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Quality and Treatment of Sugar Industry Effluent -A Study

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Abstract: The sugar industry is facing an enormous problem to manage a massive quantity of effluent generation and its pollution load. The objective of the study is to discuss the sustainable treatment to reduce pollution load and discharge the effluent as per the prescribed standard of CPCB. A study was conducted on one sugar industry (M/S. DCM Shriram Limited, Uttar Pradesh, India). The efficiency of ETP was assessed with respect to parameters like pH, TSS, TDS, BOD, COD, and sulphate in two different setups, before (November 13, 2018 to March 24, 2019) and after (November 13, 2019 to March 24, 2020) the installation of the tube settler unit in the activated sludge treatment process. There was not much variation in pH. The study revealed that after the installation of the tube settler unit, the quality of the treated effluent was improved and parameters like TSS, TDS, BOD, COD, and sulphate removal efficiency were increased from 69 to 87%, 42 to 63%, 79 to 94%, 75 to 85% and 20 to 64% respectively. The sugar industry effluent could meet statutory (surface waters and land disposal) standard of Central Pollution Control Board (CPCB, 2016). The heavy metals (HM) of effluent stored at lagoon were evaluated for common HM like Zn, Fe, Cu and Cd. The contamination factor (Cf) with respect to HM suggested that Zn, Fe and Cd falls under the category of moderate and Cu fall under the category of considerable contamination.

Keywords: **ETP, Sugar, BOD, COD, Sulphate, Heavy metal**

I. Introduction

Agro-based sugar industry plays a major role in rural livelihood in India. The sugar industry regulates the socio economic growth of rural and urban populations. The sugar industry also promotes its associated allied industries. The incremental expanding of the sugar and its allied industries is offering employment opportunities to skilled and semi- skilled rural and urban people of India (Harush et al, 2014). The Indian sugar industry is the second-largest producer of sugar after Brazil in the global sugar market (S. Solomon et al, 2011). The world demand for sugar is the primary driver for the sugarcane industry. In many developing countries especially in Asia and South America, the sugarcane industry is a prevalent agricultural industries. Sugar is produced approximately 115 countries in the world. Among them, 67 countries produce sugar from sugarcane only, whereas 39 from sugar beet and nine countries from both the sources (Lichts et al, 2007, Poddar and Sahu et al, 2015). The world's top countries like Brazil, India, Thailand, Australia, China, and South Africa produce sugar from sugar cane. The production of sugar from sugarcane in the world is approximately 70%. The Indian sugar factories crush approximately 193.43 million tons of sugarcane with an average recovery of 10.48% cane (https://www.indiansugar.com/Statics.aspx, 2014). Sugarcane cultivation is approximately covered 2.8% of the gross cropped area of India (http://agricoop.nic.in /sites/default/files/Annual_rpt_201617_E.pdf) and considered as major cash crop after food grains. Sugar is the most lovable substance in the human diet and it is an essential food for the survival of human beings. The sugar industry runs seasonally from winter to pre-monsoon period (November to May in a year) and generates a substantial quantity of effluent as well as solid wastes in the form of bagasse and press mud filter cake (Kolhe et al, 2009). Sugar production units, a massive quantity of freshwater are consumed for a series of washing of raw sugar. The effluent of the sugar industry has maximum pollution load which pollutes in and around surface water, ground water and soil resources. Approximately 50% of effluent on an average is generated by process unit like spray pond overflow or process cooling tower (Mohan and Bajpai et al, 2018). The current waste water treatment technologies adopted by sugar industries is conventional activated sludge process (ASP) to treat effluent. ASP works on the principle of growth activity of aerobic bacteria to break down the organic waste by coagulation and flocculation process. The coagulant doses should be optimum to remove the total suspended solids (TSS) and total dissolved solids (TDS). But high TSS and TDS could not be removed by normal coagulation and flocculation process. Sometimes excess concentrations of TSS and TDS intricate the treatment of ASP and resulting in the poor working efficiency of ASP. In that utmost case, it is difficult to meet the discharge norms of treated effluent prescribed by CPCB. The efficiency of the ASP can be increased by removal of unwanted dissolved solids of raw effluent. So there is a need for detail characterization of raw effluent. Most of the sugar industry facing problem due to generation of enormous concentration of TDS and especially of sulphate concentration of raw effluent. Though sulphate concentration can be reduced by calcium precipitation method (Benatti et al, 2009) but tube settler technology is widely acceptable to reduce TDS as well as sulphate concentration. The principle of advanced tube settler technology is to target the settleable fine floc and allow the larger floc to settle at the bottom of the tank. So tube settler technology not only reduced the TDS but simultaneously reduce TSS also. In general, this technology is adopted widely by common effluent treatment plant (CETP) to treat effluent of small scale industries. But this technology is too expensive and adaptation of this technology may not be possible by small scale sugar industries.

