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Subsurface flow constructed wetland model for phytoremediation of chromium from tannery wastewater using *Echinodorus palaefolius*

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Abstract. In the leather tanning process or tannery, Cr solution is usually used to modify leather properties. This results in Cr containing wastewater, which becomes a crucial issue. One promising method for removing Cr from tannery wastewater is by using subsurface flow constructed wetland (SSF-CW). A combination of adsorption and phytoremediation that occurs in the SSF-CW removes Cr from wastewater. In this research, the effect of vegetation and media on Cr removal was investigated. *Echinodorus palaefolius* was used as a phytoremediation agent, while wood charcoal and natural zeolite were used as media. The experiment was conducted in 4-different SSF-CW reactor configurations, namely CTT (wood charcoal-zeolite; no plant), CDT (wood charcoal-zeolite; with plant), ZDT (zeolite; with plant) and ADT (wood charcoal; with plant). Each reactor was filled with 70 L Cr contained water that was recirculated within the reactor for 15 days. Evidence revealed that *Echinodorus palaefolius* significantly increases the removal of Cr from wastewater, compared to that of without those plants (wood charcoal-zeolite medium only). Using an initial concentration of Cr of 2.05 mg/L, removal percentage is 63.7, 86.83, 70.37, and 83.05% for CTT, ZDT, ADT, and CDT, respectively. It is also found that zeolite media performed much better than charcoal. A combination of zeolite medium and *Echinodorus palaefolius* (ZDT) produced the highest Cr removal. In addition to that, despite its Cr intoxication indication, the *Echinodorus palaefolius* was able to grow/regenerate during the experiment.

1. Introduction

Leather tanning is considered one of the most well-known small-scale industrial sectors in Indonesia. In 2018, it was recorded to have the highest growth compared to other manufacturing products [1-2]. The tanning process consists of several processes, including beam house, tanning, and finishing, which can be divided into more detailed steps [3]. In accordance with the completion of those steps, chemicals are needed. Among several chemicals used in a tannery, Chromium (Cr) possesses 85% of the world's most used tanning chemical [4]. The use of Cr allows the leather to be processed faster, with low cost and is more favorable for the coloring step [5]. In addition to that, the Cr-based tanning process is able to produce leather with high tensile strength, more flexible, and capable of withstanding higher temperatures .

During the tanning process, the Cr is usually incorporated in the form of Chromium sulfate (60-70) [6]. However, as the leather can only absorb 60-80% of Cr which added into the system, 20-40% of Cr will be carried within the wastewater [7]. This will lead to chromium contamination in the water. As chromium ion is considered toxic [8], its removal process from water is mandatory.

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The removal of heavy metals from wastewater can be performed using several technologies, including adsorption [9-10], precipitation [11], ion exchange [12], biosorption [13], and phytoremediation [11,14]. Compared to other technologies, the phytoremediation offers more promising application due to its simplicity and naturally friendly principles. The phytoremediation process can be performed in constructed wetland (EPA, 2016). Among many types of constructed wetland, sub-surface flow constructed wetland (SSF-CW) offered more benefits compared to others [15-16].

Previous studies have shown that several aquatic plants are suitable for phytoremediation purposes, for example, melati air (*Echinodorus palaefolius*). Utilization of *Echinodorus palaefolius* for phytoremediation had been conducted in previous research [17-19]. However, a study that specifically targets Echinodorus palaefolius for phytoremediation of chromium is rarely found. Solid media is an important component for SSF-CW configuration as a nutrition provider and root stabilization. It can also act as an adsorbent for contaminant removal from wastewater. One of the most used media for phytoremediation is natural zeolite [18]. However, wood char, which also has been known in the adsorption process due to its capability in performing adsorption [9, 20], offers potential usage as well.

In this study, the performance of the SSF-CW system using *Echinodorus palaefolius* plant in removing chromium from the water was investigated. Natural zeolite, wood char, and the mixture of both were used as SSF-CW media.

