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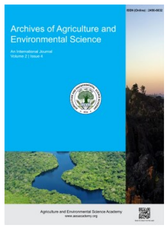

ORIGINAL RESEARCH ARTICLE

CrossMark

Efficiency assessment of faecal sludge treatment plant (FSTP): An analytical study

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ABSTRACT

The success of Swachh Bharat Mission (SBM) has increased the number of toilets in India. Treatment of septage and faecal sludge is now a big challenge to main the sanitation and hygiene in the society. Therefore, in the present study an attempt has been made to explore the concept and efficiency of Faecal Sludge Treatment (FSTP) technology. The paper also includes the study of characteristics of faecal sludge and biochar produced from faecal sludge. The efficiency of plant for biochemical oxygen demand (BOD), chemical oxygen demand (COD) and Total Suspended Solids (TSS) was observed 99.88%, 99.91% and 99.88, respectively. After the treatment all the studied parameters of treated water was found below the standards set by MOEF for FSTP discharge. After dewatering and drying, the faecal sludge is analyzed for calorific value, ash, fixed carbon, volatile matter, carbon, hydrogen, nitrogen, and sulphur. Calorific value of faecal sludge ranged from 3339.00 Kcal kg^{-1} to 3542.00 Kcal kg^{-1} with an average value of 3419.67 Kcal kg^{-1}. Then the faecal sludge is pyrolysed to produce the energy and biochar. Biochar was analyzed for pH, colour, moisture, bulk density, potassium, nitrogen, phosphorus, lead, zinc, cadmium, copper, nickel, chromium, and mercury. All the parameters of biochar were found below the standard limits of Solid Waste Management Rules (SWM), 2016 except bulk density (2.07 g cm^{-3}), potassium (1.02%), and nitrogen (3.09%). On the basis of biochar results, it may be concluded that the sludge produced can be used as manure in agriculture and gardening. Therefore, FSTP is a suitable, sustainable eco-friendly technology for the treatment of faecal sludge and also reduces the chances of soil and ground water pollution.

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INTRODUCTION

The global transmission of unaltered sanitation technologies has been a major source of involvement for environment and public health. Poor sanitation globally results in increased prevalence of diseases and pollution in the environment (Singh *et al*., 2017). To maintain the sanitation and hygiene globally, we requires onsite sanitation technologies (Diener *et al*., 2014; Katukiza *et al*., 2012). The launch of the Swachh Bharat Mission (SBM) by the Government of India for making India free from "open-defecation" (ODF) by 2 October 2019 speedup the Indian sanitation sector to a great extent. To achieve this objective, 90 million toilets were constructed in rural India. The SBM will also help India to achieve Sustainable Development Goal 6 (SDG 6), concerning to sanitation for all by 2030 (WHO, 2012). In urban India, around 70% of toilets are connected to onsite containment systems like pit latrine, or septic tanks. Based on their type, these on-site systems need to be emptied after every two-three year as per code of Bureau of Indian Standards (Ghisellini *et al*., 2016; Koné *et al*., 2010). Faecal sludge is the waste released from on-site sanitation systems and septage is the waste of properly designed septic tank (UMC, 2018; http://www.eai.in/ref/ae/wte/typ/clas/fecal_sludge.html.). In most cities, the task of assessment and treatment is performed by private agencies in irregular and informal ways. Due to a lack of regulation and enforcement of septage management in urban India, it is mostly discharged in open drains, water bodies or rivers resulting in the contamination of water bodies (Ghisellini *et al.*, 2016; Klinger *et al.*, 2020). The sludge extracted from the toilets, bathing and wash-water from kitchens is 10 times more concentrated than sewage due to solids, pathogens, anal cleansing materials, menstrual hygiene materials and organic content as a result it becomes more detrimental to the health of a water body as well as aquatic flora and fauna (https://www.downtoearth; LEDeG, 2019; NITI Aayog, 2019). Therefore, there is an urgent need to assess and regulate the treatment of this faecal matter and septage properly.

Faecal Sludge Treatment Plant (FSTP)

R&D department of the defense organization of Government of India developed a technology for the effective decomposition of human fecal matter under changed geo-climatic conditions applying the principles of anaerobic biodegradation and bio digester technologies. Water harvesting and methane generation are major advantage of this technology, which makes it an ecofriendly treatment of night soil in developing countries.

