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Performance evaluation of vinasse treatment plant integrated with physico-chemical methods

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Abstract

With an objective to assess environmental management criteria of a vinasse treatment plant (VTP) and to evaluate the critical environmental parameters, a study was undertaken in a multi-product (packaged apple juice, distillery, brewery, packaged drinking water) brewery-cum-distillery unit. The facility with a volumetric loading rate of 11-15 kg COD m^{-3}.day, 3.6-4.5 h hydraulic retention time and 20 g l^{-1} VSS had a scientifically managed technically sound effluent treatment system. While the water quality parameters were found within the acceptable limits, there was 99.07% reduction in BOD_5 from 43140.0 to 398.0 mg l^{-} and 98.61% reduction in COD from 98003.0 to 1357.0 mg l^{-1}. There was appreciable improvement in mixed liquor suspended solids (MLSS), mixed liquor volatile suspended solids (MLVSS) and sludge volume index (SVI). A striking feature was the integrated aerobic-anaerobic highly efficient Up-flow Anaerobic Sludge Blanket (UASB) treatment for biodegradation and energy production that reduced energy and space needs, producing utilisable end-products and net savings on the operational cost. The end-point waste management included terminal products such as fertile sludge, cattle feed supplement, recyclable water and biogas. Vast lagoons with combined aerobic-anaerobic approaches, biogasification unit, sludge recovery, remediated irrigable water were the notable attributes.

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Introduction

Rampant generation and disposal of waste without adequate treatment results in significant environmental pollution (Mishra *et al*., 2000; Mohana *et al*., 2009; Turkdogan-Aydınol *et al*., 2010; Oller *et al*., 2011; Olajire, 2012; Mohana *et al*., 2013) and such waters eventually receive volumes of wastes from numerous anthropogenic activities. Distilleries consume to the tune of 25-175 litre processing water per litre of alcohol produced (Mohana *et al*., 2009). Distillery spent-wash, a high strength acidic waste with soluble solids and increased levels of sulphate, presents significant disposal and treatment problems (Chauhan *et al*., 2012, Mohana *et al*., 2013). Such waste can be treated by two-stage biological process to improve indicator parameters like BOD, and could be used as 'fortified' irrigable water (Strong and Burgess, 2008; Latif *et al*., 2011; Sharma and Li, 2010). Sharma and Li (2010) suggested performance improvement of activated sludge in winery effluent and stressed on extended on-site data analyses.

Breweries and distilleries have shown increasing awareness for environmental protection and the need of sustainable production processes (Simate *et al*., 2011; Olajire, 2012). Similar observations have been made and recommended for dairy effluent, commercial pisciculture and algal production (Mishra *et al*., 2000; Carvalho *et al*., 2013).

The composition of distillery effluent as set by Indian standards (IS: 506-1980) is as follows : pH 5.5–9.0, BOD_5 0.1-0.5 g l^{-1}, TSS 0.1-0.6 g l^{-1} oil and grease 0.06-0.1 g l^{-1} for final discharge with acceptable temperature in any section of the stream within 15 m from the outlet being below 40°C, which seems to be stringent. However, the broad acceptable characteristics of Indian distillery units is as follows : pH 4-4.5, TSS 10 g l^{-1}, BOD_5 (20°C) 45-60 g l^{-1} and COD 80-120 g l^{-1}. This reputed multi-product distillery, a mega brewery unit in terms of production and important due to its ancestral heritage, is located at Latitude 28°40' N and Longitude 77°26' E. It houses a scientifically designed and engineered state-of-art vinasse treatment plant (VTP) for waste management, monitored by sophisticated laboratory, machineries and trained manpower.

Surrogacy is a relationship between indicator and the objective (target) parameter, both of which play an important role in planning working protocol. The objective of the present study was to assess the management criteria, evaluate the effects on the critical factors due to integration of independent units such as lagoons, Up-flow Anaerobic Sludge Blanket and activated sludge and, ascertain meaningful relationships between the indicator parameters.

