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EVALUATION OF A NEW METHOD FOR TREATING COFFEE EFFLUENT

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ABSTRACT

Coffee fruits are processed by either wet method or dry method at the estate level to obtain the coffee bean. Of these two methods, coffee processing by wet method requires large amount of water and thus generates enormous amount of effluent which needs to be treated extensively before discharge. Currently, the effluent treatment plant (ETP) module developed by Central Coffee Research Institute (CCRI) in collaboration with National Environmental Engineering Research Institute (NEERI) during 1980 is employed for treating the coffee effluent. The Central Pollution Control Board (CPCB) has recommended CCRI-NEERI ETP module for adoption at the estate level to treat the coffee effluent. In the present investigation, a new method viz., Acidification-Neutralization-Sedimentation-Filtration (ANSF) developed recently by CCRI was evaluated for treating the coffee effluent for four consecutive seasons (2017-2018 to 2020-2021) under field conditions. The results indicated that the BOD reduction by ANSF method is comparatively higher than the BOD reduction by CCRI-NEERI method. Further, ANSF method is relatively simple, as it does not require any chemical (or) biological inputs for treating the coffee effluent, excepting calcium oxide and biochar.

KEY WORDS: Coffee effluent, NEERI, Effluent treatment plant (ETP), BOD, TSS.

INTRODUCTION

Coffee is the second largest traded commodity in the world only after oil and grown in about eighty countries, mostly in the developing countries. Though there are more than one-hundred coffee varieties reported to be present in the nature, Arabica and Robusta are the two main coffee varieties grown on commercial scale worldwide. India is the seventh largest producer of coffee in the world with 4,59,895 ha of land under coffee cultivation with the total production of 2.98 lakh metric tonne of coffee bean during 2019-2020 harvest season (Anonymous, 2021).

Coffee processing refers to the transformation of coffee cherries (fruits) into coffee bean. Coffee is processed by two methods (wet and dry) to obtain the coffee bean from coffee cherries. Of these two processing methods, wet processing consumes lot of water at different stages of processing and thus generates effluent containing high BOD level. In wet processing, the harvested coffee fruits are sorted out manually to eliminate the unripe fruits (also known as greens) and only the ripe fruits are pulped to remove the outer skin. Each fruit usually yields two beans which are covered by thin layer of mucilage mostly consisting of sugars and pectin. The mucilage is removed using aqua washer. The washed coffee beans are soaked in water for about 8 to 10 hours to remove the residual mucilage clinging to the coffee bean and this process known as post-wash soaking. Then the coffee samples are sun dried for about six to seven days until the moisture level reaches to 10% to 11%. The coffee thus processed is called as parchment coffee and majority of the Arabica coffee in India is processed by wet method. The dry processing is a simple method where the harvested fruits are sun dried for about 10 to 15 days until the moisture reaches around 11% to 12%. The coffee processed by dry method is known as cherry coffee and a major portion of the Indian Robusta coffee is processed by dry method. Coffee processing carried out at the estate is referred as primary processing and the parchment coffee is superior in quality compared to cherry coffee. The parchment and cherry coffees produced at the estate are hulled at the coffee curing factories. During the hulling process, the outer skin of the parchment and cherry coffees are removed and coffee bean are obtained. Depending on the market requirement, the coffee beans are either graded based on the bean sizes or maintained as bulk coffee. Coffee processing at the curing factories is referred as secondary processing. About 75% of Indian coffee is exported as green coffee bean (unroasted coffee bean) and the remaining is consumed locally after roasting and grounding, which are referred as tertiary processing.

During wet processing of coffee at the estate, lot of water is used for pulping, washing and post wash soaking. The water along with mucilage removed during washing process form as effluent. The quantity of the effluent generation during wet processing depends on the type of machineries used, processing methods followed at the estate level and availability of water. The traditional wet method generates about 5,000 to 10,000 L of effluent/tonne of coffee fruit. While the high-cost advanced coffee machineries (ecopulper) generate around 1,500 to 2,000 L of effluent/tonne of coffee fruit.