A consortium has been formulated containing the Anaerobic Microbial Inoculums (AMI) and adopted to work at temperature as low as -52°C to 60°C which degrades the night soil at -55°C and produces colorless, odorless and inflammable biogas containing 50%-70% methane and carbon dioxide. In FSTP, anaerobic process is uses to inactivate the water borne diseases pathogens. Microbial heat and insulation of the reactor are two processes responsible to maintain the optimum temperature. The outlet released after the treatment from this technology is free from Pathogens and can be used in different purposes. The technology developed can be used in any area throughout the India. First Faecal Sludge Treatment Plant (FSTP) was built in Jhansi. Under SBM by October 2, 2019 more than 10million toilet was built in Uttar Pradesh and most of them were dependent on onsite treatment system.

The primary objective of the present study was to assess the efficiency of FSTP for treating the faecal sludge and along with water and secondary objective was to test the suitability of the biochar manufactured from the treated sludge for manure purpose

MATERIALS AND METHODS

About the FSTP

The FSTP under the present study consists of seven steps (Figure 1) i.e. inlet or grit chamber, primary lamella clarifier, aeration tank (MBBR 1 & 2), electro-flocculation, ozoneter, multigrade filter (MGF), and activated carbon filter (ACF). The septage is collected in grit chamber and then transferred to the lamella clarifier tank. Primary lamella clarifier is a series of inclined plates and designed to remove the particulate matter from liquids. The clear water exits the unit as the top overflow and the accumulated sludge is drawn off from the bottom of the hoppers. After that the septage is transferred to aeration chamber to mix the media thoroughly. Sufficient quantity of oxygen (minimum 2PPM dissolved oxygen) is provided for the aerobic bio-degradation of organic matter present in inlet for biological oxidation of COD/BOD and then the septage is passed from electro-flocculation process to remove the complex pollutant such as refractory organics, emulsified oil, total petroleum hydrocarbons, suspended solids, and heavy metals. After that effluent is passed from ozoneter to remove the germs and then from multi grade filter (MGF) to remove the suspended particles and pollutants from the stream of wastewater. In the last, the water is passed from activated carbon filter (ACF).

Study area

The Faecal Sludge Treatment Plant (FSTP) is located in Indirapuram Ghaziabad at 28°39'2"N 77°22'34"E. Water samples from the inlet and outlet of each process were collected in the morning hour (between 7:00AM to 10:00AM) for three months (from January 2021 to March 2021) in the prewashed plastic containers of 2 liters. The parameters such as pH, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and total suspended Solids (TSS) were analyzed following the standard methods of APHA (2012). After dewatering and drying, the faecal sludge was analyzed for calorific value, ash, fixed carbon, volatile matter, carbon, hydrogen, nitrogen, and sulphur. After that the faecal sludge was pyrolysed to produce the energy and biochar and then the biochar analyzed for pH, colour, moisture, bulk density, potassium, nitrogen, phosphorus, lead, zinc, cadmium, copper, nickel, chromium, and mercury.

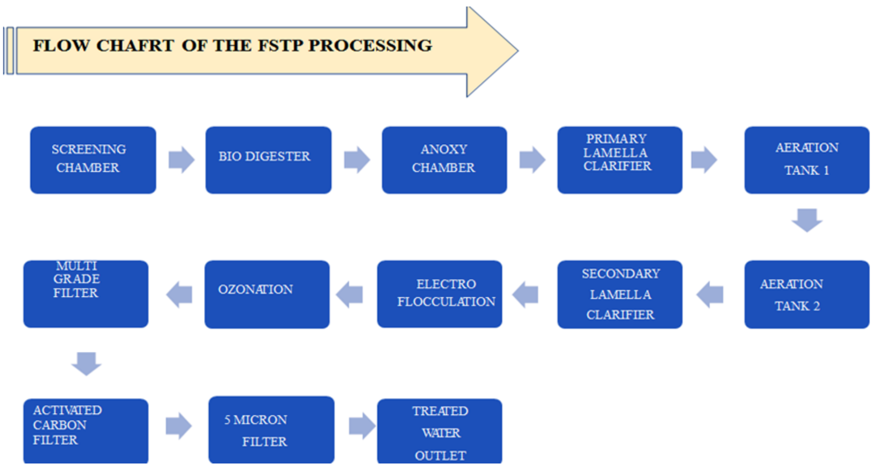

Figure 1. *Showing the flow diagram of the FSTP processing.*

RESULTS AND DISCUSSION

All the results of the inlet and outlet water released from various processes are presented in the Tables 1-4. Characteristics of faecal sludge and biochar are given in Tables 5 and 6. Figure 2 represents the efficiency of the FSTP for BOD, COD and TSS removal.