Materials and Methods

A schematic presentation of Vinasse treatment plant (highlighting the considered sampling points), whose various components are discussed in separate paragraphs, is furnished in Fig. 1. A ninety-day experiment was conducted at the plant site, with weekly water samplings from yeast settling tank (A), homogenisation tank (B), UASB reactor (C), aeration tank (D), clarifier (E) and over-head tank (F).

The distance that effluent travelled between yeast settling tank (A) and whole length of VTP, while being treated, was about 180 m. The samples collected from yeast settling tank (A) through over-head tank (F) were immediately analysed for temperature by digital thermometer Model No. Oxy 330/set, WTW, Germany), pH (digital; 4500H$^+$ electrometric method); alkalinity (2320B titration

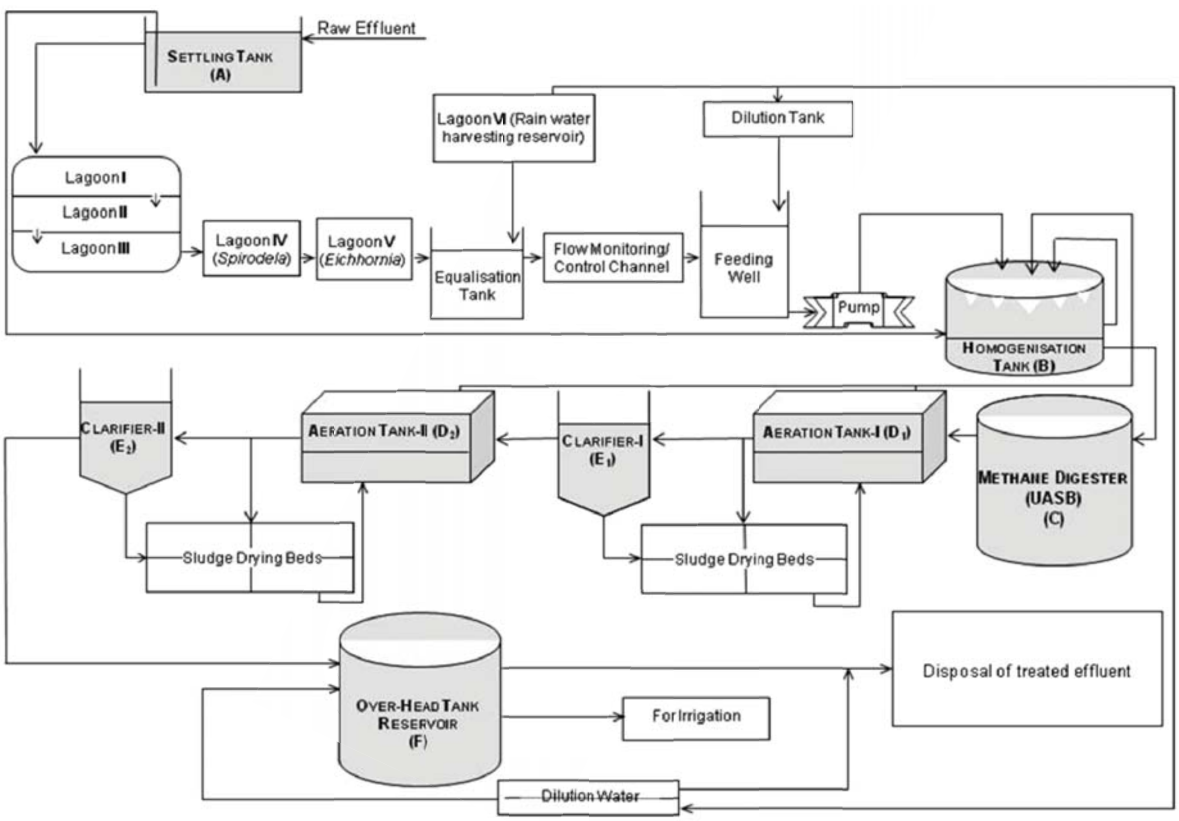

Fig. 1 : Flow chart of Vinasse Treatment Plant highlighting the sampling points (A–F; A: YST, B: Homosinisation tank, C: UASB, D_1 & D_2: Aeration tanks, E_1 & E_2: Clarifiers, F: Overhead tank)

method), ammonia-nitrogen (4500-NH_3F phenate method), organic nitrogen, phosphorus (stannous chloride method), BOD_5 (5210B 5-day BOD test), COD (5220B open reflux method), TSS (2540D total suspended solids dried at 103-105°C), TDS (2540C total dissolved solids dried at 180°C), mixed liquor suspended solids (2540D total suspended solids dried at 103-105°C), mixed liquor volatile suspended solids (2540E fixed and volatile solids ignited at 550°C) all in mg l^{-1}, and sludge volume index (2710D sludge volume index; ml g^{-1}), as per procedures laid down in APHA-AWWA-WPCF (2012).

