Tofu wastewater treatment through a combined process of coagulation-flocculation and ultrafiltration

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Abstract. Wastewater from tofu industries contain many parameters such as total suspended solid (TSS), total dissolved solid (TDS), turbidity, and chemical oxygen demand (COD). These parameters are present in high amount and can endanger the aquatic environment and also decrease water quality. Several studies have been conducted to reduce these parameters, but still require a longer time which is around 12 to 78 days. This study aims to discuss the processes and methods to reduce TSS, TDS, turbidity, and COD parameters from tofu wastewater. The processes discussed in this study include a combined process of coagulation-flocculation and ultrafiltration (UF). The results of the study show that TSS, turbidity and COD reduced to 60%, 60% and 20%, respectively, in the coagulation-flocculation process, but TDS increased to around 90% because of the neutralization process using Sodium Hydroxide (NaOH) solution. Furthermore, it was shown that the combined process of coagulation-flocculation and UF was able to reduce TSS, turbidity, COD and TDS up to 99%, 99%, 75% and 50%, respectively. All the parameters contained in the water produced from the combined process of coagulation-flocculation and UF was in line with the National Environmental Quality Standard requirements, excluding COD due to the COD content in fresh tofu wastewater is very high.

1. Introduction
Tofu is a favorite food in Asia [1, 2], especially in Indonesia because of its low-cost, and it contains good and healthy nutrition. Almost every city in Indonesia has tofu processing industries, which are usually run by small household industries, and are managed with simple technology [3]. Therefore, there is low effective and efficient use of resources such as raw materials and water [4, 5]. High amount of harmful organic and chemical compounds are present in tofu wastewater such as biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solid (TSS) in the range of 5000 - 1000 mg/L, 7000-26000 mg/L and 6000-8000 mg/L, respectively [2, 6, 7].

The waste from the tofu industry can be in the form of liquid waste and solid waste, where a portion of liquid waste can be used for subsequent production, while solid waste can be utilized as feed for animal[5, 8]. However, because of the large amount of water used for tofu processing, the wastewater is also released in great volume, and it is generally not fully reusable; so the remaining liquid waste is released into the nearby aquatic environment. Unfortunately, discharging of tofu wastewater causes environmental pollution such as bad odors and soil pollution, increased water turbidity, decreased photosynthetic rate of phytoplankton and other aquatic plants; thereby decreasing water productivity. Several health problems such as skin diseases, stomach aches, and digestive problems can also be triggered by consuming water that has been polluted by tofu wastewater [5, 9, 10].
Several recent studies have been conducted on the utilization of tofu wastewater to produce products such as bio-ethanol [11], vitamin B12 [1, 2, 12] and cultivation of micro algae [13, 14]. Several attempts have also been made to treat tofu waste water in Indonesia through anaerobic processes in the fixed dome anaerobic and anaerobic baffled reactor [5] and the combination of anaerobic baffled and activated sludge system. However, the processes take longer time which is around 12 to 78 days [15]. Another method used is ozonation. In this process, the waste water is diluted first prior to processing [16]. The aim of the study is to assess the success of the combined process of coagulation-flocculation and ultrafiltration (UF) in treating tofu industrial wastewater. The COD, TSS, TDS, and turbidity are the parameters that will be observed to assess the success and effectiveness of the proposed process. A coagulant used in the coagulation-flocculation process is poly aluminum chloride (PAC), and it is one of the best options for reducing COD, TSS, and turbidity of wastewater [17]. Meanwhile, the UF process is expected to further reduce COD, TSS, and turbidity level of the wastewater [18].

2. Materials and methods

2.1 Materials

The experimental set up for the combined process of coagulation-flocculation and UF is schematically shown in Fig. 1. The wastewater was provided by the tofu industry in South Jakarta, Indonesia. The sodium hydroxide used for pH adjustment was analytical grade and was obtained from Merck Indonesia and the filter paper used was sized 10 μm BIPMED. Meanwhile, the PAC used was technical grade and was purchased from PT Brataco Indonesia. There were three hollow fiber membrane modules used in this study, which were made of polysulfone, cellulose acetate, and ceramics and were supplied by CV GDP Filter Bandung Indonesia.

