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Treatment of wet coffee processing plant wastewater by aeration with constructed wetland/*Cyperus ustulatus* and *Typha latifolia* plants process

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ABSTRACT

The research was carried out to investigate wastewater discharge's technical viability from wet coffee processing plant (WCPP) treatments with aeration and *Cyperus ustulatus* plant, *Typha latifolia* plant. The WCPP wastewater was conducted at various aeration days (5, 10, 15, 20 and 25 d) after being irrigated for 21 d in the constructed wetland with *Cyperus ustulatus* and *Typha latifolia* plant and without a plant. The highest value of total solids, chemical oxygen demand and biochemical oxygen demand increasing were 87.8%, 97.4% and, 98.1%, respectively, in 25 d aerated with *Typha latifolia* plant (P2) wetland. After 25 d of aeration with *Cyperus ustulatus* plant (P1) treated polluted water value of biological oxygen demand (97.8%), chemical oxygen demand (96.9%) and total solids (88.5%). The *Typha latifolia* (P2) with 25 d aerated WCPWW reduced 94.2% and 98.1% of NO_3–N and PO_4^3, respectively. As a result, the aeration days were increased with the removal efficiency of pollutants discharged from wet coffee processing plant increased with a constructed wetland. It shows that aeration with constructed wetland treatment method was a low-cost, affordable, technically viable and eco-friendly treatment option for the wet coffee processing plant wastewater.

Keywords: Aeration; Constructed wetland; Coffee processing wastewater; Removal capacity; Wastewater treatment

1. Introduction

Coffee is a popular beverage and highly cultivated crop worldwide, and it is the largest consumed and traded commodity globally [1]. About 80 countries worldwide were cultivated coffee plantations and contributed to the world business sector [1]. More than 8.2 million tons of coffees are produced in 2010/2011 in the world [2]. Globally around 2,250 million cups of coffee are drunk every day [2]. More than ninety percent (90%) of coffee production occurs in developing countries, whereas utilization is mostly in industrialized economies [3]. Ethiopia is the beginning of highland coffee which is internationally traded coffee [4]. Coffee plays a crucial role in the incomes of the country's population directly or indirectly [5]. In Ethiopia, more than 1,249 wet coffee processing plants were constructed near water bodies because the industries need a lot of water to wash wet coffee beans, removing the pulp and the mucilage [6]. The wastewater discharges from the process of wet coffee plants are directly into nearby streams and rivers without treatment, and it is the cause of environmental pollution and human health [7]. Due to the problems, it is essential to treat wastewater discharge from wet coffee processing plants by using aeration with constructed wetland treatment

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before effluent to an environment. The pollutant parameters were characterized from October 1, 2020, to February 30, 2021, at Jimma University, Environmental Health Science and Technology Laboratory, Ethiopia.

2. Materials and methods

2.1. Sample collection

Cyperus ustulatus plant (P1) and, *Typha latifolia* plant (P2) are abundantly growing in Ethiopia. The plants' nurseries were collected from various wetland areas. The wastewater samples were collected in plastic containers (Polyethylene Jerricans) of 20 L capacity from Mana, Goma, Gera and Limu-Kosa District in Jimma Zone, Oromia, Ethiopia. The collected wastewaters were mixed in equal proportion (1:1 ratio) in the 200 L storage container.

2.2. Physio-chemical characterizations of wastewater

The physio-chemical characteristics of wastewater used for the experiments are shown in Table 1. The wastewater samples were analyzed in the laboratory of the Department of Environmental Health Sciences, Jimma University, Ethiopia, from October 2020 to February 2021. The wastewater was characterized as per the Standard Procedure [8]. Characterization of wet coffee processing wastewater was carried out through total solids, biological oxygen demand, chemical oxygen demand, pH, and nutrients.

