Turkish Journal of Forestry | Türkiye Ormancılık Dergisi
2024, 25(4): 506-513 | Research article (Araştırma makalesi)

Examination of wastewater generated in wood drying kilns

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Abstract: In this study, the physical treatment of wastewater obtained during the kiln drying of Calabrian pine (*Pinus brutia* Ten.) wood in a timber processing plant in Isparta was investigated by centrifugation technique. The wastewater samples were centrifuged at 1000 rpm (constant speed) for 2 to 10 minutes of duration, and some selected wastewater evaluation parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), suspended solids (SS), dissolved oxygen (DO), and turbidity (NTU) were analyzed. Also, the data obtained were statistically analyzed at 95% confidence level. When significant differences were identified, Duncan's multiple range test was applied to evaluate the homogeneity of mean values across the groups. The results showed that centrifugation caused a significant reduction in turbidity and suspended solids. It was calculated for the turbidity, decreased from 31.49 NTU to 14.60 NTU, and the suspended solids content decreased by 71%, from 38 mg/L to 11 mg/L. However, no significant change was observed in pH, EC, and TDS values. Additionally, the color analysis of the water revealed that centrifugation had a measurable effect on the total color difference (ΔE). This study concludes that while centrifugation is effective in reducing physical pollution of waste waters, it causes not noticeable changes in the chemical composition, providing useful data for future similar wastewater treatment research.
Keywords: Wastewater treatment, Centrifugation, Calabrian pine, Wood kiln drying

Ahşap kurutma fırınlarında oluşan atık suların incelenmesi

Öz: Bu çalışmada, Isparta'daki bir kereste işleme tesisinde kızılçam (*Pinus brutia* Ten.) odunlarının fırın kurutma sırasında oluşan atık suyun fiziksel arıtımı santrifüjleme tekniği ile incelenmiştir. Atık su örnekleri 1000 rpm (sabit hız) hızında 2 ila 10 dakika süreyle santrifüje tabi tutulmuş ve bazı seçilmiş atık su değerlendirme parametreleri; pH, elektriksel iletkenlik (EC), toplam çözünmüş katılar (TDS), askıda katılar (SS), çözünmüş oksijen (DO) ve bulanıklık (NTU) analiz edilmiştir. Ayrıca elde edilen veriler %95 güven düzeyinde istatistiksel olarak analiz edilmiştir. Anlamlı farklılıklar tespit edildiğinde gruplar arasındaki ortalama değerlerin homojenliğini değerlendirmek için Duncan testi uygulanmıştır. Sonuçlar, santrifüjlemenin bulanıklık ve askıda katılar üzerinde önemli bir azalma sağladığını göstermiştir. Bulanıklığın 31,49 NTU'dan 14,60 NTU'ya düştüğü, askıda katı içeriğinin ise %71 oranında azalarak 38 mg/L'den 11 mg/L'ye düştüğü hesaplanmıştır. Ancak pH, EC ve TDS değerlerinde anlamlı bir değişiklik gözlemlenmemiştir. Ayrıca, suyun renk analizi santrifüjlemenin toplam renk farkı (ΔE) üzerinde ölçülebilir bir etkisi olduğunu ortaya koymuştur. Bu çalışma, santrifüjlemenin atık suların fiziksel kirliliğini azaltmada etkili olduğunu ancak kimyasal bileşimde belirgin bir değişiklik sağlamadığını, bu durumun gelecekteki benzer atık su arıtma araştırmaları için faydalı veriler sunduğu sonucuna varılmaktadır.
Anahtar kelimeler: Atık su giderimi, Santrifüj, Kızılçam, Ahşap fırın kurutma

1. Introduction

As is known, the main structure of wood material consists of 95-99% cellulose, hemicellulose, and lignin. A much smaller portion (1-5%) consists of extractive substances that give their color, scent, and many other aesthetic and technological properties. Despite their low quantities, wood extractives are studied under various categories due to their diverse properties (Fengel and Wegener, 1984; Bowyer et al., 2003; FPL, 2010). For this reason, many chemical substances can be used for the isolation of extractive materials, and single or multi-step processes can be applied. In its simplest form, extractive substances can be classified as water-soluble (in hot or cold water), volatile in air, or soluble in different solvents such as oils, acetone, or alcohols. More detailed information on the detection, isolation, chemical properties, classification, and usage possibilities of extractive substances from wood material can be found in other sources in the literature (Fengel and Wegener, 1984).