2.2 Methods

Prior to the coagulation process, the wastewater’s pH was set to about 7.0 by addition a certain amount of 2 M NaOH as a base solution. The wastewater solution was added with 1 ml of coagulant solution in the coagulation-flocculation process, and the process was performed at 120 rpm for 2 min and then continued at 40 rpm for 10 min in the VELP JLT-6 Jar Test. After 30 minutes, the solution was filtered using a 10 μm filter paper, and the filtrate was used as feed for the UF process. In the UF process, compressed air was employed to generate the pressure driving force a cross the membrane. TSS and turbidity, COD, and TDS and pH were measured by Hach DR/890 Colorimeter, Spectrophotometer UV-Vis BEL UV-MS1 single beam and Hanna Waterproof Tester Combo pH and EC, respectively. The whole experiments were repeated for three times. All experiments to measure the observed parameters were repeated three times and the average values were taken as final data.

![Diagram](image)

**Figure 1.** Schematic diagram of a combined process experiment.

3. Results and discussion

3.1 Coagulation-flocculation process
The tofu wastewater characteristic as well as the National Environmental Quality standard [19] is shown in table 1. Based on the data present in table 1, it is clear that all the observed parameters have already passed the threshold set by the government. Besides being acidic as shown by the wastewater’s pH which is below 4.0, tofu wastewater also contains a high suspended solid as indicated by high turbidity, TSS and COD. The TSS as well as turbidity of the wastewater decreased, while TDS and COD increased after the addition base solution to neutralize the wastewater as shown in figure 2. The increase in TDS was mainly due to the increase in the level of dissolved ions present in the wastewater which is derived from Na$^+$ ions. Meanwhile, the decrease in TSS and turbidity was due to a small amount of suspended solids that precipitate during the addition base solution.

| Observed Parameters | Concentration range (mg/L) | Government Regulation [19] |
|---------------------|-----------------------------|-----------------------------|
| TSS                 | 280 - 415                   | 100                         |
| Turbidity (FAU)     | 370 - 525                   | 25                          |
| COD                 | 5980 - 7950                 | 275                         |
| TDS                 | 850 - 1050                  | 2000                        |
| pH                  | 3.4 - 3.8                   | 6.0 - 9.0                   |

Figure 2. The Observed Parameters in the Tofu Wastewater before and after adding of 2 M NaOH Solution.
The effect of PAC dose on TSS, turbidity, COD and TDS in the process of coagulation-flocculation at pH 7.0 is shown in Figure 5. There is a decrease in the level of TSS, COD and turbidity, while TDS increase after the process of coagulation-flocculation. The pH of the solution applied in the process of coagulation-flocculation is closely associated to the coagulation process efficiency. The PAC has low solubility at a pH in the range of 6-7, so that the coagulant can be maximally transformed into flock. The coagulation-flocculation process involves colloidal particles destabilizing by neutralizing forces that cause the colloids to stay far away from each other. Cationic coagulants provide a positive electrical charge which reduces the negative colloids charge. As a result, the particles collide with each other to produce macro particles known as flocks [21].

Generally, coagulants to form hydroxides when it dissolves in water, so that the metal hydroxide polymers formed will be of amorphous structures, positively charged, and have a large surface area. These hydroxides are hydrophobic, which can be absorbed onto the surface of organic anionic particles, therefore becoming insoluble [17]. As shown in Figure 5, TSS from the wastewater has been reduced to nearly 50% after the coagulation-flocculation process due to destabilization of suspended solids, so the process runs effectively. The flock formed from the process has sufficient time to settle at the bottom of the Erlenmeyer so that the filtrate of tofu wastewater was free of particles larger than 10 microns. Similar effects also occurred for the turbidity as it can be seen that the decrease is almost equal to that of TSS, so that the turbidity decreasing curve coincides with the TSS decreasing curve. Since the turbidity of the solution is strongly influenced by the amount of suspended solids, so that the solution turbidity increases with suspended solids, while the brightness of the solution decreases with suspended solids. Figure 5 also shows that the decrease in COD only in the range of 8 to 28%. Particle deposition can indeed decrease the value of COD, especially in wastewater with high TSS content. Generally, a 1mg/L decrease in TSS will also decrease COD by about 10 mg/L[22]. In this process, TSS successfully decreased by about 175 mg/L, while the COD was decreased by 1584 mg/L. Thus, for every 1mg/L decrease in TSS, there is also a 9mg/L decrease in COD. Meanwhile, Figure 5 shows that TDS tends to increase due to the addition of a base solution to neutralize the wastewater’s pH. An increase in TDS can also arise due to the fact that dissolved medium solids (colloid transition) in the wastewater solution passes through the filter paper because their size is less than 0.45 microns.