The Central Coffee Research Institute (CCRI) had developed an effluent treatment plant (ETP) in collaboration with National Environmental Engineering Research Institute (NEERI) during 1980 to treat the coffee effluent resulting from wet processing of coffee. The Central Pollution Control Board (CPCB) had recommended CCRI-NEERI ETP unit for adoption at the estate level to treat the coffee effluent. The CCRI-NEERI ETP unit is basically an anaerobic-cum-aerobic digestion method and it takes about a month time for treating the coffee effluent (Shanmukhappa *et al*., 1998). Several reports have been published for the treatment of coffee effluent following physio-chemical (Aguilera *et al*., 1998; Bhaskar *et al*., 2008; Tokumura *et al*., 2008; Asha *et al*., 2015; Panchangam *et al*., 2015; Hermosilla, 2016; Tomizawa *et al*., 2016; Sahana *et al*., 2018 and Veymar *et al*., 2019), chemicals (Teresa *et al*., 2007; Zayas Péerez *et al*., 2007; Novita *et al*., 2012 and Workineh *et al*., 2020), biological (Selvamurugan *et al*., 2010, Yans Guardia Puebla *et al*., 2013, Chagas *et al*., 2015; Padmapriya *et al*., 2015; Hubbe *et al*., 2016; Torres *et al*,. 2016; Cruz-Salomón *et. al*., 2018; Navitha *et al*., 2018; Tacias-Pascacio *et al*., 2019 and Workineh *et al*., 2020) and phyto-remediation (Nor Sakinah Mohdsaid *et al*., 2019) methods.

The coffee effluent contains pectin and macromolecules such as polyphenols and caffeine (Cardenas *et al*., 2009). These macromolecules are tough to degrade using conventional biological treatment processes and are responsible for the dark brown colour of the coffee effluent. Though the anaerobic-cum-aerobic digestion method is the most popular method for treating the coffee effluent, this method is time-consuming as the bacterial consortia responsible for the degradation process require time to adapt to the new environment before they start to consume organic matters to grow. Another disadvantage of this method is the fact that the volume and strength of the coffee effluent may not be consistent and these fluctuations hinder the efficiency of the treatment process. Lastly, this method will invariably require a further post-treatment to meet the environmental standards set by the regulatory authorities before discharge.

Although various methods have been developed to treat the coffee effluent, there is still need to explore other methods that may be more efficient as well as cost-effective. In this direction, the CCRI has recently developed a new treatment method for treating the coffee effluent. The new method viz., Acidification-Neutralization-Sedimentation-Filtration (ANSF) was evaluated for four consecutive seasons (2017-2018 to 2020-2021) under field condition at CCRI research farm and the results are presented in this paper.

MATERIALS AND METHODS

The typical characteristics of the fresh coffee effluent along with the limits prescribed for coffee effluent by the Ministry of Environment, Forest and Climate Change (Anonymous, 2020) are detailed in Table 1.

The CCRI-NEERI ETP module consist of an equalization tank followed by anaerobic lagoon, aerobic lagoon and settling tank (Fig.1). The size of the tanks/lagoons varies according to the quantity effluent generated at the estate. The depth of the equalization tank, anaerobic lagoon, aerobic lagoon and settling tank is usually in the order of 1, 3, 1.2

Table 1. Characteristics of fresh coffee effluent and the limits prescribed for coffee effluent by the Ministry of Environment, Forest and Climate Change (MoEFCC)

Parameters	Fresh coffee effluent	MoEFCC limits
pH	4 – 4.5	6.5 - 8.5
Total suspended solid (g/L)	2 – 11	-
COD (mg/L)	7,200 – 23,000	-
BOD (mg/L)	2,300 – 13,000	1000 (for storage in lined lagoon) 100 (for discharge on land for irrigation)