Wood drying, in its simplest form, can be defined as the process of removing excess water from wood structure to bring it to a moisture level suitable for use. Many advantages can be obtained by drying wood (Kantay, 1993). These advantages generally include preventing the wood from decaying due to fungal attack, reducing the wood's moisture absorption and release, making the wood easier to machining (planning, milling, cutting, carving, etc.), improving adhesion in gluing, and enhancing the success of protective surface treatments. However, wood can generally be dried either naturally in atmospheric conditions (natural drying) or in controlled kilns (technical drying) (Kantay, 1993). Due to the much shorter drying time and other advantages, technical drying has largely replaced natural drying in modern times. The most common drying methods within technical drying applications are conventional, condensation, and vacuum drying methods. The technical drying process is carried out in specially designed kilns. Depending on plant size or economic considerations, these kilns are managed in various

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Received (Geliş tarihi): 13.09.2024, **Accepted** (Kabul tarihi): 19.11.2024

Citation (Atıf)**:** Tepedelen, M.E., Özkan, U., Şahin, H.T., 2024. Examination of wastewater generated in wood drying kilns. Turkish Journal of Forestry, 25(4): 506-513.
DOI: 10.18182/tjf.1549454

ways, such as simple, semi-automatic, or fully automatic. Drying programs are used to manage and adjust drying conditions as required. Kiln drying programs are specially designed based on wood type, moisture content or drying time (Kantay, 1993; FPL, 2010). It is important to note that in any modern kiln drying process, there are four periods under different conditions. These are the heating, drying, equalization, and cooling periods. The drying parameters such as temperatures and durations of this period vary depending on the wood species (specific gravity) and lumber thickness.

The wastewater released during wood kiln drying, especially from heating/steaming operations, may contain many toxic organic and inorganic compounds that generated from wood. It is well established that the water and heat-sensitive compounds in wood can dissolve when contact with steam or water and cause the formation of dangerous and toxic compounds (Bowyer et al., 2003; Fengel and Wegener, 1984). However, the wastewater generated during the kiln drying of wood is usually discharged directly into the environment without any treatment. Moreover, the pollution characteristics and chemical content of these waters have not been properly evaluated. If the pollution characteristics of these waters can be analyzed, it may provide insights into the potential effects of wastewater generated from the kiln drying of different tree species on the natural ecological balance and human health. In this regard, there is a need to identify the contents of those wastewaters and apply effective treatment methods.

In general, numerous parameters and techniques are used in the treatment and testing of wastewaters, but the most fundamental parameters recommended for analyzing wastewater from industrial production facilities include pH, electrical conductivity (EC), total dissolved solids (TDS), oxidation-reduction potential (ORP), suspended solids (SS), biological oxygen demand (BOD), chemical oxygen demand (COD), turbidity, color measurement, and dissolved oxygen (DO) (Şengül and Türkman, 1998; Cırık et al., 2013; Sawyer et al., 2020).

In this study, the primary characteristics of wastewater generated by the kiln-drying facility of a medium-sized sawmill were investigated in detail, based on the assumption that certain extractive substances, soluble in both hot and cold water, could contribute to environmental pollution. The main objective of the research was to determine whether these wastewater effluents, when discharged into the environment without any additional treatment, possess pollutant characteristics, by measuring various water quality parameters. In this context, the analysis of the potential pollutant nature of the water aimed to identify the presence of compounds that could negatively impact the environment.

To achieve this, wastewater samples were collected from a medium-sized sawmill in Isparta, which is equipped with a technical drying facility, following the drying process of Calabrian pine. Since the drying process is a phase where extractive substances leach into the water, the wastewater samples were collected during different stages of the drying process and analyzed. The wastewater samples were then subjected to centrifugation, followed by essential water quality measurements to determine their pollutant properties.

As a result, this research aims to better understand the potential environmental hazards of wastewater from sawmills and to identify the necessary measures for managing these effects. By measuring various fundamental parameters and analyzing the pollutant nature of the water, the study seeks to provide a clearer understanding of the potential environmental impacts of these wastewater discharges. Furthermore, determining effective treatment techniques for managing such wastewater is an important step towards supporting sustainable industrial practices.

2. Materials and methods

2.1. Collection of wastewaters from a technical wood drying facility and centrifugation process

The material used in this study is wastewater generated during the drying procedure of pine lumber in the kiln of a medium-sized softwood lumber (mainly Calabrian pine) processing facility (lumber, parquet, paneling, etc.) located in Isparta. This wastewater, which is generally released into the environment without any treatment, was collected from the plant in March 2024 following standard procedures, and standard physicochemical analyses were conducted. Prior to analysis, the wastewater was subjected to centrifugation at constant speed (1000 rpm) for five different durations (2, 4, 6, 8 and 10 minutes) at intervals of 2 minutes to physical reduction pollutants. The centrifugation process was carried out using a laboratory centrifuge (Medwelt 800 D China) with a tube capacity of 20 mL (Özkan and Şahin, 2023). After centrifugation, the quality parameters of the wastewater were measured according to internationally accepted standards.