Efficiency of grit and screening chamber

In grit and screening chamber, minimum reduction in BOD was observed 29.70% (from 6398 mgL^{-1} to 4498 mgL^{-1}) in January and maximum was observed 32.85% (from 6487 mgL^{-1} to4356mgL^{-1}) in March and the average reduction was observed 31.91% (from 6494.33 mgL^{-1} to 4420.67 mgL^{-1}). Minimum reduction in COD was observed 29.17% (from 31985 mgL^{-1} to 22654 mgL^{-1}) in March and maximum was observed 29.90% (from 31875 mgL^{-1} to 22343 mgL^{-1}) in January and the average reduction was observed 29.63% (from 31919.33mgL^{-1} to 22462.00mgL^{-1}). Minimum reduction in total suspended solids (TSS) was observed 30.07% (from 12856 mgL^{-1} to 8987 mgL^{-1}) in January and maximum was observed 31.85% (from 12887 mgL^{-1} to 8821 mgL^{-1}) in February and the average reduction was observed 30.60% (from 12836.00 mgL^{-1} to 8907.33 mgL^{-1}).

Efficiency of bio-digester

In Bio-digester, minimum reduction in BOD was observed 83.24% (from 4408 mgL^{-1} to 739.0 mgL^{-1}) in February and maximum was observed 83.92% (from 4498 mgL^{-1} to 723.5 mgL^{-1}) in January and the average reduction was observed 83.67% (from 4420.67 mgL^{-1} to 721.67 mgL^{-1}). Minimum reduction in COD was observed 79.51% (from 22389 mgL^{-1} to 4587 mgL^{-1}) in February and maximum was observed 80.48% (from 22654 mgL^{-1} to 4423 mgL^{-1}) in March and the average reduction was observed 79.90% (from 22462.00 mgL^{-1} to 4514.00 mgL^{-1}). Minimum reduction in TSS was observed 63.49% (from 8821 mgL^{-1} to 3220.7 mgL^{-1}) in February and maximum was observed 65.96% (from 8914 mgL^{-1} to 3034.7 mgL^{-1}) in March and the average reduction was observed 64.89% (from 8907.33 mgL^{-1} to 3126.70 mgL^{-1}).

Efficiency of Lamella clarifier 1

In Lamella clarifier 1, minimum reduction in BOD was observed 36.50% (from 702.5 mgL^{-1} to 443.0 mgL^{-1}) in March and maximum was observed 39.05% (from 739.0 mgL^{-1} to 450.4 mgL^{-1}) in February and the average reduction was observed 37.77% (from 721.67 mgL^{-1} to 448.93 mgL^{-1}). Minimum reduction in COD was observed 33.53% (from 4423.0 mgL^{-1} to 2939.8 mgL^{-1}) in March and maximum was observed 34.22% (from 4587.0 mgL^{-1} to 3012.9 mgL^{-1}) in February and the average reduction was observed 33.98% (from 4514.00 mgL^{-1} to 2980.10 mgL^{-1}). Minimum reduction in TSS was observed 32.84% (from 3124.7 mgL^{-1} to 2098.7 mgL^{-1}) in January and maximum was observed 36.50% (from 3220.7 mgL^{-1} to 2045.1 mgL^{-1}) in February and the average reduction was observed 34.20% (from 3126.70 mgL^{-1} to 2056.33 mgL^{-1}).