2. Materials and method

2.1. Material

The wastewater-containing chrome in this experiment was obtained from the outlet of the wastewater treatment facility of a tannery located in Banyakan village, Piyungan, Special Region of Yogyakarta. The wastewater used in this experiment was characterized in terms of temperature (SNI 06-6989.23-2005), pH (SNI 06-6989.11-2004), and total chrome content (SNI 06-6989.17-2009). The characterization result is presented in table 1.

Table 1. Synthetic wastewater characteristic.

Parameter	Value	Unit
pH	8.30	-
Temperature	29.57	°C
Total Chrome	2.05	mg/L

Echinodorus palaefolius (melati air) was obtained from a local plant shop in Sleman, Regency Special Region of Yogyakarta. The Echinodorus palaefolius plants used in this experiment were ± 3 months old. The natural zeolite used in this experiment was obtained from Gunung Kidul, Special Region of Yogyakarta. The size of natural zeolite was around 2- 7 mm. The natural zeolite was analyzed using X-Ray Diffraction (XRD), which is shown in figure 1. Wood charcoal was made from a mixture of local wood in Gunung Kidul, Special Region of Yogyakarta.

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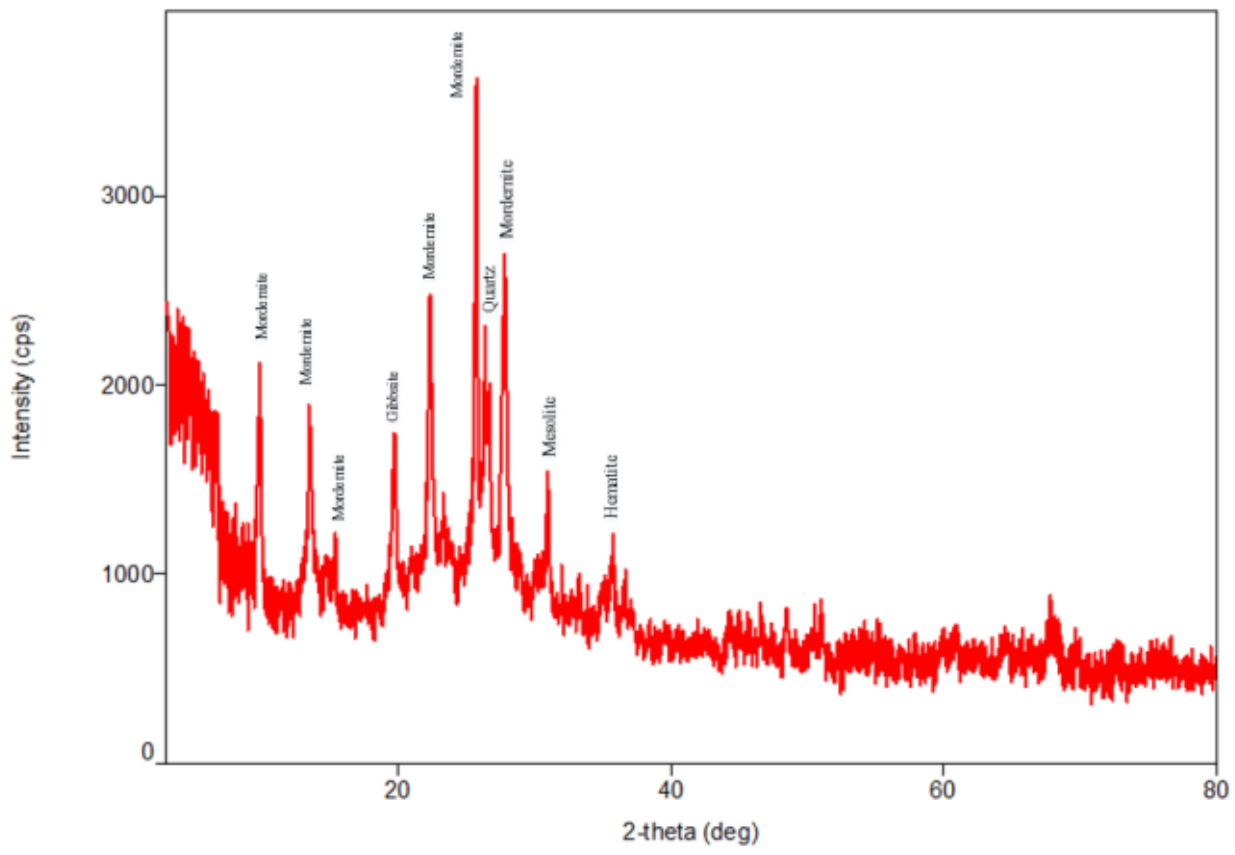