To run season based sugar industry, withdrawal of massive quantity of groundwater, arises an additional problem in terms of continuous depletion of ground water level. The freshwater depletion is a serious issue, so notable attention is required to reduce both water pollution as well as fresh water consumption by adopting different strategies in industrial and domestic sectors. In this present scenario, most suitable strategy is to recycle the treated water as freshwater by improving the conventional treatment practices. If sugar industry effluent discharged without appropriate treatment can pose a pollution threat in both aquatic and terrestrial ecosystems (Kushwaha et al, 2013). In the present alarming situation in India, the regulatory agency like the CPCB has directed to each sugar industry that maximum effluent discharge limit of 200 litres per tonne of crane crushed. It is also mandatory to install online continuous emission monitoring systems (OCEMS) at the outlet of the ETP for continuous evaluation of treated effluent quality and to store the treated effluent into the lagoon and apply time to time to agricultural land. Accordingly sugar industry adopted the common practice to store treated effluent into the lagoon for further application to different purposes. In general treated effluent is widely applied to the agricultural land in India. But the sugar industry treated effluent have the potential treats to pollute both water bodies and agricultural land if not treated properly. There may have the possibilities that heavy metal (HM) of treated effluent may contaminate soil, groundwater and plant tissues. So there is a need to analyse the HM concentrations of treated effluent and to assess the effluent quality with the help of pollution indicator tools. This paper is discussed the physic-chemical as well as HM quality of the sugar effluent.

II. MATERIALS & METHOD

Description of the Sugar Industry

The present study was carried out one of the well- reputed sugar industry namely M/S. DCM Shriram Limited, Loni, Hardoi (27.635979N, 79.999091E), located at the central part of Uttar Pradesh state in India. The google map of the industry location is shown in **Fig 1**. The industry manufactures white sugar by double sulphitation process. Flow chart of the process for production of white sugar and waste water generation points is shown in **Fig 2**. The selected sugar industry crushing capacity is 7500 tonne per day. The total quantity of effluent generation is normally varied within the range of 1000 to 1200m^3 per day which is an average of 160 litres/ton of sugarcane crushed. CPCB has restricted to maximum of 200 litres/ton of sugarcane crushed. Spray pond overflow 600 to 800m^3 per day (106 litres/ton of sugarcane crushed). The effluent generations from other unit are approximately 55 to 60% of the total flow. Spray pond overflow contains maximum TDS due to precipitation of calcium bi sulphide, so it is always desirable to treat separately spray pond overflow/cooling tower effluent through tube settler technique. The layout plan of conventional activated sludge process (ASP) to treat generated effluent is shown in **Fig 3**. The layout plan to treat spray pond or cooling tower overflow with advanced tube settler technique is shown in **Fig 4**. The chemicals such as lime (CaO), commercial poly aluminum chloride (PAC) and magna flocculent are used as common coagulants to remove TSS as well as TDS of cooling tower effluent. The doses of coagulants are determined by the jar test. This method is necessary for adjustment of pH, variations in various types of coagulant or polymer doses, testing of different coagulant or polymer types in pilot scale in the laboratory to understand the functioning of a large scale treatment operation. A known quantity of raw effluent is kept in each beaker and is treated with a different dose of the coagulants. Other parameters may be altered besides dosage, including chemical types, mixing rate, aeration level, time, filtration type, etc. By comparing the final effluent quality achieved in each beaker, the effect of the different treatment parameters is determined.

Short time, a variation of treated effluent quality were assessed before the installation of the tube settler unit (November 13, 2018, to March 24, 2019) in the present sugar industry and after the installation of the tube settler unit (November 13, 2019, to March 24, 2020). In general sugar industry has conventional activated sludge process (ASP) which consist of various units like bar screen, oil and grease trap, equalization tank, primary clarifier, internal circulation reactor (anaerobic), aeration tank, secondary clarifier, and tertiary treatment units like pressure sand filter (PSF) and an activated carbon filter (ACF). The performance efficiency of the ETP was assessed with respect to common parameters like pH, total suspended solids (TSS), total dissolved solids (TDS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulphate and heavy metals. The analysis procedure is described below.