2.2. Tests and measurements applied to wastewater

2.2.1. pH measurements of water samples

The pH value is important for understanding the general characteristics of polluted wastewater. In chemical processes, the pH of the environment affects the ability of pollutants to precipitate, while in biological processes, it influences the activity of organisms. pH measurements were carried out using a multiparameter water analysis instrument, Apera PC5 (Wuppertal, Germany), which was calibrated before each measurement according to standard measurement methods.

2.2.2. Electrical conductivity (EC) Measurements of water samples

Electrical conductivity (EC) is a numerical value used to determine a solution's ability to conduct electricity, providing information about the mineral or other substance content in the solution. In general, EC indicates the total and relative concentrations, mobility, and valence of ions in the water, as well as the temperature at which the measurement is taken. EC measurements were performed using the Apera PC5 multiparameter water analysis device (Wuppertal, Germany), calibrated according to standard measurement methods before each measurement. Measurements for each sample were made in 10 repetitions. The results are given by averaging the measurements.

2.2.3. Total dissolved solids (TDS) measurements of water samples

TDS (Total Dissolved Solids) represent both dissolved and suspended solids in the samples. The formula is given in Equation (1):

TS (Total Solids) - TSS (Total Suspended Solids) (1)

However, as shown in Equation (2), TDS is typically related to EC (Electrical Conductivity) and is used to evaluate the ion load and pollution in water.

$$\text{TDS (mg/L)} = \text{EC (Conductivity) x } (0.55 - 0.70) \quad (2)$$

This relationship with EC is commonly used (Sawyer et al., 2020). TDS measurements were performed using the Apera PC5 multiparameter water analysis device (Wuppertal, Germany), calibrated before each measurement in accordance with standard measurement methods. Measurements for each sample were made in 10 repetitions. The results are given by averaging the measurements.

2.2.4. Oxidation-reduction potential (ORP) measurements of water samples

The Oxidation-Reduction Potential (ORP) is a measure of a substance's ability to oxidize or reduce another substance. Positive ORP indicates that the substance is an oxidizing agent, while negative ORP suggests that the substance is a reducing agent (Sawyer et al., 2020). ORP measurements of the water samples were performed using a multiparameter water analysis device (Jinan Huiquan Electronic Co., Ltd, China). Calibration of the device was conducted before each measurement. Measurements for each sample were made in 10 repetitions. The results are given by averaging the measurements.

2.2.5. Suspended solids (SS) measurements of water samples

Suspended solids (SS) values of the samples were calculated using the standard method (APHA, 2005). According to the 2540 D method, Whatman GF/C glass fiber filter papers were dried for 60 minutes at 103-105°C, then placed in a desiccator for 60 minutes. The initial weights of the samples were measured using a precision scale. The filter papers were then placed in a filtration apparatus, and vacuum was applied. The filters were washed three times with 20 ml of distilled water each time. Afterward, 100 ml of the sample was filtered, and the filter was removed with tweezers, dried again for 60 minutes at 103-105°C, placed in a desiccator to cool, and weighed. Finally, the SS values were calculated using the following equation (3):

$$\text{Suspended Solids (SS): } (\text{A} - \text{B}) \text{ x } 1000 / \text{mL sample} \quad (3)$$

A: Weight of the filter and retained solids (mg), B: Weight of the filter (mg)

2.2.6. Color measurements of water samples

Using the CIE Lab* 1976 standard (Commission Internationale d'Eclairage), the brightness/darkness (L*), redness/greenness (a*), yellowness/blueness (b*), and total color difference (ΔE_{ab}) of the water samples were automatically calculated using the following equation (4):

$$\Delta Eab: \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (4)$$

In these equations: L represents the brightness/darkness level (ranging from 0 to 100, where a lower number indicates more darkness, 0 being black, and 100 being perfect white). a represents the redness (a+)/greenness (a-) level. b represents the yellowness (b+)/blueness (b-) level. ΔE represents the total color difference, which is a combination of all these factors. All the calculations described above were performed automatically using an X-Rite 962 spectrophotometer (Grand Rapids, Michigan) with a 10° observer angle and daylight illumination of 6500 Kelvin (D65).

2.2.7. Turbidity measurements of water samples

Turbidity in water can be caused by various organic and inorganic substances, either dissolved or suspended. This provides information about the cloudiness or contamination of the water based on how much light is blocked or scattered when passing through the water. However, some wastewater treatment process such as coagulation, sedimentation, and filtration processes can significantly reduce turbidity (Alley, 2000; Cırık et al., 2013; Sawyer et al., 2020).

The turbidity of water is measured in NTU (Nephelometric Turbidity Units) as per the standards set by the EPA and the World Health Organization (WHO). Turbidity is generally measured using the nephelometric technique, in which a light source illuminates the sample, and the intensity of light scattered at a 90 angle is measured to determine the turbidity (Cırık et al., 2013; Sawyer et al., 2020). In this study, the turbidity properties of both control and centrifuged samples were measured according to the ISO 7027 standard, with six measurements taken from each sample group. The turbidity measurements were carried out using a Hanna HI 93703 turbidity meter (Woonsocket, USA) (Kardeş et al., 2024).