Yeast settling tank (YST; 'A'): Raw effluent was discharged into YST to separate out yeast, removal of heavy metals and other suspended matter and then passed through the hydraulic head balancing tank. From balancing tank, the effluent was passed into a thermo-controlled feeding well. Fermentation operation was maintained on a continuous mode.

Lagoons: There were six lagoons in all, throughout the VTP. 'A' was followed by 'diluter', 'sedimentor' and 'bioremediator' lagoons. The fourth and fifth lagoons were specifically dedicated for bioremediation, by *Spirodela* and *Eichhornia* respectively, and the sixth one was for rainwater harvesting.

Homogenisation tank ('B'): Diluted effluent was passed through the plate-heat exchangers that lowered the temperature to 37°C, and fed to the homogenisation tank for pre-acidification.

Up-flow anaerobic sludge blanket ('C'): The conditioned effluent was pumped into the bottom of UASB reactor (the methane digester), percolating through granular sludge bed.

Aeration Tanks ('D'): A set of two aeration tanks ('D_1': low speed turbine type surface aerator and 'D_2': diffused aerator) received the effluent from UASB.

Clarifier ('E'): This had two sub-units, 'E_1' & 'E_2' that were used for sludge removal from mixed liquor from aeration tanks. The ideal retention time in the clarifiers varied from 5-7 hr.

Sludge Pit: Sludge settling at the bottom of the clarifier and containing biological cells flew under static head of liquid into the adjacent sludge (sludge drying) pit/bed. The ideal retention time was between 2 and 3 days.

Over-Head Tank ('F'): Treated effluent collected in overhead tank was recycled back to lower the BOD to safe limits, and also utilised for in-house horticultural purposes. Excess water was released out of the factory to irrigate adjacent land areas. All the parameters were analysed at the sampling points 'A', 'B', 'C', 'D', 'E', and 'F' except for MLSS, MLVSS and SVI which were further analysed in detail at both 'D_1' & 'D_2', and 'E_1' & 'E_2', for 'D' and 'E' respectively. For other parameters, average analysed data of both 'D_1' & 'D_2', and 'E_1' & 'E_2' have been presented as 'D' and 'E' respectively. Data were subjected to statistical analyses on MS Excel and graphs were prepared using GraphPad Prism Ver. 5.00 for Windows (San Diego, California, USA).

Results and Discussion

A highlight point of Vinasse treatment plant was the highly efficient UASB that served both the purpose of biodegradation as well as that of energy production (España-Gamboa *et al*., 2012; Schievano *et al*., 2012). This was apparently dead and slow but was highly productive unit that required less electricity, accessories and manpower as compared to other alternatives. This high capacity unit has also been recognised by Sharma and Li (2010), Wolmarans and De Villiers (2002) and Schievano *et al*., (2012) as a striking feature. The combined aerobic and anaerobic bioremediation, as an economical and ecofriendly approach involving bioaugmentation and/or biostimulation, has emerged as an advantageous clean-up strategy for industrial sites (Tyagi *et al*., 2011).