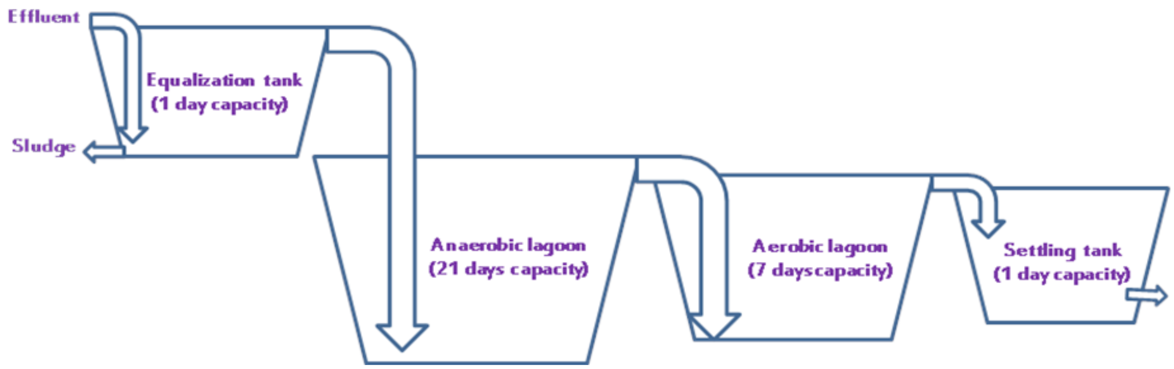


Fig. 1. Schematic representation of the CCRI-NEERI ETP unit

and 1 meter, respectively. The fresh effluent from the coffee processing unit is held in equalization tank for about 24 hours and the effluent is neutralized by adding calcium oxide at the rate of 5 gr/L in the equalization tank to raise the pH of the effluent to neutral range. Then, the effluent flows to anaerobic lagoon by gravity force and held for twenty-one days followed by aerobic lagoon (effluent held for seven days) and finally collected in the settling tank. The anaerobic lagoon is charged with 4% cow dung slurry up to 10% of the total capacity of the anaerobic lagoon two weeks prior to the onset of the coffee processing to encourage the growth of methanogenic bacteria. As coffee effluent is deficient in nutrients, urea and super phosphate are added into the anaerobic lagoon at the rate of 4.5 kg and 2.5 kg/20,000 L of effluent, respectively. Urea and super phosphate are also added into the aerobic lagoon at the dosage of 500 and 250 gr/20,000 L of effluent, correspondingly to hasten the degradation process.

The basic units of the new treatment method viz., Acidification-Neutralization-Sedimentation-cum-Filtration (ANSF) are depicted in Fig. 2 and 3. It consists of two units of acidification tank (A1 and A2 each having a dimension of 8.8 x 3 x 4.8 feet LBW and holds 3,500 L effluent) followed by a neutralization tank (9.6 x 3 x 8.8 feet LBW and holds 7,000 L effluent) and four sedimentation tanks (S1, S2, S3 and S4 having a dimension of 6.2 x 4.9 x 4.75 feet LBW and holds 4,000 L effluent). A perforated screen (75 x 56 inches LB) with 8 mm diameter holes is placed by leaving one foot from the bottom of the S2 and S3 tanks and these tanks are filled with gravel stones of different sizes (20 mm and 40 mm), fine sand and biochar in proportion. The S1 and S4 tanks serve as sedimentation tanks while S2 and S3 tanks serve as filtration tanks. The effluent inlet is provided at the bottom by leaving one foot at the bottom and outlet is provided at the top by leaving one foot from the top using 8" PVC pipes in all the tanks. As the effluent inlet is at the bottom of the tank, the quantity of effluent entering each tank will replace the same quantity of effluent at the top of the tank. The approximate holding time of effluent in each tank will be six to eight hours.

