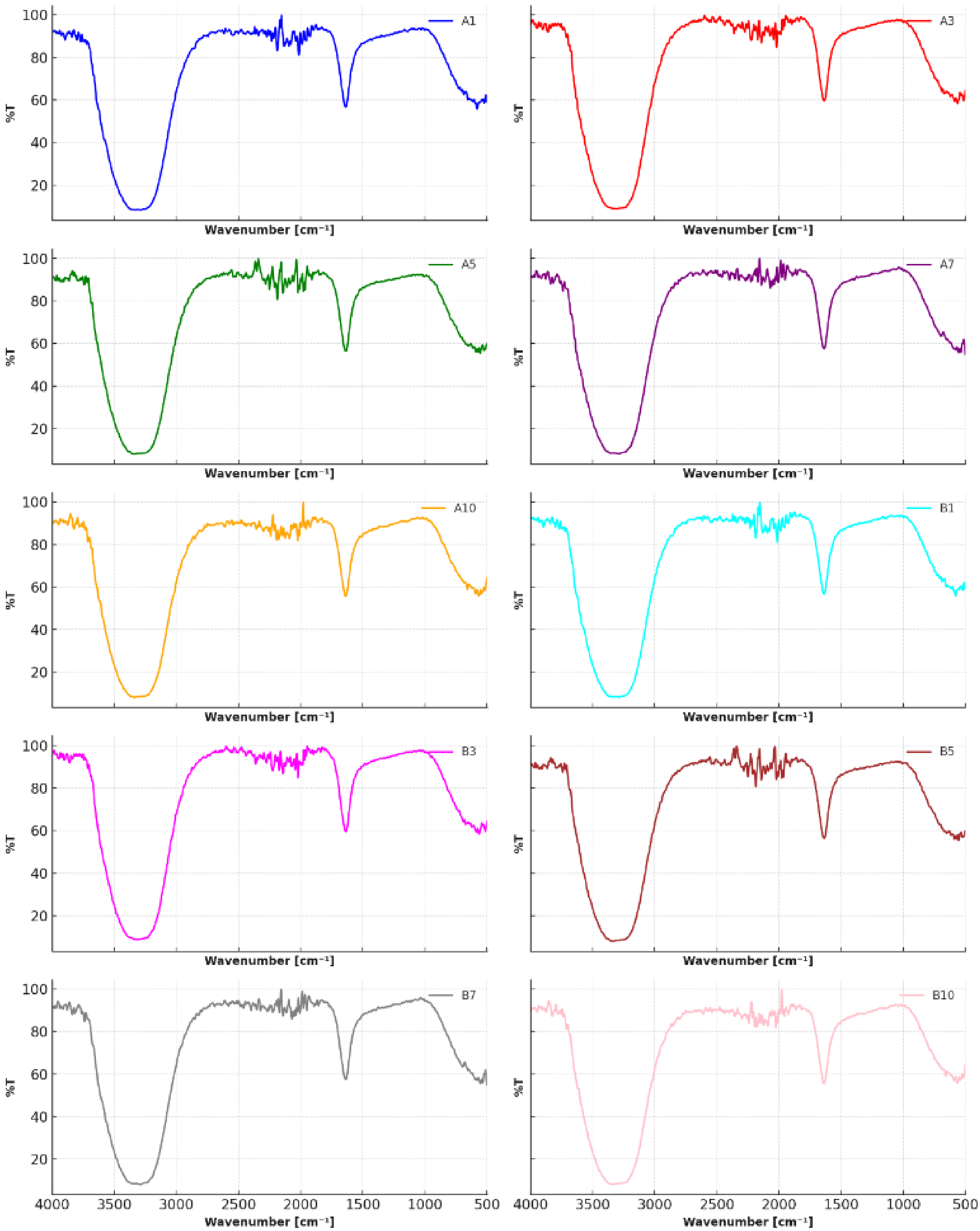
Figure 5 shows the Fourier Transform Infrared (FT-IR) results. FT-IR spectroscopy was conducted on wastewater samples using a resolution of 4 cm^{-1} over the spectral range of 4000 to 400 cm^{-1}. This technique captures the infrared absorption, reflection, transmission, or emission characteristics of the sample to generate a spectrum that reveals information about its molecular composition. FT-IR is especially useful for detecting and quantifying compounds containing specific functional groups such as amides, carboxylic acids, and C–H bonds (Ikhtiyarova et al. 2012, Belcaid et al. 2024).