Figure. 1 XRD analysis result of the natural zeolites.

2.2. Reactor setup

The experiment was conducted in 4 SSF-CW reactor models, having a size of 110 x 60 x 60 cm, respectively. All reactors that were manufactured in Universitas Gadjah Mada were operated in batch mode (figure 2). Each reactor was filled with different media, symbolized as CTT (a mixture of zeolite-wood char as media, without plants), CDT (a mixture of zeolite-wood char as media, with plants), ZDT (zeolite media, with plants) and ADT (wood char media, with plants). The size of the zeolite and wood charcoal were 0.16-6 cm and 2-3 cm respectively.

During the process, the wastewater was pumped into the inlet zone of the reactor (left-side of figure 1). Due to the suction of the pump, the wastewater would flow into the medium. After passing the medium, the wastewater was recirculated into inlet zone. This process was carried out for 15 days. Sample intake was done in day 0, 3, 6, 10 and 15, through sample hole in the Outlet Zone. Total chromium determination was performed using SNI 06-6989.17-2009.

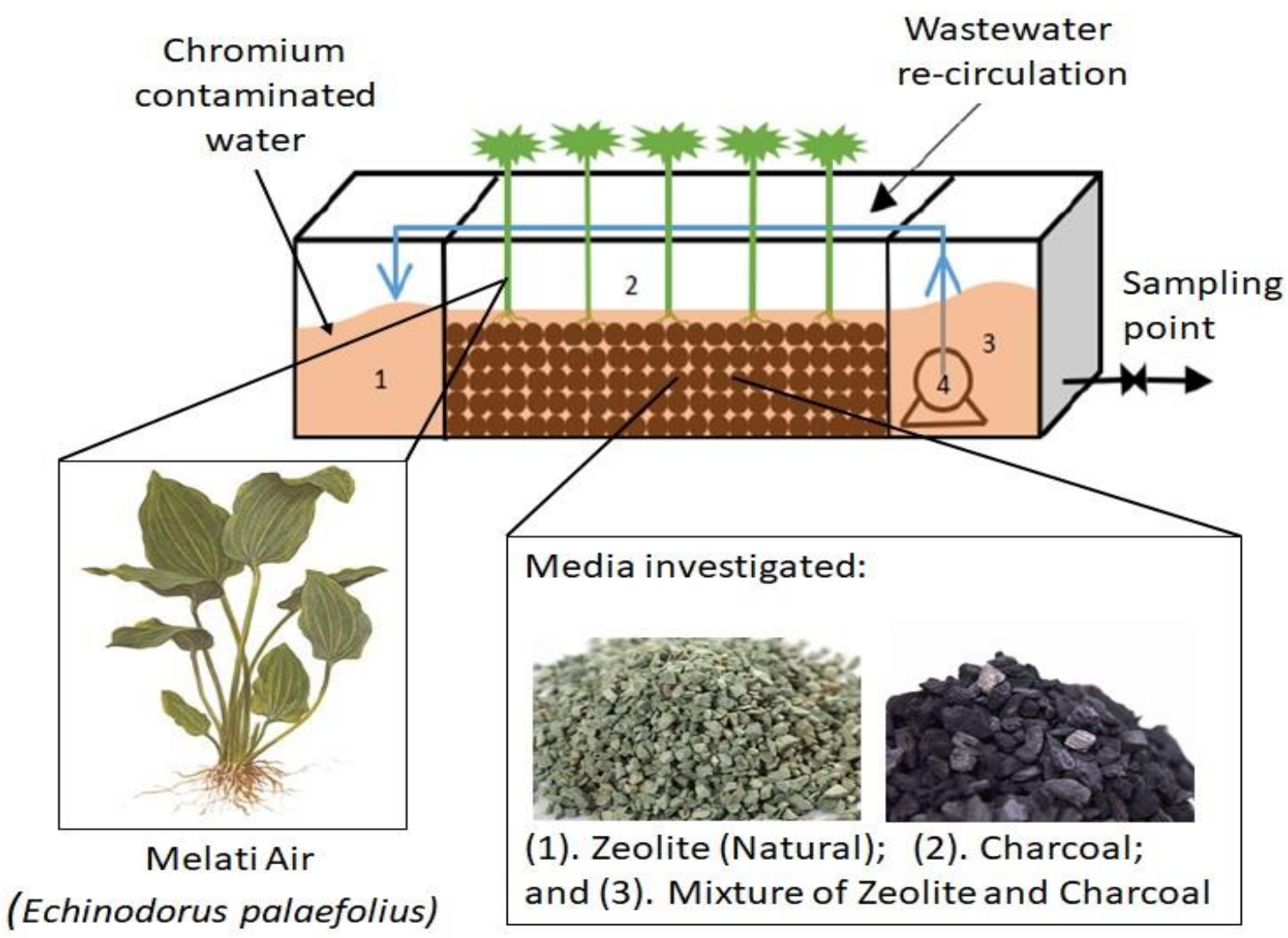


Figure 2. Subsurface constructed wetland configuration used in experiment.

2.3. Plant acclimatization

The plant acclimatization step was conducted prior to the Cr removal experiment. The acclimatization step was carried out to adapt the plants to the new condition. The *Echinodorus palaefolius* was grown in CDT, ZDT, and ADT reactors to study the effect of the media towards the plant's adaptability and

growth (figure 2). The acclimatization step was proceeded by recirculating water (free of Cr contaminant) within the reactor for 30 days. The adaptability and growth of the plants was measured by calculating the number of stems which grew and died, and the number of new sprouts in each reactor.

3. Result and discussion

3.1. Plant acclimatization