The fresh effluent and the effluent from various tanks/lagoons of both CCRI-NEERI and ANSF ETP units were sampled at regular intervals in clean containers up to brim of the container. The effluent samples were brought to the laboratory immediately and tested for pH (Lab Man make pH meter model no. LMPH-10). The BOD levels in the effluent samples was measured following the method outlined in Standard Methods manual (APHA, 1992) for 3 days at 27^0 C in a BOD incubator (M/s. Scientex Instrument make BOD incubator). The total suspended solid content in the effluent sample was estimated by gravimetric method following the procedure set out in Standard Methods manual (APHA, 1992).

RESULTS AND DISCUSSION

Influence of effluent treatment methods on pH level

It is a well known fact that the coffee effluent is inherently acidic in nature due to the presence of various organic acids. The average pH in the fresh effluent sample recorded in the present study ranged from 4.28 (Table 2) to 4.58 (Table 3) which is good agreement with the findings of Rani *et al.*, (2008), Selvamurugan *et al.*, (2010) and Cruz-Salomón *et al.*, (2018). The pH value in fresh coffee effluent reported by these authors ranged from 3.88 to 4.5. In CCRI-NEERI method, the pH of the effluent has increased from an initial value of 4.58 to 5.2 during the process of treatment over a period of about thirty days (Table 2). Though the fresh effluent is neutralized by adding calcium oxide at the recommended rate of 5 gr/liter in the equalization tank, the pH of the treated effluent has not increased to neutral range. This is mainly due to the production of organic acids through continuous fermentation of sugars present in the effluent. While in case of ANSF method, the fresh effluent is allowed to rest in acidification tanks (A1 and A2) for about 12 to 16 hours in each tank. During acidification, the pH value of effluent has reduced to 4.2 from an initial value of 4.58 due to the production of organic acids generated through fermentation of sugars in the effluent (Table 3). During the course of treatment, the pH of the effluent has gradually increased to 6.23 in about six to seven days. The increase in pH of the effluent is due to the contact of effluent with the gravel stones, sand and particularly biochar present in S2 and S3 tanks. As reported by Kiran Reddy *et al.*, (2013), biochar has the potential to increase the pH of the medium where it is applied.

Influence of effluent treatment methods on BOD level

The average BOD level in the fresh effluent sample recorded in the current study ranged from 6,862 mg/l (Table 2) to 6,555 mg/l (Table 3). The BOD level in the fresh coffee effluent has been reported by few authors and it ranged from 3,800 mg/l (Selvamurugan *et al.*, 2010), 15,850 mg/l (Velmourougane *et al.*, 2012) to as high as 37,944 mg/l (Cruz-Salomón *et al.*, 2018). The reason for the wide variation of BOD levels in the fresh coffee