Efficiency of aeration tank 1&2

In aeration tank 1&2, minimum reduction in BOD was observed 89.89% (from 443.0 mgL^{-1} to 44.8mgL^{-1}) in March and maximum was observed 90.32% (from 450.4 mgL^{-1} to 43.6 mgL^{-1}) in February and the average reduction was observed 90.05% (from 448.93 mgL^{-1} to 44.67 mgL^{-1}). Minimum reduction in COD was observed 89.72% (from 3012.9 mgL^{-1} to 309.7 mgL^{-1}) in February and maximum was observed 90.13% (from 2939.8 mgL^{-1} to 290.1 mgL^{-1}) in March and the average reduction was observed 89.95% (from 2980.10 mgL^{-1} to 299.50 mgL^{-1}). Minimum reduction in TSS was observed 34.59% (from 2025.2 mgL^{-1} to 1324.7 mgL^{-1}) in March and maximum was observed 36.50% (from 2098.7 mgL^{-1} to 1332.6 mgL^{-1}) in January and the average reduction was observed 35.50% (from 2056.33 mgL^{-1} to 1329.07 mgL^{-1}).

Efficiency of Lamella clarifier 2

In Lamella clarifier 2, minimum reduction in BOD was observed 54.02% (from 44.8 mgL^{-1} to 20.6 mgL^{-1}) in March and maximum was observed 55.96% (from 43.6 mgL^{-1} to 19.2 mgL^{-1}) in February and the average reduction was observed 54.94% (from 44.67 mgL^{-1} to 20.13 mgL^{-1}). Minimum reduction in COD was observed 74.32% (from 290.1 mgL^{-1} to 74.5 mgL^{-1}) in March and maximum was observed 75.13% (from 309.7 mgL^{-1} to 75.3 mgL^{-1}) in February and the average reduction was observed 75.02% (from 299.50 mgL^{-1} to 74.77 mgL^{-1}). Minimum reduction in TSS was observed 74.44% (from 1329.9 mgL^{-1} to 339.9 mgL^{-1}) in February and maximum was observed 74.88% (from 1332.6 mgL^{-1} to 334.7 mgL^{-1}) in January and the average reduction was observed 74.69% (from 1329.07 mgL^{-1} to 336.43 mgL^{-1}).

Table 1. Showing the parameters before and after the treatment with different processes and % removal of each process in January 2021.

Parameters /process	BOD			COD			TSS			pH
	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	
Grit & Screening Chamber	6398	4498	29.70	31875	22343	29.90	12856	8987	30.09	1.5-12.6
Bio – digester	4498	723.5	83.92	22343	4532	79.72	8987	3124.7	65.23	6.5-8.5
Lamella Clarifier 1	723.5	453.4	37.33	4532	2987.6	34.08	3124.7	2098.7	32.84	6.5-8.5
Aeration Tank 1&2	453.4	45.6	89.94	2987.6	298.7	90.00	2098.7	1332.6	36.50	6.5-8.5
Lamella Clarifier 2	45.6	20.6	54.82	298.7	74.5	75.06	1332.6	334.7	74.88	6.5-8.5
Electro-flocculation	20.6	12.4	39.81	74.5	44.4	40.40	334.7	267.8	19.99	6.5-8.5
MGF & Ozonation	12.4	8.9	28.23	44.4	31.6	28.83	267.8	42.5	84.13	6.5-8.5
ACF& Micron Filter	8.9	7.9	11.24	31.6	25.5	19.30	42.5	16.6	60.94	6.5-8.5
Final Treated Water	7.9 (99.88%)			25.5 (99.92%)			16.6 (99.87%)			6.5-8.5

Table 2. Showing the parameters before and after the treatment with different processes and % removal of each process in February 2021.

Parameters /process	BOD			COD			TSS			pH
	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	
Grit & Screening Chamber	6598	4408	33.19	31898	22389	29.81	12887	8821	31.55	1.5-12.6
Bio – digester	4408	739	83.24	22389	4587	79.51	8821	3220.7	63.49	6.5-8.5
Lamella Clarifier 1	739	450.4	39.05	4587	3012.9	34.32	3220.7	2045.1	36.50	6.5-8.5
Aeration Tank 1&2	450.4	43.6	90.32	3012.9	309.7	89.72	2045.1	1329.9	34.97	6.5-8.5
Lamella Clarifier 2	43.6	19.2	55.96	309.7	75.3	75.69	1329.9	339.9	74.44	6.5-8.5
Electro-flocculation	19.2	11.9	38.02	75.3	45.8	39.18	339.9	271.3	20.18	6.5-8.5
MGF & Ozonation	11.9	7.4	37.82	45.8	30.9	32.53	271.3	41.8	84.59	6.5-8.5
ACF& Micron Filter	7.4	6.2	16.22	30.9	23.8	22.98	41.8	14.7	64.83	6.5-8.5
Final Treated Water	6.2 (99.91%)			23.8 (99.93%)			14.7 (99.89%)			6.5-8.5

Table 3. Showing the parameters before and after the treatment with different processes and % removal of each process in March 2021.