The results of plant acclimatization showed that the *Echinodorus palaefolius* was able to adapt in all of the reactors medium, which was indicated by an increase of plant height of about 0.05-0.15 cm/day. Each media produced a different growth rate of plants. The effect of the media on the plant growth was represented by the total stem appeared in the plant, which is presented in table 2.

Table 2. Different medium effects during plant acclimatization.

Medium	Number of stem*			
	Initial	**Dead**	**New**	**Total**
Zeolite (ZDT)	30	1	32	61
Woodchar (ADT)	30	3	13	40
Zeolite+Woodchar (CDT)	30	4	18	44

*after 30 days

As shown in table 2, the number of new and dead stems varied differently depending on the type of media. It was revealed that the plant growth in a zeolite (ZDT) had the highest number of new stems and the lowest dead stems. On the other hand, wood char (ADT) produced the least new stems and the highest dead stems, while the combination of zeolite and wood char (CDT) was performed in between.

Different content of mineral and nutritional elements of natural zeolite and wood char were probably responsible for a different rate of growth of the plants. A previous investigation by Sabilu [21] concluded that the ability of zeolite to provide better growth conditions lied in the availability of micro/macronutrients in zeolite, which slowly released to the plants. Other studies on zeolite as a growth medium also supported the evidence of increasing plant growth and development [22-23]. The lower growth rate in the wood char probably occurred due to the inability of wood char to provide nutrient content as that in the natural zeolite. Moreover, the zeolite may have retained nutrient which was contained in the water itself, the slow release process allowed the plant to absorb nutrients when needed. A similar phenomenon was also found in other studies, which reported that zeolite was able to become a fertilizer carrier and channel of chemicals that may be useful for the plant. Natural zeolite also contains several needed plant nutrients in the form of cation, including K+, Na+, Mg+, and Ca2+, which are interchangeable with other cations, such as metal contained in the wastewater [24].