The FT-IR spectroscopy results show the relationship between the wavenumber (cm^{-1}) and percent transmittance (%T) of the spectra of different samples. FT-IR analysis plays an important role in determining the chemical composition and functional groups of the samples (Bayram et al. 2024). The broadening observed in the 3200–3600 cm^{-1} region is attributed to O–H stretching vibrations, indicating the presence of water molecules adsorbed onto the surface. In contrast, the bands in the 1650–1700 cm^{-1} range, corresponding to C–O and C=O stretching, exhibited increased sharpness. This spectral change suggests the formation of new carboxyl functional groups as a result of oxidation processes occurring during the treatment. In addition, The absorption bands observed in the regions of 466–470 cm^{-1} and 528–535 cm^{-1} indicate the presence of clay and silicate minerals, while the bands in the range of 1612–1622 cm^{-1} are attributed to aromatic C=C stretching vibrations (Georgakopoulos et al. 2003). Although Group A and B samples exhibit similar band patterns in general, there are significant intensity differences in some spectra. While stronger absorption bands are observed in some regions in the B group spectra, bandwidths and intensities may differ in the A group samples.

UV-Vis Spectroscopy Results

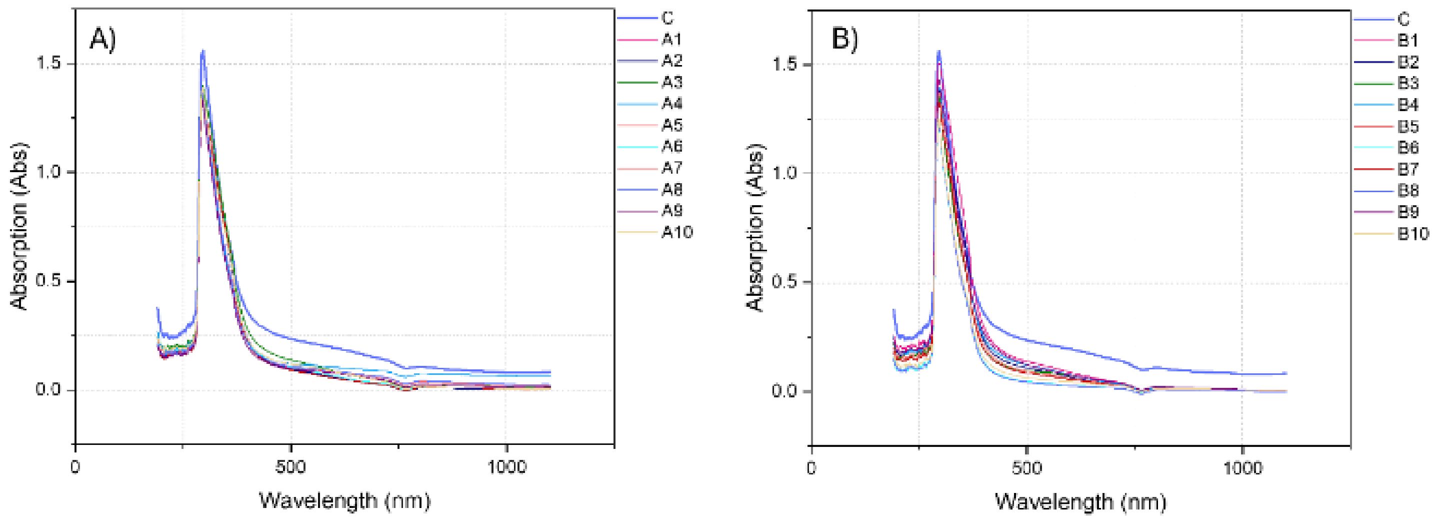
Figure 6 shows the results of UV-Vis spectroscopy. The ultraviolet and visible region light absorption properties of different samples were compared. When the spectra are examined, it is seen that all samples have a characteristic absorption peak in a certain wavelength range. Especially the peaks showing high absorption in the 200-300 nm range indicate the presence of conjugated systems, aromatic compounds or functional groups with $\pi \rightarrow \pi^*$ electronic transitions. Such transitions are usually observed in compounds containing aromatic rings, carbonyl groups or double bonds.

Although there are spectral similarities in both graphs, it is noteworthy that there are differences in the absorption intensities of some samples. These variations in the absorption curves may be related to the concentration, molecular structure or interactions of the samples in solution. The fact that the spectra show relatively low absorption values in the high wavelength region (above 400 nm) indicates that these samples are mostly active in the ultraviolet region and do not exhibit significant absorption in the visible region.



.Figure 5. FT-IR results

Figure 6. UV-Vis results



Correlation Results

The correlation matrices presented in Figure 7 show the relationships between various water quality parameters for two different data sets (A and B). Correlation coefficients range from -1 to +1, with positive values indicating a strong linear relationship between variables and negative values indicating an inverse relationship.