The yeast settling tank (A), (Fig. 2) measured an average BOD_5 of 43.14 g l^{-1}. The outflow of homogenisation tank (B) had an average BOD_5 level of 10.573 g l^{-1} (a reduction by 75%) and the same from UASB reactor (C) recorded 1.076 g l^{-1} (greatest percent reduction by 89%). The same values, as recorded at

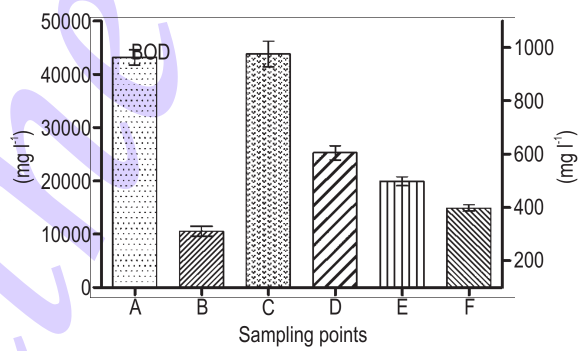

Fig. 2 : Comparative mean values of BOD5. Left Y-axis presents values for 'A' (YST) and 'B' (Homosinisation tank) and the right Y-axis presents for 'C' (UASB), 'D' (Aeration tanks), 'E' (Clarifiers) and 'F' (Overhead tank)

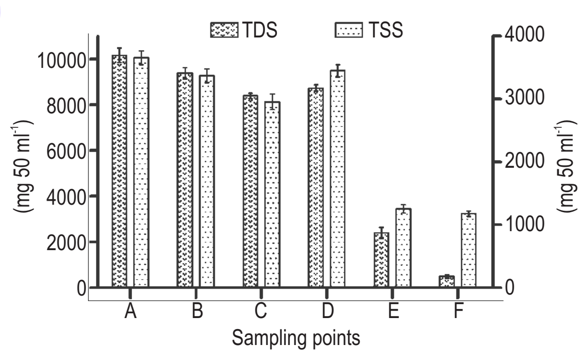

Fig. 3 : Comparative mean values of the total dissolved (left Y-axis) and suspended (right Y-axis) solids at the various sampling points

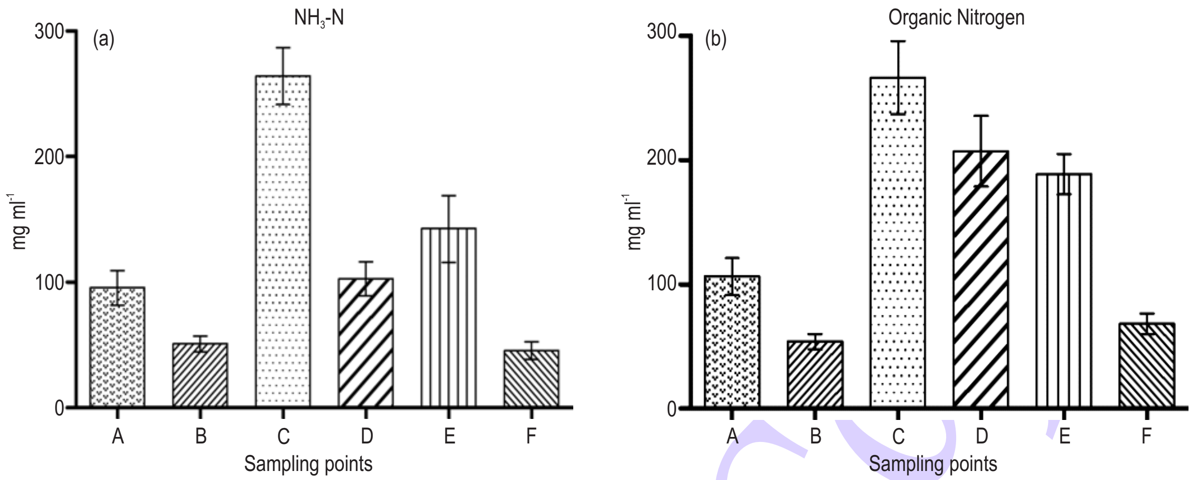

Fig. 4 : Comparative mean values of ammonium (a) and organic nitrogen (b) contents at various sampling points