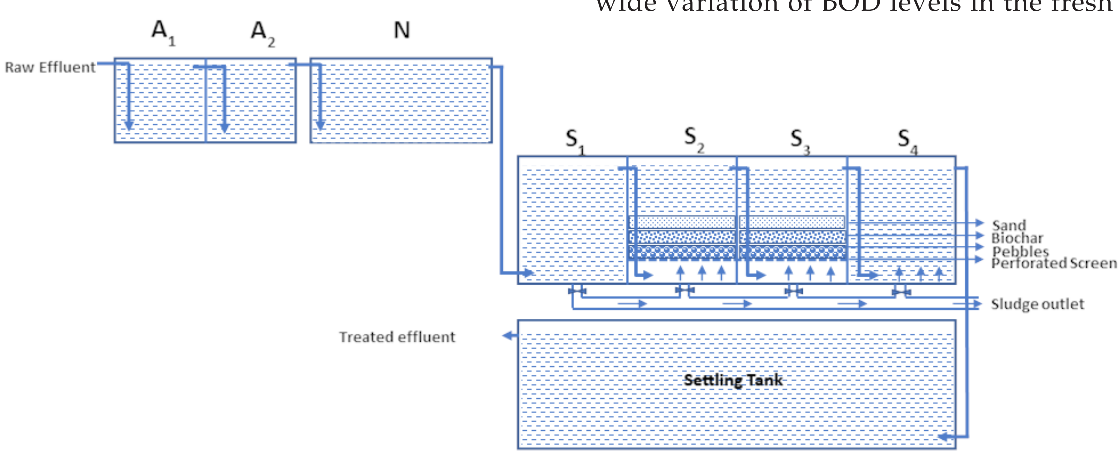


Fig. 2. Schematic representation of the ANSF ETP unit

Table 2. Influence of CCRI-NEERI method on pH and BOD levels in coffee effluent

Treatment level	pH		BOD (mg/l)		Reduction of BOD load (%)
	Range	Average	Range	Average	
Fresh effluent	3.71-5.23	4.28 ± 0.38	5,965-8392	6,862 ± 603	-
Equalization tank	4.00-5.71	4.77 ± 0.59	3,997-5706	4,773 ± 594	30.45
Anaerobic lagoon	4.14-5.63	4.96 ± 0.45	3,547-4818	4,248 ± 386	38.00
Aerobic lagoon	4.82-6.80	5.56 ± 0.49	1,983-2794	2,284 ± 201	66.70
Settling tank	4.36-6.22	5.20 ± 0.65	1,799-2568	2,148 ± 267	68.70

± - Represent standard deviation of means effluent due to fact that the volume and strength of the effluent varies every day and primarily depends on the quantum of water used for coffee processing (i.e. lesser the water, higher the strength of effluent and vice-versa) and processing methods followed at the estate. The data on the influence of effluent treatment methods on reduction of BOD load indicated that the average BOD reduction by the CCRI-NEERI treatment method was 68.7% (Table 2) while the average BOD reduction by the ANSF method was 76.6% (Table 3). Various technologies have been employed for treating the coffee effluent, mostly under laboratory conditions and the reported BOD reduction varies from 71% (Selvamurugan *et al*., 2010) to 99% (Rani *et al*., 2008).

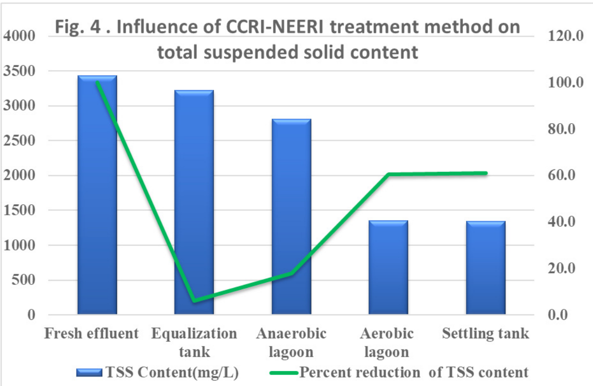
There are several reasons for the enhanced performance of ANSF method over CCRI-NEERI method. The initial acidification of fresh effluent for about 24 to 38 hours results in the removal of mucilage (mostly the pectinaceous substances) from the fresh effluent which floats on the top of the acidification tanks as crust. Under acidic condition, the pectinaceous substances present in the coffee effluent comes out of the effluent due to precipitation. These pectic substances reacts with the calcium or other multivalent ions present in the effluent and forms into a non-soluble gel of calcium pectate. The removal of pectinaceous substances from the fresh coffee effluent makes further treatment easier. Further to this, the use of fine sand and biochar as filtering/adsorbing materials in the ANSF method could have attributed to the reduction of the BOD load in the coffee effluent. Activated carbon technology has shown great efficiency in the removal of pollutants than many conventional methods of organic wastewater treatment method (Rani *et al*., 2008). Bicohar is a carbonized solid form of organic material resulting