Parameters /process	BOD			COD			TSS			pH
	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	
Grit & Screening Chamber	6487	4356	32.85	31985	22654	29.17	12765	8914	30.17	1.5-12.6
Bio – digester	4356	702.5	83.87	22654	4423	80.48	8914	3034.7	65.96	6.5-8.5
Lamella Clarifier 1	702.5	443	36.94	4423	2939.8	33.53	3034.7	2025.2	33.27	6.5-8.5
Aeration Tank 1&2	443	44.8	89.89	2939.8	290.1	90.13	2025.2	1324.7	34.59	6.5-8.5
Lamella Clarifier 2	44.8	20.6	54.02	290.1	74.5	74.32	1324.7	334.7	74.73	6.5-8.5
Electro-flocculation	20.6	11.7	43.20	74.5	43.8	41.21	334.7	266.1	20.50	6.5-8.5
MGF & Ozonation	11.7	7.8	33.33	43.8	31	29.22	266.1	41.1	84.55	6.5-8.5
ACF& Micron Filter	7.8	6.7	14.10	31	24.7	20.32	41.1	15.9	61.31	6.5-8.5
Final Treated Water	6.7 (99.90%)			24.7 (99.92%)			15.9 (99.88%)			6.5-8.5

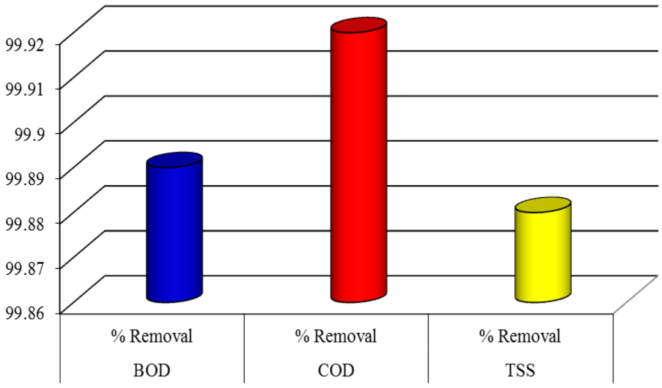

Figure 2. *Showing the percentage removal of BOD, COD and TSS with the complete process of FSTP.*

Efficiency of electro-flocculation

In electro-flocculation, minimum reduction in BOD was observed 38.02% (from 19.2 mgL^{-1} to 11.9 mgL^{-1}) in February and maximum was observed 43.20% (from 20.6 mgL^{-1} to 11.7 mgL^{-1}) in March and the average reduction was observed 40.34% (from 20.13 mgL^{-1} to 12.00 mgL^{-1}). Minimum reduction in COD was observed 39.18% (from 75.3 mgL^{-1} to 45.8 mgL^{-1}) in February and maximum was observed 41.21% (from 74.5 mgL^{-1} to 43.8 mgL^{-1}) in March and the average reduction was observed 40.26% (from 74.77 mgL^{-1} to 44.67 mgL^{-1}). Minimum reduction in TSS was observed 19.99% (from 334.7mgL^{-1} to 267.8 mgL^{-1}) in January and maximum was observed 20.50% (from 334.7 mgL^{-1} to 266.1 mgL^{-1}) in March and the average reduction was observed 20.22% (from 336.43 mgL^{-1} to 268.40 mgL^{-1}).