2.2.8. Dissolved oxygen (DO) measurements of water samples

The dissolved oxygen content of the wastewater sample allocated for qualitative analysis was measured. This serves as an indicator of the oxygen level in the wastewater and, therefore, its quality. The dissolved oxygen measurements were performed using a HACH dissolved oxygen meter (Pocket Colorimeter II), which is an important parameter for evaluating the environmental impact of wastewater and the effectiveness of treatment processes (Özkan et al., 2024).

2.2.9. FT-IR analysis of water samples

Fourier Transform Infrared (FT-IR) spectroscopy plays an important role in detecting chemical components in wastewater. This analytical technique is particularly effective in identifying a wide range of organic and inorganic components, including proteins, lipids, carbohydrates, phenols, and other pollutants. By measuring the absorption of infrared light at characteristic frequencies for each molecular vibration in the sample, FT-IR enables the identification of chemical bonds and functional groups.

FT-IR measurements were conducted with a wavelength range of 400-4000 cm^{-1}, and spectra were recorded at a resolution of 4 cm^{-1}.

2.2.10. Statistical analysis

The collected data were analyzed using IBM SPSS Statistics 22 software with a 95% confidence interval. To assess potential differences among the groups, a one-way analysis of variance (ANOVA) was performed. When significant differences were identified, Duncan's multiple range test was applied to evaluate the homogeneity of mean values across the groups.

3. Results

3.1. pH Properties of water samples

The pH properties of the water samples, an essential parameter for understanding their general chemical characteristics, were first measured. Table 1 provides a comparison of the pH values determined for water samples subjected to centrifugation at intervals of 2 minutes for a total of five different durations (2, 4, 6, 8, and 10 minutes) at constant speed (1000 rpm). The control sample's pH value was measured as 11.05. The highest pH value of 11.25 was observed in the sample centrifuged for 2 minutes, while the lowest of 11.01, was measured in the sample centrifuged for 10 minutes. The difference between the highest and lowest pH values was only 0.24. Since centrifugation is a physical separation technique, no major changes in the pH levels were observed, and only very slight variations were recorded. This situation was considered normal due to the presence of various foreign substances in the water samples and the non-selective nature of the centrifugation process for a specific group of substances. Therefore, it can be reasonable to conclude that the pH values of the water samples showed insignificant changes within very small ranges and theoretically the centrifugation process had no significant effect on the pH values of the water samples.

3.2. Electrical conductivity (EC) properties of water samples

Table 1 provides a comparison of the EC (µS/cm) values measured for the water samples. It was observed that the EC values of the centrifuged water samples were lower than those of the control sample. The highest EC value was 5829 µS/cm in the control sample, while the lowest was 5124 µS/cm in the sample centrifuged for 4 minutes. The difference between the highest and lowest EC values was 705 µS/cm. This indicates that, as expected, the centrifugation process caused the precipitation of ions or pollutants in suspension to some extent. However, no trend or relationship was found between centrifugation time and the measured EC values.

3.3. Total dissolved solids (TDS) properties of water samples

The TDS values measured after five different centrifugation durations are shown in Table 1. Like EC, it was determined that the TDS values of all centrifuged samples were lower than those of the control sample. The highest TDS value was 2910 ppm in the control sample, while the lowest was 2531 ppm in the sample centrifuged for 4 minutes. The difference between the highest and lowest TDS values was 379 ppm. Like EC, it can be concluded that the centrifugation process caused the precipitation of pollutants in suspension to some extent. However, no trend or relationship was found between centrifugation time and the measured TDS values.

3.4. Oxidation-reduction potential (ORP) properties of water samples

The oxidation-reduction potential (ORP) is important for determining the quality of water. A high positive ORP value indicates that the water has oxidizing properties, meaning it can cause rust and decay, while a negative ORP value suggests that the water has reducing properties, meaning it has antioxidant power and can prevent rusting (Cırık et al., 2013; Sawyer et al., 2020). In this study, all the wastewater samples had positive ORP values. Like EC and TDS, the ORP values of the centrifuged samples were higher than those of the control sample (control: 30.7 mV), ranging from 3.6 mV (2-minute centrifuged sample) to 17.9 mV (4-minute centrifuged sample). These higher ORP values, compared to the control sample, suggest that the centrifugation process was not effective in reducing chemical pollution.