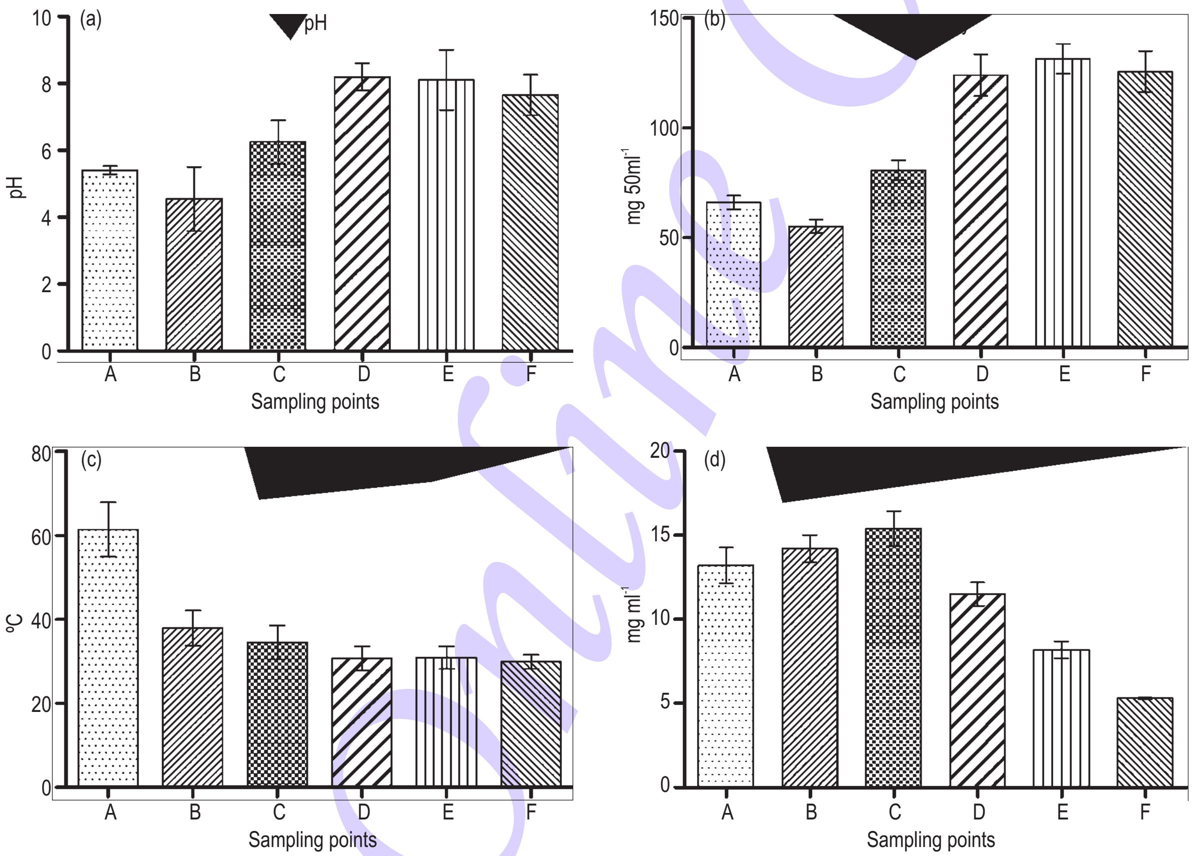

Fig. 5 : Relational variation in (a) pH; (b) alkalinity; (c) temperature and (d) phosphorous

aeration tanks (D), averaged to 0.605 g l^{-1} (a 44% reduction). It was further reduced by about 17.5% to 499 mg l^{-1} at clarifiers (E). Point over-head tank (F) contained BOD of 0.398 g l^{-1}, indicating an overall average reduction of 99% in the process. COD followed a similar trend of 98.003 g l^{-1} and 61.785 g l^{-1} to 4.789 g l^{-1} to 1.976 g l^{-1} to finally 1.357 g l^{-1}. Total average reduction recorded was 98.6%. An active microbial biodegradation of biological and nonbiological compounds coupled with physico-chemical