In Figure 7A, high positive correlation values were observed between COD and SS, Turbidity (0.96 and 1.00 respectively). High positive correlation values were also observed between SS and Turbidity (0.96). This indicates that as the organic matter load of the water increases, the suspended solids and turbidity also increase. On the other hand, there is a negative correlation between DO and COD, turbidity, SS (-0.91, -0.91 and -0.81 respectively), indicating that as the pollution of the water increases, the amount of dissolved oxygen decreases. The correlation between pH and other parameters is lower. In Figure 7B, very high positive correlations (0.98 and 0.97) are observed between COD and SS and turbidity. This shows that water quality variables are directly related to each other. Parameters such as ORP, DO and TDS have strong inverse correlations with COD (-0.96, -0.92 and -0.96). This indicates that the oxidation-reduction potential and the amount of dissolved oxygen decrease significantly with deteriorating water quality. Furthermore, a strong positive correlation (0.86) was observed between EC and TDS, indicating that the conductivity of water is directly related to the amount of dissolved solids.

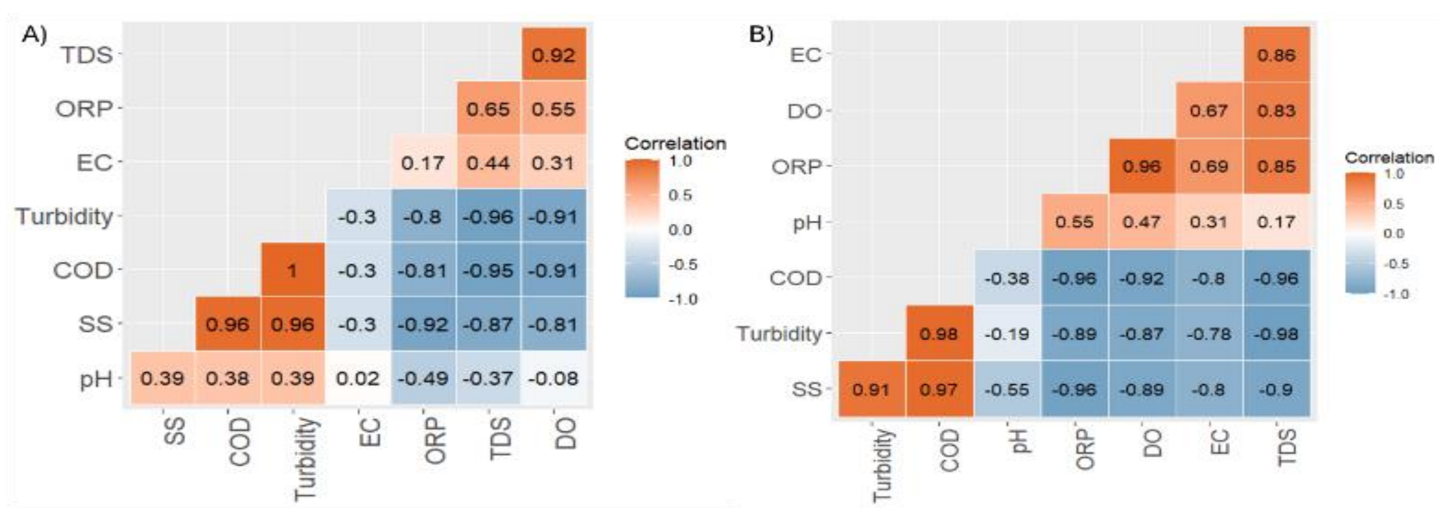


Figure 7. Correlation matrix

CONCLUSION

This study investigated the key pollution parameters of wastewater generated from the recycling of waste egg cartons by centrifugation procedures. As expected, the centrifugation significantly impact on suspended solids, turbidity and organic pollutants generated from paper recyling process. Comparing treatments performed at different rotational speeds (1000 RPM and 3000 RPM) and durations, it was found that higher centrifugation speeds resulted in higher participation efficiencies. The findings revealed that Group B (3000 RPM) exhibited more stable water quality parameters and achieved greater reductions in turbidity, suspended solids (SS) and chemical oxygen demand (COD) levels compared to Group A (1000 RPM). Correlation analysis confirmed that parameters such as COD, SS and turbidity were strongly interrelated and that higher pollutant loads resulted in a decrease in oxidation-reduction potential (ORP) and dissolved oxygen (DO) levels with an increase in suspended solids. Fourier Transform Infrared (FT-IR) spectroscopy and UV-Vis spectroscopy analyses supported those findings, revealing changes in the chemical composition of the effluent after centrifugation.

In the study, as a result of wastewater separation by centrifugation process, COD of 580 mg/L was reduced to 265 and 247 mg/L, SS of 236 mg/L was reduced to 46 and 27 mg/L, turbidity of 52 NTU was reduced to 17 and 9 NTU. pH of 6.5-7.1 and 6.3-6.7 did not show a significant change.

The Annexes to the Regulation on the Amendment of the Water Pollution Control Regulation published in the Official Gazette dated 17/12/2022 and numbered 32046, pH 6-9, COD 350 mg/L, SS 150 mg/L are the discharge permit limit standards. When the effluent analysis results of the process proposed in this study are compared with the discharge permit parameters, it can be said that the process could be successful in physical treatment of the paper recycling (egg carton) wastewater and determining the pollution parameters.

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