2.3. Experimental design procedure

2.3.1. Aeration

The mixed wastewater was aerated at the rate of 0.016 L S^{-1} for various days duration. T_1 = WCPWW with 5 d aeration; T_2 = WCPWW with 10 d aeration; T_3 = WCPWW with 15 d aeration; T_4 = WCPWW with 20 d aeration; T_5 = WCPWW with 25 d aeration. The aerated wastewater effluents were characterized by each treatment before being used for wetland experiments.

2.3.2. Constructed wetland

The experiment was carried out with a constructed wetland with a plastic box (i.e., 0.45 m length × 0.20 m width × 0.27 m height). Each box was filled with gravel at the bottom, sand at middle and top by soil; then, the box was seated on the construction concrete stage by randomized block design method for *Cyperus ustulatus* plant (P1) and *Typha latifolia* plant (P2) and without plant (control) under greenhouse. The inflow rates for irrigated experiments were 0.0375 L min^{-1} for all treatments with P1, P2 and controls for 21 d. Characterize the effluents of each treatment according to standards procedure [8] and calculated residence time using Eq. (1) is given below [9,10].

$$\text{Residence time} = \frac{\text{Plant bed volume} \times \text{Porosity}}{\text{Coffee waste water flow}} \quad (1)$$

2.4. Analysis

2.4.1. Data analysis

Organic load, nutrient and total solid removal efficiency of aerated with constructed wetland treatment were calculated using Eq. (2) is given below [11,12].

$$\text{Removal Efficiency}(\%) = \frac{(C_0 - C_d)}{C_0} \times 100 \quad (2)$$

where C_0 = initial parameter of WCWW concentration (mg L^{-1}) and C_d = final parameter of treated WCWW concentration (mg L^{-1})

Table 1
Physico-chemical analysis of wet coffee processing plant raw wastewater (WCPPRWW) and before aerated treatment

Parameters	Raw CWW	Initial concentration of CWW before aeration treatment				
		T_1	T_2	T_3	T_4	T_5
Colour (cu)	602 ± 43	580 ± 29	562 ± 21	530 ± 24	491 ± 32	465 ± 30
pH	3.50 ± 41	3.83 ± 0.15	4.14 ± 0.67	4.08 ± 0.76	4.13 ± 0.61	4.15 ± 0.73
Electrical conductivity (µs cm^{-1})	735 ± 50	1,631 ± 65	2,047 ± 63	2,660 ± 102	2,730 ± 68	2,890 ± 82
Total suspended solids (mg L^{-1})	29,07 ± 68	2,857 ± 58	2,566 ± 79	2,112 ± 47	2,015 ± 38	2,054 ± 73
Total dissolved solids (mg L^{-1})	1,940 ± 69	1,825 ± 72	1,805 ± 47	1,220 ± 38	1,025 ± 43	925 ± 54
TS (mg L^{-1})	3,820 ± 69	3,650 ± 52	3,290 ± 76	3,100 ± 65	2,900 ± 98	2,960 ± 81
Turbidity (NTU)	729 ± 21	511 ± 68	793 ± 14	801 ± 26	577 ± 58	188 ± 79
Dissolved oxygen (mg L^{-1})	1.66 ± 0.6	1.35 ± 0.4	1.33 ± 0.3	1.29 ± 0.5	1.43 ± 0.6	2.79 ± 0.4
BOD_5 (mg L^{-1})	4,322 ± 110	4,023 ± 90	4,244 ± 62	4,277 ± 80	3,484 ± 64	3,244 ± 72
COD (mg L^{-1})	7,612 ± 43	7,224 ± 49	7,511 ± 68	6,554 ± 110	6,524 ± 98	6,174 ± 104
BOD_5–COD ratio	0.57 ± 0.01	0.56 ± 0.01	0.57 ± 0.01	0.65 ± 0.01	0.53 ± 0.01	0.53 ± 0.01
NH_4–N (mg L^{-1})	10.78 ± 0.32	7.12 ± 0.43	7.04 ± 0.64	8.9 ± 0.86	9.74 ± 0.62	9.3 ± 0.81
NO_3–N (mg L^{-1})	260 ± 30	230 ± 40	193 ± 35	160 ± 47	120 ± 44	84 ± 21
PO_4^3 (mg L^{-1})	10.48 ± 0.4	8.15 ± 0.9	7.15 ± 0.8	5.3 ± 0.8	4.33 ± 0.8	3.19 ± 0.9