3.2 Ultrafiltration process

Figure 6 shows the water fluxes in the UF process for polysulfone (PS), cellulose acetate (CA) and ceramic membranes. As expected, water flux increases with increasing trans-membrane pressure (TMP) in the ultrafiltration process. The fluxes of the PS and ceramic membranes are almost the same, while that of the CA membrane is lower due to the smaller membrane pore size.
The effects of PAC dose on TSS, turbidity, COD and TDS in the process of coagulation–flocculation are shown in Figure 5. Figure 6 shows the effects of trans-membrane pressure (TMP) on the water flux in the ultrafiltration process. Figure 7 illustrates the effect of TMP on TSS in the ultrafiltration process using PS, CA and ceramic membranes. All the membranes used were able to produce products with very low TSS levels (<10mg/L) with a rejection of 92 to 99%. Figure 8 demonstrates the significant decrease in turbidity by more than 95% as shown in the figure. The lowest turbidity of the water produced was 4 FAU, far below the National Standard of 25 FAU. The effects of TMP on TDS and TDS rejection on the UF process are shown in Figure 9. TDS decreases at TMP of 1.5 bar and then increases at TMP of 2.0 bar for PS membranes. This is due to the fact that at TMP of 2.0 Bar, more dissolved solids penetrate the membrane, so it increases the TDS of the water produced.

Figure 7 shows the effects of trans-membrane pressure (TMP) on TSS and TSS Reduction in UF process using PS, CA and ceramic membranes. Figure 8 illustrates the effects of trans-membrane pressure (TMP) on turbidity and turbidity reduction in UF process using PS, CA and ceramic membranes.

Figure 10 shows the COD of the water produced after the UF process. The COD decreases with TMP of 1.5 and 1.0 bar and then increases at TMP of 2.0 and 1.5 bar for PS and ceramics membranes, respectively. Meanwhile, the COD decreases with TMP applied in the experiments for the CA membrane. It reveals that the UF membranes could retain the soluble and particulate organic matter in water not to cross the membrane pores up to TMP of 1.0 and 1.5 Bar for ceramic and PS membranes, respectively. The CA membrane was also able to hold soluble and particulate organic matter in water not to cross the membrane pores in the TMP applied in the experiment. The lowest COD of water that
can be produced in the UF process is around 1460 mg/L, which still does not meet the National Standards. A high COD contents is mainly due to the presence of soluble and particulate organic matter in water which cannot be completely discarded by membrane pores in the UF process. Therefore, it is necessary to do a further process so that the COD of produced water complies with government regulations. The reverse osmosis (RO) process can be recommended for this purpose.

![Graph](image1)

**Figure 9.** The effects of trans-membrane pressure (TMP) on TDS and TDS Rejection in UF process using PS, CA and ceramic membranes.

![Graph](image2)

**Figure 10.** The effects of trans-membrane pressure (TMP) on COD and COD rejection in ultrafiltration process using PS, CA and ceramic membranes.

4. **Conclusion**

Tofu industries produce a lot of wastewater that cannot be discharged directly into the aquatic environment without any treatment process as they contain a high level of TSS, TDS, turbidity and COD. This study aims to reduce TSS, TDS, turbidity, and COD parameters from tofu wastewater through a combined process of coagulation-flocculation and UF. The results of experiment revealed that TSS, turbidity and COD can be reduced up to 60%, 60% and 20%, respectively, while TDS increased by about 90% in the coagulation-flocculation process. The increase in TDS was due to adding of base solution when neutralizing the wastewater. Meanwhile, TSS, turbidity, COD and TDS can be reduced up to 99%, 99%, 75%, 50%, respectively, after UF Process. All parameters in the water produced from UF process fulfill the National Standard except COD, which is still above the
standard due to the high COD content in the fresh tofu wastewater. COD content in the fresh tofu wastewater can be reduced from 8000 ppm to 1460 ppm, while the requirement should not exceed 275 ppm.

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