3.2. Effect of Phytoremediation on Chromium Removal

The result of Cr adsorption using several types of media (CTT, ZDT, ADT and CDT) are presented in figure 3. It was revealed that the chromium content in the water had decreased in day 15. The figure shows that the presence of *Echinodorus palaefolius* had quite significant effect on chromium removal from water.

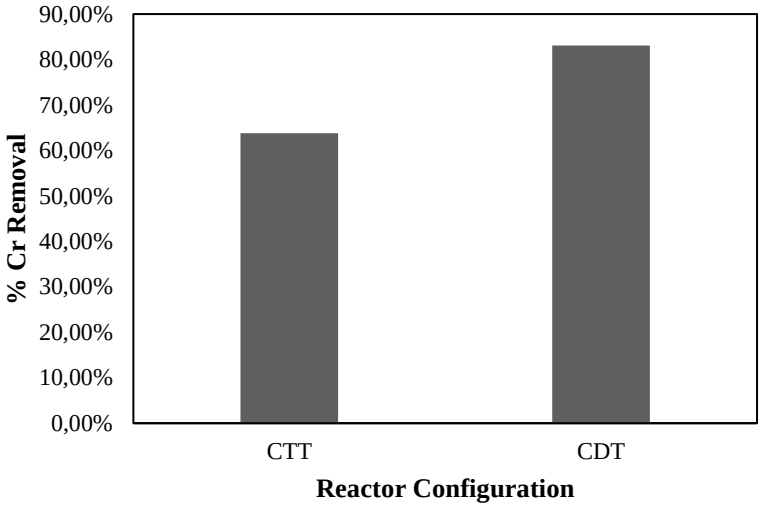


Figure 3. Effect of *Echinodorus palaefolius* on chromium removal.

Zeolite-wood char media, without plant (CTT) had lower chromium removal (64%) compared to that of zeolite-wood char media, with plants (CDT), which was able to remove 83% of chromium. This results clearly indicated that *Echinodorus palaefolius*, as a phytoremediation agent, plays important role in Cr removal from water. The plant's capability to adsorb metal was previously discussed by several works [25-26]. The mechanism of metal removal, such as chromium follows complex process of physiochemical and biological [28] that occurs within the root zone or rhizosphere [26]. Moreover, it was suggested that even though *Echinodorus palaefolius* was able to remove chromium, it seemed that zeolite media provides significant increase of Cr removal, probable due to the higher adsorption capacity compared to that of wood-charcoal.

Figure 4 reported the effect of media in the removal percentage of chromium after 15 days of experiment, which represented by different performance of zeolite and wood-char in adsorbing chromium. The zeolite media with plants (ZDT) was shown to give higher Cr removal (89.26%) compared to that of wood-charcoal media with plants (ADT). Comparison of figure 2 and figure 3 revealed that the Cr removal in ZDT reactor was even higher than that in the CDT. This implied that at least two phenomenons, in which wood char did not give significant contribution on the adsorption compared to that of zeolite, as well as in the rate of growth of the plants that affected the performance of phytoremediation of *Echinodorus palaefolius*.