2.4.2. Fourier-transform infrared and X-ray diffraction analysis

Fourier-transform infrared (FTIR) spectroscope analysis was performed (Model No. FTIR-L1600300, Spectrum TWO LiTa, Llantrisant, UK) was determined functional group of the soil before and after wetland treatment. The soil structure was studied using an X-ray diffractometer (XRD) (Model No. XRD-7000, Shanghai Drawell Scientific Instrument Co., Ltd., China).

3. Results and discussions

3.1. Description of the study area

The study was carried out in Mana, Goma, Gera and Limu-Kosa districts located in Jimma Zone, around 19 km south-west, 55 km south-west, 75 km to the south-west direction and 25 km to the west of Jimma Town, respectively. Jimma town is located 352 km from A.A. in south-west Ethiopia (Fig. 1). Greater than 250 wet coffee processing industries (WCPI) were established in these four districts. It is indicated that these four weredas cover greater than 75% WCPI from the Jimma Zone. These wet coffee processing plants discharge their wastewater into near water bodies without treat by using eco-friendly technology. These four weredas (districts) and Jimma Town are lying between latitude 7°33′ (Gera district) up to 8°26′ (Limu-Kosa district) north and longitude 35°91′ (Gera district) up to 37°36′ (Limu-Kosa district) east and with an elevation of 1,643 m (Mana district) up to 1,967 m (Gera district) above sea level. The mean minimum and maximum annual temperature range between 20°C and 32°C, respectively.

3.2. Characteristics of wastewater

Characteristics of raw wastewater (Table 1) were made in triplicate for each parameter. The instruments used for the analysis of parameters such as total dissolved solids and total suspended solids by gravimetric method, biological oxygen demand (BOD_5) by Azide Modification of the Winkler Method, total nitrogen, total phosphorus and chemical oxygen demand (COD) colorimetrically by DR 5000™ UV-Vis spectrophotometer by using HACH instructions. Due to pectin and tannin's degradation results, the color of WCPWW was changed [13]. The pH value was from 3.09 to 4.88 it indicates that the sugars changed to alcohol and CO_2. Then the alcohol is changed to acetic acid by the process of fermentation [14]. The presences of total solids were high due to the biodegradable nature of wastewater. The BOD_5 value was from 3,172 to 4,432 mg L^{-1}, which shows that organic load amounts were high. According to Shanmukhappa et al. [15] studied that BOD_5 amount 10,000–12,000 mg L^{-1} in CPWW. Due to the low degrading compound fCOD amount (6,070–7,655 mg L^{-1}) in the WCPWW. According to Haddis and Devi [16] in Ethiopia and Mburu et al. [17] in Kenya, the finding of their study agreed with the result of this study.

3.3. Treatment of wet coffee processing wastewater

3.3.1. Treatment of coffee wastewater using constructed wetland

The constructed wetland (CW) was processed at various hydraulic retention times of 5, 10, 15, 20 and 25 d in Table 2. The CW was irrigated with aerated coffee wastewater (CWW) containing BOD_5 and COD amount from 3,172 to 4,357 and 6,070 to 7,579 mg L^{-1}. The total solids (TS) value is from 2,879 to 3,702 mg L^{-1}. The pH range of 3.68–4.38. At 25 d aeration with the *Typha latifolia* plant, after 21 d irrigated, the removal capacity for COD and BOD_5 was 96.8% and 97.4%, respectively. The highest removal capacity of TS by the *Typha latifolia* Plant was achieved at 84.3%. The pH of treated effluent from *Typha latifolia* ranged from 6.72 to 6.94.