Efficiency of MGF and ozonation

In MGF and ozonation, minimum reduction in BOD was observed 28.23% (from 12.4 mgL^{-1} to 8.9 mgL^{-1}) in January and maximum was observed 38.02% (from 11.9 mgL^{-1} to 7.4 mgL^{-1}) in February and the average reduction was observed 33.12% (from 12.00 mgL^{-1} to 8.03 mgL^{-1}). Minimum reduction in COD was observed 28.83% (from 44.4 mgL^{-1} to 31.6 mgL^{-1}) in January and maximum was observed 32.53% (from 45.8 mgL^{-1} to 30.9 mgL^{-1}) in February and the average reduction was observed 30.20% (from 44.67 mgL^{-1} to 31.17 mgL^{-1}). Minimum reduction in TSS was observed 84.13% (from 267.8 mgL^{-1} to 42.5 mgL^{-1}) in January and maximum was observed 84.59% (from 271.3 mgL^{-1} to 41.8 mgL^{-1}) in February and the average reduction was observed 84.43% (from 268.43 mgL^{-1} to 41.80 mgL^{-1}).

Efficiency of ACF and micron filter

In MGF and ozonation, minimum reduction in BOD was observed 11.24% (from 8.9 mgL^{-1} to 7.9 mgL^{-1}) in January and maximum was observed 16.22% (from 7.4 mgL^{-1} to 6.2 mgL^{-1}) in February and the average reduction was observed 13.85% (from 8.03 mgL^{-1} to 6.93 mgL^{-1}). Minimum reduction in COD was observed 19.30% (from 31.6 mgL^{-1} to 25.5 mgL^{-1}) in January and maximum was observed 22.98% (from 30.9 mgL^{-1} to 23.8 mgL^{-1}) in February and the average reduction was observed 20.87% (from 31.17mgL^{-1} to 24.67 mgL^{-1}). Minimum reduction in TSS was observed 60.94% (from 42.5 mgL^{-1} to 16.6 mgL^{-1}) in January and maximum was observed 64.83% (from 41.8 mgL^{-1} to 14.7 mgL^{-1}) in February and the average reduction was observed 62.36% (from 41.80 mgL^{-1} to 15.37 mgL^{-1}).

Table 4. Showing the average parameters before and after the treatment with different processes and % removal of each process.

Parameters /process	BOD			COD			TSS			pH
	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	Inlet	Outlet	% Removal	
Grit & Screening Chamber	6494.33±100.2	4420.67±71.8	31.91±1.9	31919.33±58.0	22462.00±167.9	29.63±0.4	12836.00±63.4	8907.33±83.2	30.60 ±0.8	1.5-12.6
Bio – digester	4420.67±71.8	721.67±18.3	83.67±0.4	22462.00±167.9	4514.00±83.5	79.90±0.5	8907.33±83.2	3126.70±93.0	64.89±1.3	6.5-8.5
Lamella Clarifier 1	721.67±18.3	448.93±5.4	37.77±1.1	4514.00±83.5	2980.10±37.1	33.98±0.4	3126.70±93.0	2056.33±38.0	34.20±2.0	6.5-8.5
Aeration Tank 1&2	448.93±5.4	44.67±1.0	90.05±0.2	2980.10±37.1	299.50±9.8	89.95±0.2	2056.33±38.0	1329.07±4.0	35.35±1.0	6.5-8.5
Lamella Clarifier 2	44.67±1.0	20.13±0.8	54.94±1.0	299.50±9.8	74.77±0.5	75.02±0.7	1329.07±4.0	336.43±3.0	74.69±0.2	6.5-8.5
Electro-flocculation	20.13±0.8	12.00±0.4	40.34±2.6	74.77±0.5	44.67±1.0	40.26±1.0	336.43±3.0	268.40±2.7	20.22±0.3	6.5-8.5
MGF & Ozonation	12.00±0.4	8.03±0.8	33.12±4.8	44.67±1.0	31.17±0.4	30.20±2.0	268.40±2.7	41.80±0.7	84.43±0.3	6.5-8.5
ACF& Micron Filter	8.03±0.8	6.93±0.9	13.85±2.5	31.17±0.4	24.67±0.9	20.87±1.9	41.80±0.7	15.73±1.0	62.36±2.1	6.5-8.5
Final Treated Water	6494.33±100.2	6.93±0.9	99.89	31919.33±58.0	24.67±0.9	99.92	12836.00±63.4	15.73±1.0	99.88	6.5-8.5

Efficiency of the complete plant for BOD removal

BOD is the amount of oxygen required for the oxidation of organic and inorganic matter by bacterial community available in water sample in a fixed period of time. BOD removal was observed minimum (13.85%) in ACF and Micron filter while maximum (90.05%) was observed in aeration tank 1&2 and the average removal was observed 99.89%. Similarly, Rayavellore Suryakumar and Pavithra (2020) observed the 99.97% efficiency for BOD removal.