3.5. Dissolved oxygen (DO) properties of water samples

Dissolved oxygen (DO), one of the essential requirements for aquatic life, is an important water quality variable included in the classification of surface water resources under the Surface Water Quality Management Regulation (YSKY, 2012). Dissolved oxygen is a measure of the amount of oxygen gas present in water. In general, clean drinking water at 1 atm pressure and 20°C can contain up to 14.6 mg/L of dissolved oxygen. As factors such as water stagnation, depth, temperature, and the presence of minerals and pollutants increase, the amount of dissolved oxygen decreases. When organic pollutants are present in water, microorganisms break them down through a process called decomposition, which consumes dissolved oxygen and leads to lower oxygen levels. The solubility of oxygen in water also decreases as water temperature increases. The classification is as follows: Class I water > 8 mg/L, Class II: 6 mg/L, and Class III: < 6 mg/L. In general, healthy water should have a dissolved oxygen level of 6.5-8 mg/L or higher. Water with dissolved oxygen levels less than 2 mg/L is considered hypoxic (oxygen-deficient), and water with 1 mg/L or less is defined as "devoid of life," meaning aquatic organisms cannot survive in such conditions (Rounds et al., 2006).

Table 1. Basic Properties of Water Samples

Time (minute)	pH	EC (µS/cm)	TDS (ppm)	ORP (mV)
0	11.05 (A)	5829 (C)	2910 (D)	30.7 (A)
2 min.	11.25 (C)	5255 (A)	2626 (B)	34.3 (A)
4 min.	11.03 (A)	5124 (A)	2561 (A)	48.6 (D)
6 min.	11.21 (C)	5411 (B)	2702 (C)	40.1 (B)
8 min.	11.11 (B)	5305 (B)	2649 (B)	43.10 (C)
10 min.	11.01 (A)	5160 (A)	2578 (A)	43.90 (C)

*Letters in parentheses indicate group differences between Duncan Homogeneity Groups

When examining Figure 1, the dissolved oxygen level of the control water sample was measured at 3.46 mg/L. The dissolved oxygen levels of all centrifuged water samples were lower than the control, ranging from 2.43 mg/L to 2.82 mg/L. From this, it is understood that the centrifugation process did not result in an increase but rather a decrease in dissolved oxygen levels. However, in any case, the dissolved oxygen levels of the water samples were found to be very low. Using the dissolved oxygen values of the samples, it is difficult to draw a definitive conclusion regarding the change in pollution characteristics caused by centrifugation.

3.6. Turbidity properties of water samples

Turbidity in water can be caused by various organic and inorganic substances, either dissolved or suspended. This provides information about the cloudiness or contamination of the water based on how much light is blocked or scattered when passing through the water. However, some wastewater treatment process such as coagulation, sedimentation, and filtration processes can significantly reduce turbidity (Alley, 2000; Cırık et al., 2013; Sawyer et al., 2020).

The turbidity values of the control sample and samples subjected to the standard centrifugation procedure for five different durations are shown comparatively in Figure 2. The turbidity value of the untreated raw control water sample was measured at 31.49 NTU. It was observed that the turbidity values of the samples decreased consistently with increasing centrifugation time. The lowest turbidity value, 14.60 NTU, was recorded in the sample that underwent centrifugation for 10 minutes. As expected, significant reductions in turbidity values were calculated, ranging from 31.9% to 53.6%, because of the centrifugation process.

3.7. Suspended solids (SS) properties of water samples

Foreign substances that cause water pollution are the main factors that make water appear turbid or dirty, and particles larger than 1µm in diameter can generally be filtered out. Suspended solids (SS) are an important parameter developed to explain the degree of pollution in water. Figure 4 shows the measured SS values of the water samples, presented comparatively. The SS value of the control sample was measured as 38 mg/L. As seen in Figure 3, there is a positive correlation between centrifugation time and the reduction of SS. The lowest SS value, 11 mg/L, was recorded in the sample centrifuged for 10 minutes, which is significant as it indicates approximately 71% lower SS compared to the control sample.