Table 2 shows the efficiency of CW pollution amount decreased because of the aeration treatment of wastewater in various days' aeration. The CW treatment efficiency was increased both 25 and 20 d with *Typha latifolia* plant wetland treatment and 25 d performed with higher efficiency than 20 d with *Typha latifolia* plant. But, the amount of removal efficiency was different with days. For example, COD decreased by 18%, BOD_5 decreased by 15.2%, and TS decreased by 22.1% between 5 and 25 d of aeration. The difference in aeration days using *Typha latifolia* plant with constructed wetland efficiency for the three parameters (COD, BOD_5 and TS) was the smallest amount, but the aeration days taken for pollutant decreasing were small 5 d compared with 25 d aerations. Aerobic treatment is good at 20 d aeration and 25 d aeration because COD of <250 mg L^{-1} according to the Central Pollution Control Board Standards [10]

3.3.2. Aeration on CPWW

The raw CPWW had contained; pH, electrical conductivity, BOD_5, COD and TS of supply were 3.5, 735 µs cm^{-1}, 4,322,

Table 2
Removal capacity of various aeration days with constructed wetland

Aerated days with *Typha latifolia* plants (d)	COD (Raw CWW 7,612 mg L^{-1})	BOD_5 (Raw CWW 4,322 mg L^{-1})	TS (Raw CWW 3,820 mg L^{-1})	NO_3–N (Raw CWW 260 mg L^{-1})	PO_4^3 (Raw CWW 10.48 mg L^{-1})
	Removal (%)	Removal (%)	Removal (%)	Removal (%)	Removal (%)
25	195 (97.4%)	82 (98.1%)	465 (87.8%)	15 (94.2%)	0.2 (98.1%)
20	235 (96.9%)	123 (96.9%)	760 (80.1%)	36 (86.2%)	0.5 (95.2%)
15	711 (90.7%)	363 (91.6%)	1,023 (73.2%)	78 (70.0%)	1.1 (89.5%)
10	925 (87.8%)	486 (88.8%)	1,268 (66.8%)	103 (60.3%)	1.7 (83.8%)
5	1,564 (79.4%)	737 (82.9%)	1,312 (65.7%)	147 (43.5%)	2.2 (79.0%)

7,612 and 3,820 mg L^{-1}, respectively. The removal efficiency of BOD_5 and COD was 98.1% and 97.4%, respectively, after aeration treatments of 25 d and irrigated with 21 d. The maximum removal efficiency increase with increase aerations days increase due to additional supply of O_2 it is improved the degradation of organic matters (Fig. 3). According to Vishnumurthi [18], described that removed 98.98% BOD_5 from domestic wastewater due to the aeration process.

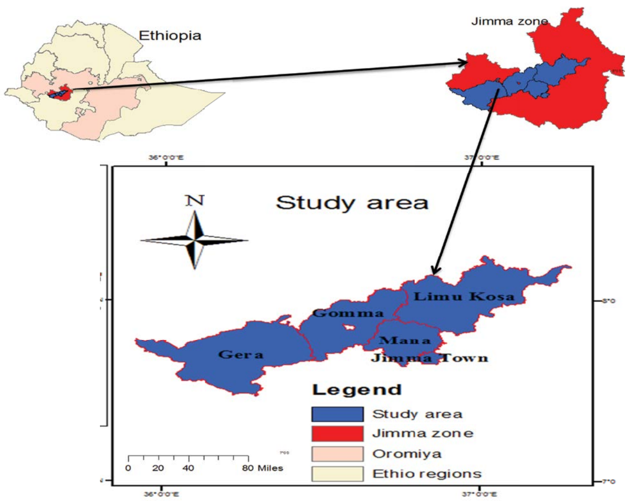

Fig. 1. Location map of Gera, Goma, Mana, Limu-Kosa Districts and Jimma Town.

The removal efficiency of TS decreased with aeration days decreased by 87.8% for 25 d, 80.1% for 20 d, 73.2% for 15 d, 66.8% for 10 d and 65.7% for 5 d. According to Choudhury et al. [19], the removal capacity of TS was 54% wastewater from Kraft paper by batch aeration.