Fig. 3. A view of ANSF ETP unit established at CCRI research farm

Table 3. Influence of ANSF method on pH and BOD levels in coffee effluent

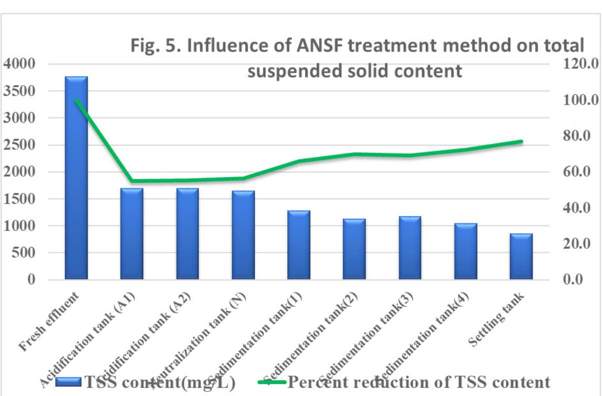
Treatment level	pH		BOD (mg/l)		Reduction of BOD load (%)
	Range	Average	Range	Average	
Fresh effluent	3.71 - 5.59	4.58 ± 0.50	5,285 -7,963	6,555 ± 731	-
Acidification tank-1	3.41 - 5.14	4.21 ± 0.47	2,189 - 3,298	2,715 ± 303	58.6
Acidification tank-2	3.40 - 5.12	4.20 ± 0.47	2,191 - 3302	2,718 ± 303	58.5
Neutralization tank	3.91 - 5.89	4.84 ± 0.54	2,217 - 3340	2,749 ± 307	58.0
Sedimentation tank-1	3.98 - 6.00	4.94 ± 0.55	2,084 - 3140	2,585 + 288	60.5
Sedimentation tank-2	4.04 – 6.08	5.02 ± 0.56	1,567 - 2361	1,943 + 217	70.4
Sedimentation tank-3	4.86 – 7.32	6.04 ± 0.67	1,568 - 2362	1,944 ± 217	70.4
Sedimentation tank-4	4.43 – 6.67	5.52 ± 0.61	1,422 - 2142	1,763 ± 197	73.1
Settling tank	5.00 -7.73	6.23 ± 0.69	1,238 -1866	1,536 ± 171	76.6

± - Represent standard deviation of means from the heating of biomass in an oxygen-limited environment. Biochar shares many characteristics with activated carbon and studies have shown that biochar can be used to treat effluent (Tran Thi Thu Huong *et al*., 2021).



Influence of effluent treatment methods on total suspended solid content

The average total suspended solid (TSS) content in the fresh effluent samples tested in the present study ranged from 3,430 mg/l (Fig. 4) to 3,770 mg/l (Fig. 5). The reported TSS content in fresh coffee effluent varies widely and it ranged from 399 mg/l (Nor Sakinah Mohdsaid *et al*., 2019), 1,450 mg/l (Workineh *et al*., 2020), 2,390 mg/l (Veymar *et al*., 2019) and 2,820 mg/l (Selvamurugan *et al*., 2010). The data on the influence of effluent treatment methods on TSS content indicated that the average TSS reduction by CCRI-NEERI treatment method was 61% (Fig. 4) while the average TSS reduction by the ANSF method was 77% (Fig. 5). The reduction of TSS content varies with the technology employed for treating the coffee effluent and studies have reported reduction of TSS content from 94% (Nor Sakinah Mohdsaid *et al*., 2019) to 99% (Workineh *et al*., 2020).



CONCLUSION

In the current study, a new treatment method viz., Acidification-Neutralization-Sedimentation-Filtration (ANSF) was evaluated with the recommended treatment method (CCRI-NEERI) for treating the coffee effluent. The results of the study indicated that the ANSF method is comparatively more effective, as compared to the CCRI-NEERI method. Further, the ANSF method is relatively simple, as it does not require any chemical or biological inputs (excepting calcium oxide and biochar) for treating the coffee effluent. Another advantage of ANSF method is the fact that it takes about a week time for the treatment of coffee effluent, as compared to CCRI-NEERI ETP unit which takes about a month time for the treatment. Nevertheless, the ANSF did not reduce the pollution load to the limits prescribed for coffee effluent by the Ministry of Environment, Forest and Climate Change. Therefore, it is contemplated to take up further field trials on the integration of phyto-remediation technique (use of reed-plant) in the ANSF treatment method and assess its impact on further reduction of pollution load in coffee effluent.

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