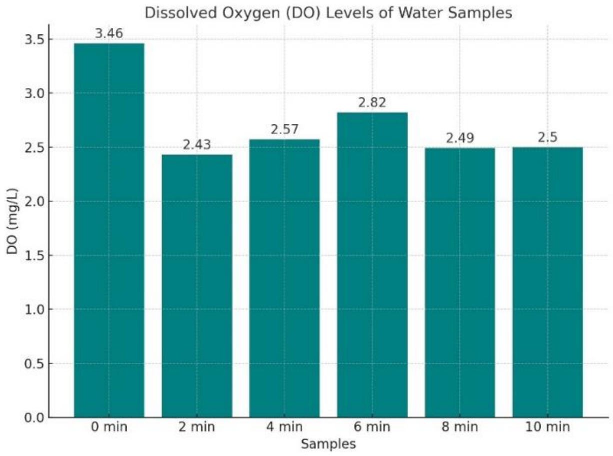

Figure 1. Dissolved Oxygen (DO) Properties of Water Samples

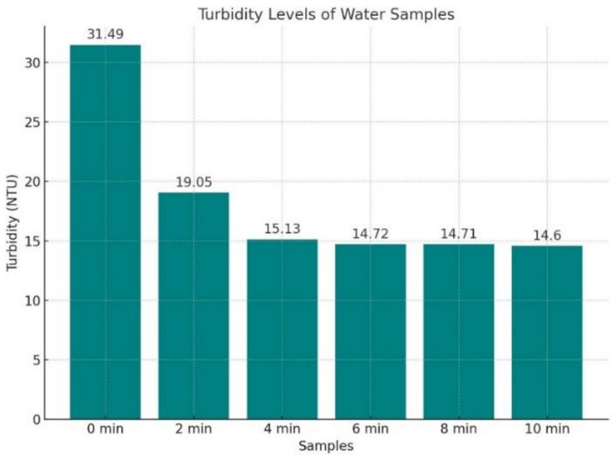

Figure 2. Turbidity Properties of Water Samples

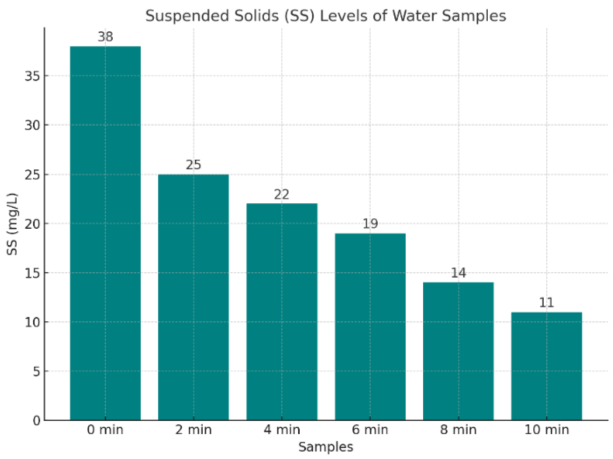

Figure 3. Suspended Solids (SS) Properties of Water Samples

3.8. Color properties of water samples

In general, water is colorless if no foreign substances are present. The presence of organic or inorganic foreign materials, along with biological activities (such as bacteria, fungi, etc.), can cause the water to change color. Wood contains many extractive, color-giving substances that can dissolve even in cold water. Therefore, when wood encounters water or steam, these color-giving substances can be released into the water, changing its color. Since the water used in this study was collected from a kiln drying facility which hot water (steam) has used to operate, it was observed that the water had a color characteristic. It is important to note that the color of water and its turbidity are different concepts and should not be confused. For example, water may be dark in color but not turbid (Sawyer et al., 2020).

There may be specific circumstances for measuring watercolor in each industry, and a method suitable for one sector may not be appropriate for another. Therefore, it is challenging to determine the color of wastewater from different industrial processes using a single parameter (Polat, 2018; Hach-Lange, 2023). As a result, several color measurement methods have been developed for different industries based on the characteristics of the water being measured. Examples of color measurement methods used for liquids include the Hazen (Pt-Co) color scale, (APHA3-method or platinum-cobalt), Gardner color scale, Iodine color scale (DIN 6162), Lovibond color system, Tristimulus colorimeter and CIE Lab* (Hach-Lange, 2023).

In this study, the CIE Lab* (1976) method, widely used for measuring the color of solid and liquid materials, was employed to determine the color properties of the water samples. The measured values are presented comparatively in Table 2. The brightness (L*) values of the water samples ranged from 25.11 (metric) for the sample centrifuged for 9 minutes to 34.92 (metric) for the sample centrifuged for 1 minute. Considering the L* value of the control sample was 28.31 (metric), it can be suggested that there is no relationship between centrifugation and the L* value.

When examining the redness-greenness values (a*) of the water samples, it was found that the sample centrifuged for the longest duration had an a* value of 10.18 (metric), which is approximately 2.92 units less redness compared to the control sample. The highest a* value, 21.84 (metric), was measured in the sample subjected to centrifugation for 6 minutes, which is approximately 8.74 units redder than the control sample. Like brightness, no clear trend or relationship was observed between centrifugation time and the a* values of the samples.

When the yellowness-blueness values (b*) of the water samples were examined, it was found that all centrifuged samples had b* difference values between 0.66 and 4.44 units lower than the control sample, indicating that the color of the water shifted from yellow toward blue to some extent. The lowest b* value, 5.64 (metric), was measured in the sample centrifuged for 7.0 minutes, while the highest b* value, 10.08 (metric), was observed in the control sample.