3.3.3. Constructed wetland treatment of WCPWW

The aerated CPWW with 5, 10, 15, 20 and 25 d were irrigated for *Cyperus ustulatus* (P1), *Typha latifolia* (P2) and control without plants for 21 d. The effluents result indicated that (Fig. 2) from the two plants, *Typha latifolia* remove 98.1% of BOD_5 in aerated with 25 d WCPWW. *Cyperus ustulatus* followed it with 97.8% of BOD_5 removal in aerated with 25 d WCPWW. A similar study indicated that the removal capacity of BOD_5 was 75% with the wetland process [20,21].

The TS removal efficiency of 87.8% was shown in aerated 25 d CPWW treated with *Typha latifolia*. It was followed by 88.5% of TS removal in aerated 25 d CPWW treated with *Cyperus ustulatus.* The removal of total suspended solid shows in between 75% to 89%. According to Sapkota and

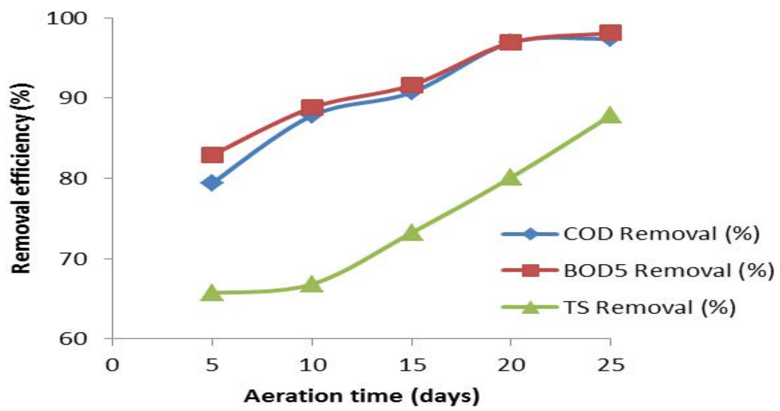

Fig. 2. Effect of aeration days on the efficiency of constructed wetland in the removal of COD, BOD_5 and TS.

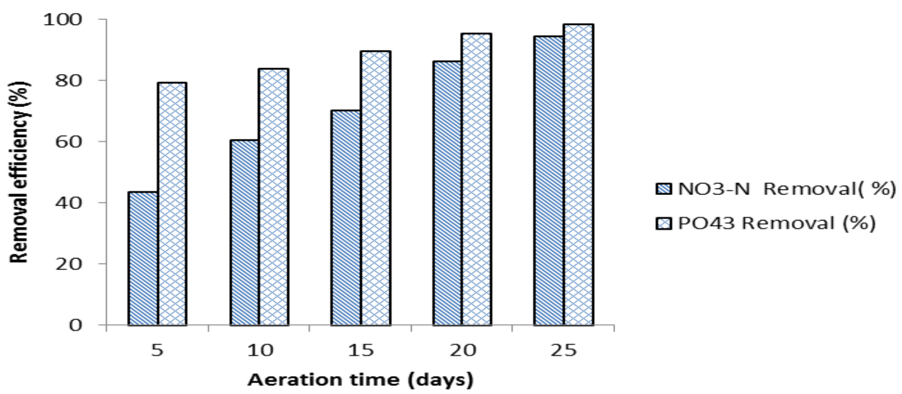

Fig. 3. The removal efficiency of nutrients in various days of aeration with wetland treatment.