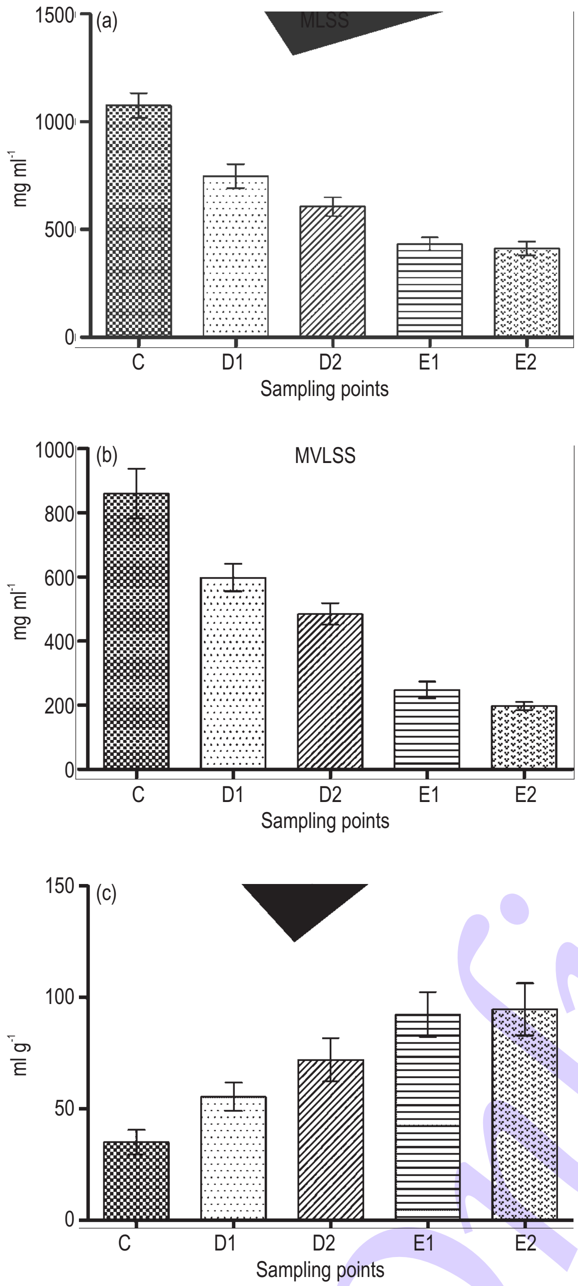

Fig. 6 : Comparative mean MLSS (a), MLVSS (b) and SVI (c) values of solid and liquid wastes and their ratios at the UASB (C), Aeration tanks (D1 & D2) and Clarifiers (E1 & E2)

treatments such as oxygenation/aeration could be generally attributed to reduction in BOD and COD level. Homogenisation tank showed sudden spurt in BOD levels possibly, due to high acidification involved. The levels again increased in the next step attributabled to highly active anaerobic microflora. Clarifier recorded higher COD attributable to higher retention time (Thalla *et al*., 2010; Alanya *et al*., 2012). The data corroborated well with that of industrial effluent analyses by Emongor *et al.* (2005) and also wineries and distilleries wastewater analyses by Bustamante *et al.* (2005). Hur and Cho (2012) suggested a correlation between BOD, COD and total nitrogen (r>0.970; p<0.001), Kwak *et al*. (2012) hypothesised BOD and DOC correlation (the correlation coefficients established between the model-predicted values and the measured values were 0.78 for the river waters and 0.90 for wastewaters) and Fadini *et al*. (2004) proposed a BOD, COD and DOC correlation for anaerobic pond effluent (COD = 1.08 DOC + 79 and BOD = 0.82 DOC + 12), the major routine surrogate test parameters.

For TDS average values were 3.658 g l^{-1} at yeast settling tank (A), 3.370 g l^{-1} at homogenisation tank (B), 2.956 g l^{-1} at UASB reactor (C), 3.451 g l^{-1} at aeration tanks (D), 1.253 g l^{-1} at clarifiers (E) and 1.779 g l^{-1} at over-head tank (F) (Fig. 3), the average overall reduction being 67.7%. The trend in TSS values showed gradual reduction between points yeast settling tank (A) and homogenisation tank (B). The average value at UASB reactor (C) was 8.389 g l^{-1}, A slight increase in aeration tanks (D) and reduction at clarifiers (E), total reduction of 95.1%, and eventually a combination of settling, acidification, clarification and oxygenation steps contributed to such reduction.