Table 2. Color properties (CIE L*a*b*) of water samples

Time (minute)	L*	a*	b*
0	28.31 (b)	13.10 (b)	10.08 (f)
1 min.	34.92 (d)	15.26 (c)	9.42 (e)
2 min.	32.86 (c)	16.08 (d)	8.34 (d)
3 min.	25.81 (a)	17.01 (d)	5.83 (a)
4 min.	34.59 (d)	12.49 (b)	6.37 (b)
5 min.	31.56 (c)	18.42 (d)	6.73 (b)
6 min.	31.88 (c)	21.84 (e)	7.47 (c)
7 min.	32.15 (c)	21.76 (e)	5.64 (a)
8 min.	27.31 (b)	13.25 (b)	6.75 (b)
9 min.	25.11 (a)	13.32 (b)	9.20 (e)
10 min.	27.98 (b)	10.18 (a)	8.87(d)

*Letters in parentheses indicate group differences between Duncan Homogeneity Groups

The relationship between each CIE color coordinate parameter (L*a*b*) and centrifugation time is illustrated in Figure 4. Upon examining the graphs in Figure 4, it was observed that there was a very low correlation between L* and centrifugation time (R^2: 0.3071). There was a higher, but still relatively low, correlation between a* and centrifugation time (R^2: 0.4461). Interestingly, a moderate correlation was found between the b* color parameter and centrifugation time (R^2: 0.7455).

In the literature, many reports suggest that it is more appropriate to analyze the color properties of materials and identify differences between them by reducing the three main color parameters (Lab*) to a single mathematical value, known as the total color difference (ΔE). In our study, using the basic values provided in Table 2, the color differences (total color difference, ΔE) of the water samples were calculated in comparison to the control sample and are shown in Figure 6.

As seen in Figure 5, the highest color difference compared to the control sample was 10.46 (metric) in the sample centrifuged for 7.0 minutes, followed by 10.06 (metric) in the sample centrifuged for 9.0 minutes, and 9.8 (metric) in the sample centrifuged for 6.0 minutes. The lowest color difference, 3.18 (metric), was calculated for the sample centrifuged for the longest duration (10 minutes). Based on the data presented, it can be concluded that centrifugation can affect the color difference or color reduction in colored/contaminated water samples, but establishing a clear relationship between centrifugation duration and the color values of the samples appeared to be very complex.

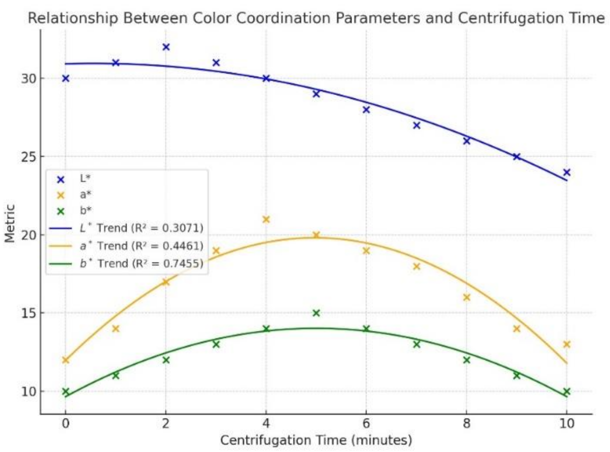

Figure 4. The Relationship Between Color Coordination Parameters and Centrifugation for Water Samples

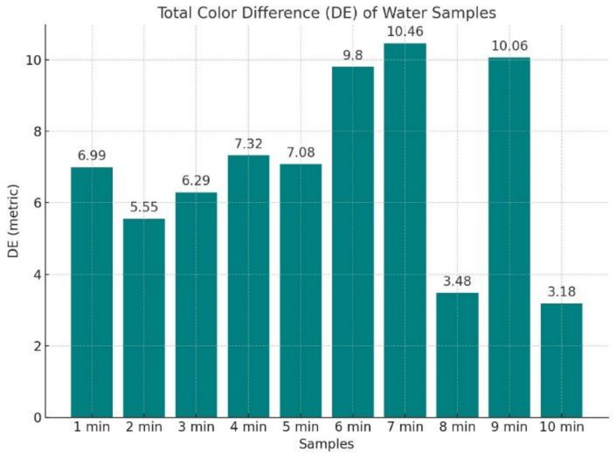

Figure 5. Total Color Differences (ΔE) of Water Samples Compared to the Control Sample

3.9. FTIR analysis of water samples

Figure 6 presents a comparison of the FTIR spectra of the control sample and the water sample with the lowest turbidity (centrifuged for 10 minutes). In wastewater generated during the artificial drying of pine wood, it is generally expected to find small-molecule carbohydrates, glucosides, and polysaccharides degraded by heat (Fengel and Wegener, 1984). The peak regions in the FTIR spectra of lignocellulosic materials (wood) have been studied by many researchers (Yilgor et al., 2013; Ceylan and Pekgözlü, 2019). Upon examining the spectra in Figure 6, no significant difference was observed between the spectra of the control and the sample centrifuged for 10 minutes. In both spectra, aromatic C-C bonds (1515-1605 cm^{-1}), C=O bonds (1660-1710 cm^{-1}), and aliphatic and phenolic O-H bonds (3450-3400 cm^{-1}) were distinctly observed. Only minor changes were detected in some small peaks in the 1980-2500 cm^{-1} wavelength range, with slight increases or decreases in intensity.