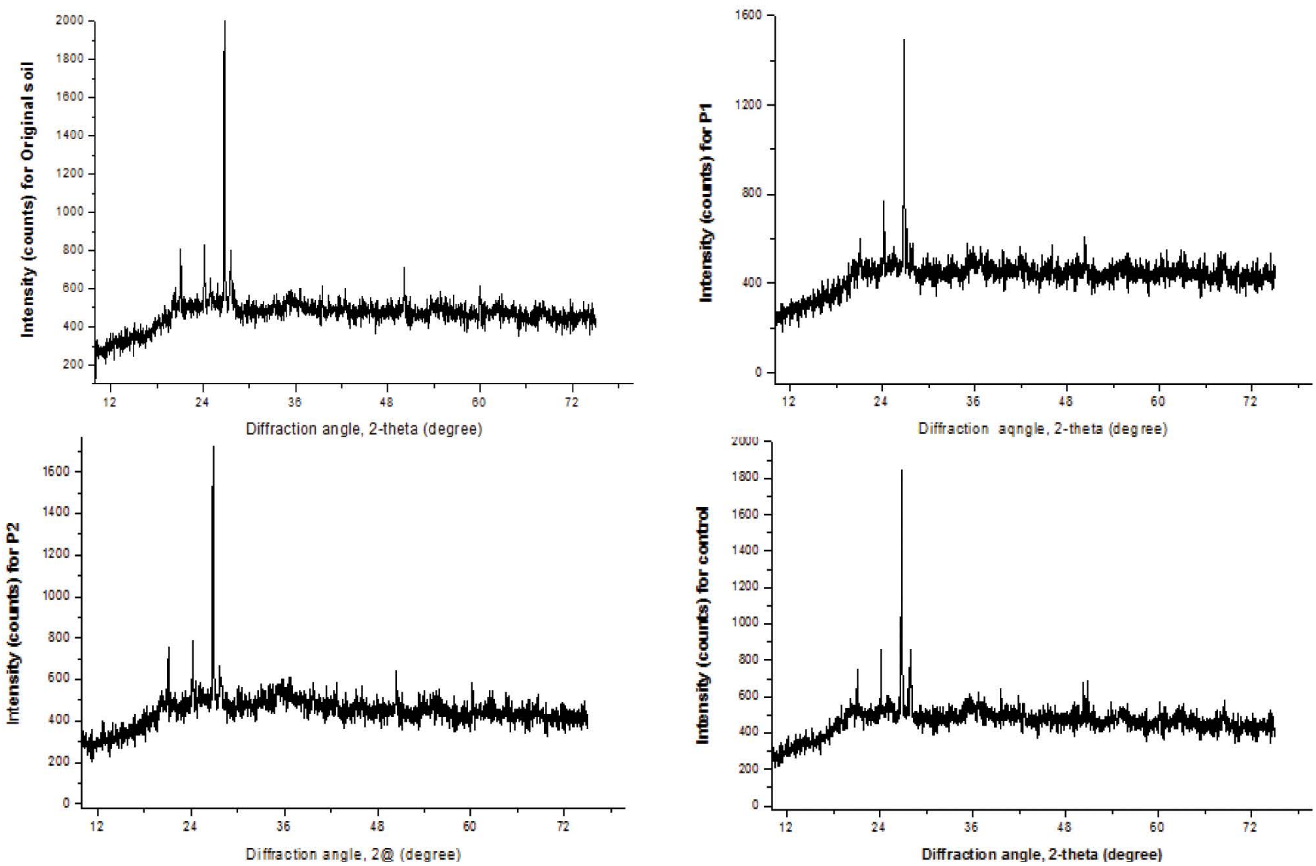

Fig. 4. XRD analysis of before-treated dried original soil, after-treated dried soil from *Cyperus ustulatus* plant (P1) in CW, *Typha latifolia* plant (P2) in CW, and without plant (control) in CW, respectively.