Efficiency of the complete plant for COD removal

COD is the rapid test to confirm the presence of organic material in water samples. COD is the amount of oxygen required for the oxidation of chemical present in water sample. COD removal was observed minimum (20.87%) in ACF and Micron filter while maximum (89.95%) was observed in aeration tank 1&2 and the average removal was observed 99.92%. Recently, Rayavellore Suryakumar and Pavithra (2020) observed the 99.92% efficiency for COD reduction.

Efficiency of the complete plant for TSS removal

TSS is the amount of solids that remains on filter paper after the filtration of a fixed quantity of water. It includes the all the salts and ion and soil particles in present in water in suspended form. Suspended solids also contribute to turbidity. TSS removal was observed minimum (20.22%) in electro-flocculation while maximum (84.43%) was observed in MGF and Ozonation and the average removal was observed 99.88%. Our results are in agreement with Rayavellore Suryakumar and Pavithra (2020) who observed the 43.54% enhancement in TSS of treated septage.

Characteristics of faecal sludge

All the results of faecal sludge were presented in table 5. Calorific values ranged from 3339.00 Kcal Kg^{-1} to 3542.00 Kcal Kg^{-1} with an average value of 3419.67 Kcal Kg^{-1}. Rayavellore Suryakumar and Pavithra (2020) observed the calorific values between 2320 Kcal Kg^{-1} to 5260 Kcal Kg^{-1}. Likewise, Murray Muspratt *et al.* (2014) observed the calorific values between 2698.48 Kcal Kg^{-1} to 4561 Kcal Kg^{-1}. Ash values ranged from 30.98% to 31.67% with an average value of 31.37%. Fixed carbon values ranged from 5.45% to 5.76% with an average value of 5.58%. Volatile matter values ranged from 72.67% to 73.23% with an average value of 72.92%. Carbon values ranged from 32.79% to 34.67% with an average value of 33.71%. Hydrogen values ranged from 5.34% to 5.67% with an average value of 5.50%. Nitrogen values ranged from 2.45% to 2.76% with an average value of 2.57%. Sulphur values ranged from 1.98% to 2.34% with an average value of 2.15%. Rayavellore Suryakumar and Pavithra (2020) observed the nitrogen, sulphur, carbon content, volatile matter, and ash content between 1.5% to 4.3%, 0.39% to 1.23%, 27.47% to 43.8%, 50.41% to 78.05% and 21.95% to 30.64%, respectively.

Table 5. Characteristics of faecal sludge during the study period.

Parameter	January	February	March	Average	Minimum	Maximum
Calorific value (Kcal Kg^{-1})	3339.00	3542.00	3378.00	3419.67	3339.00	3542.00
Ash (%)	31.45	30.98	31.67	31.37	30.98	31.67
Fixed carbon (%)	5.45	5.76	5.53	5.58	5.45	5.76
Volatile matter (%)	73.23	72.67	72.87	72.92	72.67	73.23
Carbon (%)	34.67	32.79	33.67	33.71	32.79	34.67
Hydrogen (%)	5.34	5.67	5.49	5.50	5.34	5.67
Nitrogen (%)	2.45	2.49	2.76	2.57	2.45	2.76
Sulphur (%)	2.34	1.98	2.13	2.15	1.98	2.34

Table 6. Characteristics of Biochar and their comparison with SWM rules, 2016 (India) organic compost standards.