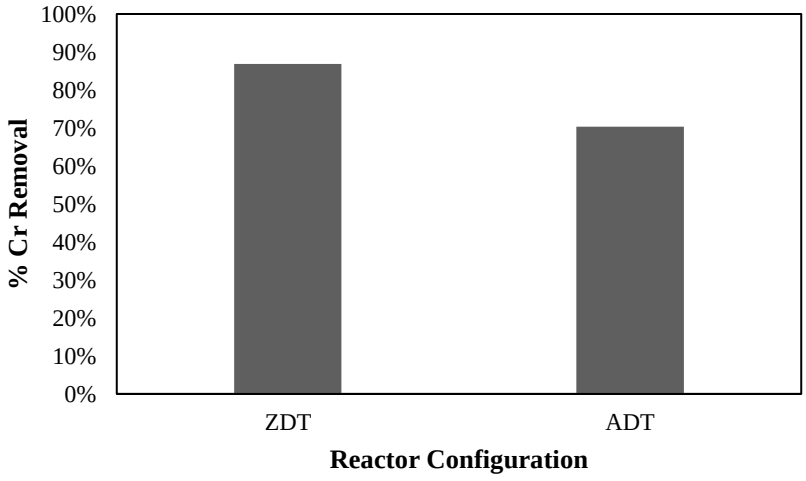


Figure 4. Effect of medium on chromium removal.

Chromiun content in the plants after day 15 of experiments was analyzed in the stems, leaves, and roots, shown in table 3. Chromium accumulation in plants was clearly due to adsorption of Cr ions from water through the plants' roots. This also discovered that the accumulation of Cr mainly occurred in the roots. This was because distribution of metal in other tissues were relatively slow and formation of less-mobile complex with carboxyl group in the root [28-29].

Table 3. Chromium accumulation in plant by parts.

Part	Cr (Initial), mg/kg	Cr (after process). mg/kg	Adsorbed Cr, mg/kg
Root	0.26	2.16	1.90
Stem	0.12	0.88	0.76
Leaves	0.16	0.53	0.37

Nevertheless, this study also found that Cr had adverse effect on the plants after some period. It was observed that within 8 days, the leaves started to wrinkle and turn yellow. This phenomenon might be attributed to chlorosis as Cr inhibited Mg and Fe intake for chlorophyll formation, which then followed by cell death (necrosis) [29]. This process probably occurred in parallel with *Echinodorus palaefolius* high regeneration to withstand Cr toxicity [19]. The evidence had also supported that although the plant still showing Cr yellowish-wrinkled leaves, it kept alive after 15 days. Toxicity of Cr in plants can be caused by both Cr(III) and Cr(VI) [30], although Cr(VI) causes more severe effect. Several studies reported that Cr was able to reduce root growth (Prasad, et al., 2001), reduce photosynthesis rate, reduce enzyme activity, photophosphorylation, electron transport and fixation of CO2 [31].

4. Conclusion

This study unraveled the possibility of using phytoremediation, specifically using *Echinodorus palaefolius* to reduce chromium content in water. Using 4 different configurations of sub-surface constructed wetland (SSF-CW), chromium removal from water was attained. Comparison of CTT and CDT configuration proved that adding using *Echinodorus palaefolius* in the reactor was able to increase chromium removal from 64% to 83%. In addition, examination on medium effect reported that zeolite-only medium (ZDT) had better performance to ADT medium. Further comparison of ZDT and CDT configuration revealed that probably zeolite-only medium gave higher chromium removal compared to CDT. This might be attributed to either lower performance of wood char or incompatibility effect of wood char for phytoremediation with the *Echinodorus palaefolius*. Therefore, it can be concluded that the most suitable configuration is the ZDT medium, which involves plant and zeolite medium.