This region generally corresponds to the O-H stretching region (2500 cm^{-1}) and the symmetric carboxylic compound region (2000-1990 cm^{-1}) in organic compounds. This result is considered normal, as no chemical treatment was applied only physical centrifugation was used to precipitate some of the suspended compounds in the wastewater, without removing them from the environment. This finding is consistent with the SS (Suspended Solids) results explained in Figure 3.

4. Discussion and conclusion

In this study, the basic properties of wastewater obtained from a medium-sized Calabrian pine lumber kiln processed plant were evaluated. Additionally, the effect of centrifugation (at a constant rotational speed of 1000 rpm) on the pollution properties of the water samples was examined comparatively, based on the duration of centrifugation. Thus, the properties of the water were analyzed after the pollutants in suspension were precipitated through centrifugation. The water samples were visibly colored and turbidity, primarily due to colloidal wood compounds (degraded/short-chain carbohydrates, polysaccharides) that dissolved into the water during the drying process.

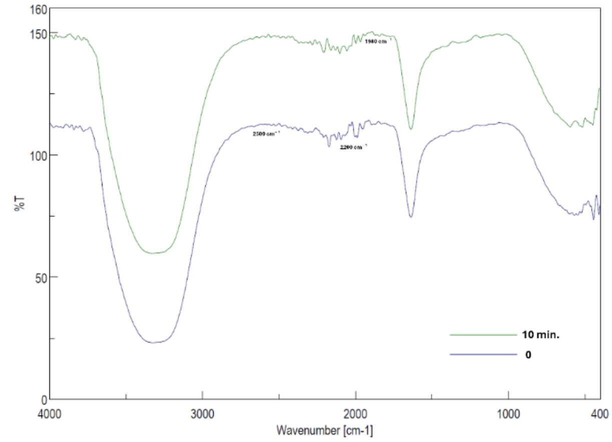

Figure 6. FTIR Spectra of Water Samples (0: control, 10 min.: sample centrifuged for 10 minutes)

Centrifugation is fundamentally based on the principle of separating particles in a suspension based on their shape, size, and density using the centrifugal force generated by circular rotational motion. The rotational speed of the centrifuge, measured in RPM (Revolutions Per Minute), directly influences the settling of solid particles. As such, the movements induced by the rotational speed must result in a centrifugal force greater than the gravitational acceleration (9.81 m/s^2). It has been observed that as both the centrifugation time and rotational speed increase, the solid particles settle more rapidly.

In general, improvements or adjustments were observed in key pollution parameters (EC, TDS, ORP) of the water samples, which were assumed to contain pollutants derived from water-soluble extractive substances in the wood during the kiln drying of pine lumber. However, no clear trend was identified between the centrifugation duration and changes in these parameters. This is understandable since centrifugation is a physical separation process, and the chemistry of the water did not change significantly after the suspended pollutants were precipitated (as evidenced by the marginally close pH values of the samples), suggesting that the obtained values were meaningful. As expected, it was found that the turbidity and suspended solids (SS) values of the water samples were closely related to the duration of centrifugation.

Although significant changes were calculated in the primary color values (L*a*b*) and total color difference (ΔE) of the water samples compared to the control sample, no clear trend was established between centrifugation duration and the color values of the samples. However, a stronger relationship (R^2: 0.7455) was observed between the b* color coordinate parameter and centrifugation duration compared to the other color parameters. When the measured color parameters (L*a*b*) were reduced to a single variable as total color difference (ΔE) and correlated with centrifugation durations, the highest color difference (ΔE: 10.46) was calculated in the sample centrifuged for 7.0 minutes, and the lowest (ΔE: 3.18) in the sample centrifuged for 10 minutes. In general color measurements, if the total color difference between two objects is ΔE < 1.0, it is imperceptible to the human eye; if ΔE is between 1.0 and 2.0, it can be detected through careful observation; and if ΔE > 3.0, it is easily noticeable to the naked eye (Hach-Lange, 2023).

Considering the obtained data, it can be concluded that centrifugation created a noticeable difference (turbidity and color reduction) compared to the control samples, which is visible to the naked eye. Since no chemical treatment was applied to the polluted/wastewater generated during the artificial drying of pine lumber, and only physical treatment was applied via centrifugation, no significant changes were observed in the FTIR analysis of the water samples. Upon reviewing the experimental results and the data obtained from the control samples, it can be concluded that the wastewater generated during the artificial kiln drying of pine lumber contains suspended substances and exhibits pollution characteristics, and that centrifugation is somewhat effective in reducing this pollution. It is expected that the experimental approaches selected in this study and the obtained data will serve as a basis for similar future studies on this topic.

Acknowledgements

This study has been carried out with the support of TÜBİTAK 2209-A. We would like to thank TÜBİTAK for enabling the execution of this work.

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