The mean average values of organic and ammonium nitrogen reduced to about half between yeast settling tank (A) and omogenisation tank (B), with an intense increase at UASB reactor (C) (Fig. 4). At aeration tanks (D), the levels decreased with a better trend observed in ammonium nitrogen. At clarifiers (E), the organic nitrogen load was 0.19 g l^{-1}, while ammonium nitrogen levels increased to 0.14 g l^{-1}. The values were 0.068 g l^{-1} and 0.045 g l^{-1} (an overall decrease by 48% and 64%, respectively) at over-head tank (F). Reduction in these values was possibly due to active nitrification-denitrification processes corroborating with the observations of Thalla *et al*. (2010), Mojiri *et al*. (2012) and Hu *et al*. (2013). Organic nitrogen levels were seen to decrease from 'C' (UASB reactor) to 'E' (Clarifiers), contrary to the trend observed with inorganic nitrogen. Comparative data analyses revealed an on-going high mineralisation in the system with organic nitrogen being transformed into inorganic nitrogen (Thalla *et al*., 2010; Ni and Zhang, 2013).

pH values and alkalinity concentrations exhibited trends opposite to each other, the average values fluctuating throughout (Fig. 5). The mean phosphorus levels were nearly same between yeast settling tank (A) and homogenisation tank (B), with reduction at UASB reactor (C), slight increase in aeration tank (D) and 47% reduction in over-head tank (F) total reduction being 60%.

The MLSS, MLVSS and SVI levels could be measured only at UASB reactor (C), aeration tank (D) and clarifier (E) (Fig. 6). Both MLVSS (0.20-0.86 g l^{-1}) and MLSS (0.41-1.08 g l^{-1})

showed similar trends with overall reduction of more than 50%. On the contrary, SVI values (35.02-94.74 ml mg^{-1}) showed an increasing trend, with an overall increase of about 33%. A SVI of 35.02 ml g^{-1} at UASB reactor (C) takes into account that UASB generated maximum sludge with gradual decrement, attributable to active chemical and biological processes (Pratt *et al*., 2012). Phosphorus load also reduced and was attributable to possible flocculating phosphate-solubilising/utilising bacterial biodegradation in dissolved air flotation similar observation was also noted by Posadas *et al*. (2013) and Kodera *et al*. (2013).

pH greatly influences microbial growth and activity in a biological treatment process. Alkalinity is dependent on pH, both being directly related. Physico-chemical parameters like temperature, TDS (3658.0 to 1179.0 mg l^{-1}), TSS (10160.0 to 496.0 mg l^{-1}), phosphorus (13.2 to 5.3 mg l^{-1}), organic nitrogen (106.0 to 68.1 mg l^{-1}), ammonium nitrogen (95.6 to 45.4 mg l^{-1}), MLSS (1075.0 to 411.0 mg l^{-1}) and MLVSS (860.0 to 197.0 mg l^{-1}) indicated cyclical reduction in values, whereas SVI exhibited about three-fold increment (35.0 to 94.0 ml g^{-1}), agreeing with the earlier observations of Wang *et al*. (2013) and Kushwaha *et al*. (2011).

VTP system worked efficiently with post-treatment wastewater quality indicators being being within the acceptable limits (BOD_5 reduced by 99.07%, from 43140.0 to 398.0 mg l^{-1}; and COD reduced by 98.61%, from 98003.0 to 1357.0 mg l^{-1}). Notable attributes in the VTP system was vast lagoons with combined aerobic-anaerobic approaches, biogasification unit, sludge recovery and remediated irrigable water. UASB treatment that produced utilisable end-products (fertile sludge, cattle feed supplement, recyclable water and biogas) was a striking feature. Chemical treatments, currently restricted to homogenisation tank ('B'), can be extended to other relevant units through the use of specialty chemicals such as zeolite and alum to enhance performance.

The study suggests that an aerobic-anaerobic combined system with vast lagoons, biodigestor unit, sludge recovery system and a foolproof mechanism to use irrigable treated water and mineral-rich dried sludge as manure are healthy indicators of VTP. Such efficiently managed and effectively developed system may be ideal for effluent treatment facilities, particularly in similar geophysical (tropical) conditions.

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