5. Reference

[1] Databoks 2018 Industri Manufaktur: Produksi Industri Kulit dan Alas Kaki Tumbuh Tertinggi accessed on June 15th 2021 from https://databoks.katadata.co.id/datpublish/2018/08/02/industri-manufaktur-produksi-industri-kulit-dan-alas-kaki-tumbuh-tertinggi
[2] Kementerian Perindustrian (Kemenperin) 2020 Analisis Perkembangan Industri Indonesia accessed from https://kemenperin.go.id/download/24444/Laporan-Analisis-Perkembangan-Industri-Edisi-I 2020
[3] Mella B, Glanert A C and Mariliz G 2015 *Process Safety and Environmental Protection* **95** 195-201
[4] Bacordit A A, 2014 *Journal of The American Leather Chemist Association* **109(4)** 99–109
[5] Hafez A E-M 2002 *Desalination* **144** 237-242
[6] Sugihartono 2016 *Majalah Kulit, Karet, dan Plastik* **32(1)** 21
[7] Mayasari, Eka H and Muhammad S 2016 *Jurnal Kimia Mulawarman* **13(2)**
[8] Goswani S and Ghosh U C 2005 *African Journal Online* **31(4)**
[9] Duan C, Ma T, Wang J and Zhou Y 2020 *Journal of Water Process Engineering* **37** 101339
[10] Mukherjee S, Kumar S, Misra A H and Fan M 2007 *Chemical Engineering Journal* **129** 113-142

[11] Uchimiya M, Bannon D, Nakanishi H, McBride M B, Williams M A and Yoshihara T 2020 *Agric. Food Chem.* **68(46)** 12856–12869
[12] Zewail T M and Yousef N S 2015 *Alexandria Engineering Journal* **54** 83-90
[13] Qin H, Hu T, Zhai Y, Lu N and Aliyeva J, 2020 *Environmental Pollution* **258** 113777
[14] Prasetya A, Prihutami P, Warisaura A D, Fahrurrozi M and Petrus H T B M 2020 *Journal of Environmental Chemical Engineering* **8** 103781
[15] Tangahu B and Warmadewanthi I 2001 *Purifikasi* 2(3)
[16] Haberl R and H Langergraber 2002 *Wat. Sci. Technol.* **40** 11-17
[17] Koesputri, Safira A, Nurjazuli and Dangiran H L 2016 *Jurnal Kesehatan Masyarakat* **4(4)**
[18] Setiyanto, Andri R, Darundiati Y and Joko T 2016 *Jurnal Kesehatan Masyarakat* **4(1)**
[19] Malik R A, Surakusumah W and Surtikanti H K 2016 *Jurnal Riset Teknologi Pencegahan Pencemaran Industri* 45-52
[20] Pehlivan E, Kahraman H and Pehlivan E 2010 *Fuel Processing Technology* **92** 65-70.
[21] Sabilu Y 2016 *Biowallacea* **3(2)** 394-407
[22] Ernawanto Q D, Noeriwan B S and Sugiono 2011 *Prosiding Seminar Hasil Penelitian Tanaman Aneka Kacang dan Umbi*
[23] Yilmaz E, Sonmez I and Demir H 2015 *Communication in Soil Science and Plant Analysis* **45** 2767-2777
[24] Suprayogi D 2009 Adsorpsi dan Desorpsi Kromium (VI) pada Zeolite Alam Asal Lampung Termodifikasi Heksadesiltrimetilamonium Bromida (Thesis, Institut Pertanian Bogor)
[25] Wang T T, Ying G G, He L Y, Liu Y S and Zhao J L 202 *Sci Total Environ*. **733** 139383
[26] Stottmeister U, Wiebner A, Kuschk P, Kappelmeyer U, Kastner M, Bederski O, Muller and Moormann H 2003 *Biotechnol. Adv.* **22(1-2)** 93-117
[27] Baldantoni D, Ligrone R and Alfani A 2009 *Journal of Geochemical Exploration* **101**
[28] Zhang B Y, Sheng J S and Sharp R G 2010 *International Society for Environmental Information Sciences 2010 Annual Conferences* (ISEIS), *Procedia Environmental Sciences* **2** 1315-1325
[29] Zayed A M and Terry N 2003 *Plant soil* **249** 139-156
[30] Rehman A U, Nazir S, Irshad R, Tahir K, Rehman K U, Islam R U and Wahab Z 2020 *Journal of Molecular Liquids* **321** 114455
[31] Clijster H and Assche F V 1985 *Photosynthesis Research* **7** 31-40

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