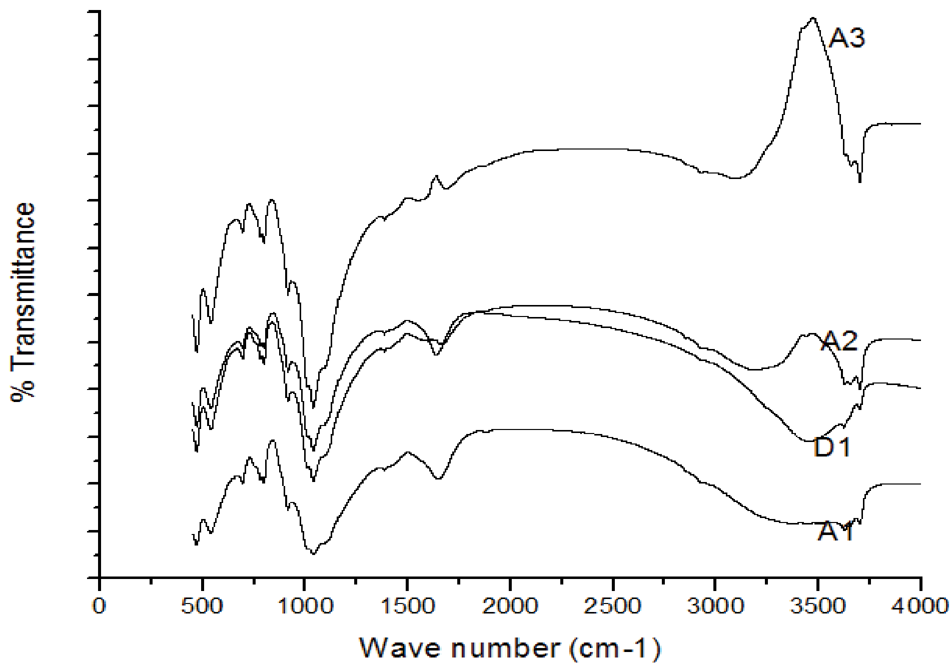

Fig. 5. FTIR spectra soil (D1) before treated dried original soil, (A1) after treated dried soil with *Cyperus ustulatus* (P1), (A2) after treated dried soil with *Typha latifolia* (P2), and (A3) after treated dried soil without plant (control).

Bavor [22], the removal capacity of total suspended solids in between 30% to 86% in the gravel-based sub-surface flow process.

3.4. X-ray diffraction and Fourier-transform infrared spectroscopy analysis

3.4.1. X-ray diffraction analysis

The X-ray diffraction (XRD) analysis result is shown in Fig. 4. The XRD analysis of the original soil before treatment and the sludge after treatment in constructed wetland shows that polymeric compounds are present in the raw materials. All types of filling materials to constructed wetland system reveal diffuse peaks in the spectrum that peaks indicated the amorphous crystalline in nature and the soil contain metals [23]. A few small humps were described in the original soil's range and treated soil without plants (control that indicated an amorphous phase.

3.4.2. Fourier-transform infrared spectroscopy analysis

The FTIR spectra of original soil (Fig. 5: D1) and after treated (Fig. 5: A1, A2, and A3) with coffee wastewater was shown in Fig. 5. In the case of original soil before treated (D1) in Fig. 5, it indicated that various peaks represented different stretching such as 1,050 cm^{-1} for –OH, 3,400 cm^{-1} – CH_2, 450 cm^{-1} for C=O, 600 cm^{-1} for C=C, 700 cm^{-1} between 900 cm^{-1} for C=C and 1,300 and 1,650 cm^{-1} for C–O [24–27]. The FTIR spectrum of wastewater absorbent shows that in Fig. 5. (A1) after treated dried soil with *Cyperus ustulatus* (P1), (A2) after treated dried soil with *Typha latifolia* (P2), and (A3) after treated dried soil without plant (control), shows that the peaks because of functional groups are a little affected in their intensity and position. It indicates that the wetland treatments absorption of wastewater on the surface of soil, sand and plants are with complexation or weak electrostatic interaction and Van der Waals forces [24–27].

4. Conclusions

The above results may conclude that the wet coffee processing wastewater was appropriate for biological treatment. The discharged wastewater from wet coffee processing plant followed by aeration and constructed wetland with *Cyperus ustulatus* and *Typha latifolia* plants were low-cost, affordable, technically viable and eco-friendly treatment technology.

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