Parameters	January	February	March	Average	Min	Max	SWM Rules, 2016
pH	7.4	7.2	7.4	7.33	7.2	7.4	6.5-7.5
Colour	Black	Black	Black	-	-	-	Dark brown to black
Moisture (%)	8.70	8.50	9.10	8.77	8.50	9.10	15-25
Bulk density (gm cm^{-3})	1.98	2.09	2.13	2.07	1.98	2.13	<1
Potassium as K (%)	0.97	1.23	0.85	1.02	0.85	1.23	Minimum 0.4
Nitrogen as N (%)	2.64	3.45	3.19	3.09	2.64	3.45	Minimum 0.8
Phosphorus as P (%)	0.16	0.45	0.23	0.28	0.16	0.45	Minimum 0.4
Lead (mg Kg^{-1})	0.02	0.02	0.02	0.02	0.02	0.02	100
Zinc (mg Kg^{-1})	0.23	0.29	0.29	0.27	0.23	0.29	1000
Cadmium (mg Kg^{-1})	ND	ND	0.01	0.01	0.01	0.01	5
Copper (mg Kg^{-1})	0.01	0.11	0.01	0.04	0.01	0.11	300
Nickel (mg Kg^{-1})	0.12	0.09	0.10	0.10	0.09	0.12	50
Chromium (mg Kg^{-1})	0.09	0.08	0.09	0.09	0.08	0.09	50
Mercury (mg Kg^{-1})	0.01	ND	0.01	0.01	0.01	0.01	0.15

Characteristics of biochar

All the results of biochar were presented in table 6. pH values ranged from 7.2 to 7.4 with an average value of 7.33. Colour of biochar was observed black throughout the study. Moisture values ranged from 8.50% to 9.10% with an average value of 8.77%. Bulk density values ranged from 1.98 g cm^{-3} to 2.13 g cm^{-3} with an average value of 2.03 g cm^{-3}. Potassium (K) values ranged from 0.85% to 1.23% with an average value of 1.02%. Nitrogen (N) values ranged from 2.64% to 3.45% with an average value of 3.09%. Phosphorus (P) values ranged from 0.16% to 0.45% with an average value of 0.28%. Gopinath *et al.* (2013) and DeLuca *et al.* (2006) also observed the reduced nitrogen and sulphur content in volatized biochar. pH, colour, moisture content and phosphorus of biochar was found within the limit of Solid Waste Management Rules (SWM), 2016 while bulk density, potassium and nitrogen was above the standard limit of SWM.

Lead (Pb) values were found 0.02 mg Kg^{-1} throughout the study period. Zinc (Zn) values ranged from 0.23 mg Kg^{-1} to 0.29 mg Kg^{-1} with an average value of 0.27 mg Kg^{-1}. Cadmium (Cd) values were found 0.01 mg Kg^{-1} in March while in January and February values were below the detectable limit. Copper (Cu) values ranged from 0.01 mg Kg^{-1} to 0.11 mg Kg^{-1} with an average value of 0.04 mg Kg^{-1}. Nickel (Ni) values ranged from 0.09 mg Kg^{-1} to 0.12 mg Kg^{-1} with an average value of 0.10 mg Kg^{-1}. Chromium (Cr) values ranged from 0.08 mg Kg^{-1} to 0.09 mg Kg^{-1} with an average value of 0.09 mg Kg^{-1}. Mercury (Hg) values were found 0.01 mg Kg^{-1} in January and March. The concentration of all the heavy metals was found below the standard limit of SWM. More or less same results were also reported by Rayavellore Suryakumar and Pavithra (2020). Many studies carried out by several scholars reported that biochar can improve the soil characteristics making them fit for agriculture and can increase the crop production (Gopinath *et al.*, 2013; Srinivasarao *et al.*, 2013).

Conclusion

The present study was carried out to explore the Faecal Sludge Treatment (FSTP) technology including concept, process, operational procedure, and major advantages. The technology was found effective for the treatment of night soil. The technology is in continuous operation in several states of India (UP, Leh, Karnataka, Telangana, and Delhi) for the treatment of faecal sludge to maintain the hygienic conditions. The technology also plays major role in controlling the disease outbreak due to effective control on disease vectors. On the basis of present study, we can conclude that BOD removal was observed 99.88% while COD removal was observed 99.91% and TSS removal was observed 99.88%. After the treatment all the studied parameters was found below the standards set by MOEF for FSTP discharge. All the parameters of biochar were found below the standard limits of SWM 2016 except bulk density, potassium and nitrogen. On the basis of biochar results, it may be concluded that the sludge produced can be used as manure in agriculture and gardening. FSTP may be a suitable, sustainable an eco-friendly technology for the treatment of faecal sludge and also reduces the chances of soil and ground water pollution.

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