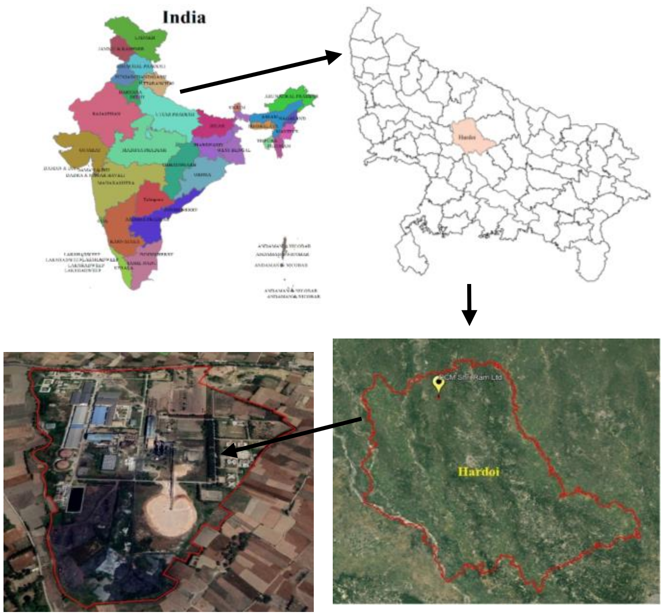

Fig 1: The Location of the industry (M/S. DCM Shriram Limited Sugar Unit- Loni. Hardoi Uttar Pradesh)

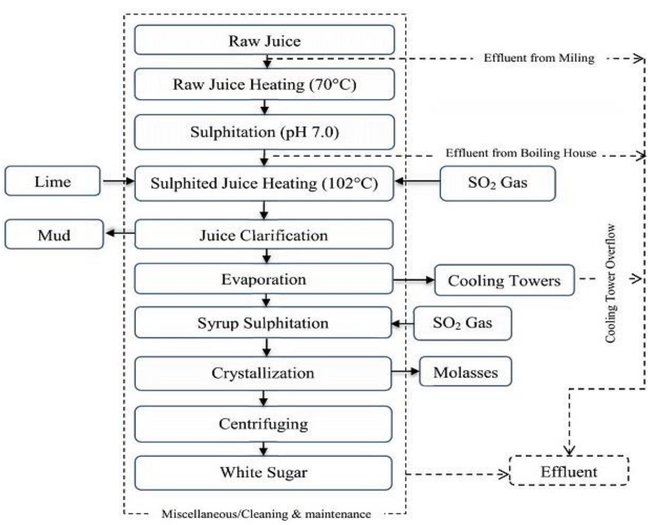

Fig 2: Flow chart of process for production of white sugar and waste water generation points

Analysis of Physico-chemical Parameters

pH is expressed in the negative logarithm of the hydrogen ion concentration and is the indicator of pollution index. pH of collected raw and treated effluent were measured by instrumental electrometric method by using digital pH meter. In the broad narration, pH of the effluent can affect the growth rate of biological process of several microorganisms and reduce the removal efficiency of treatment process. To purify the sugar cane juice, the usage of phosphoric acid and sulfur dioxide lower the pH values of raw effluent.

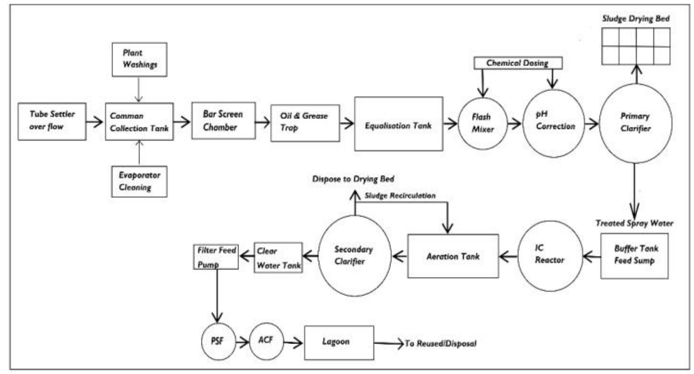

Fig 3: The layout plan of conventional activated sludge process to treat generated effluent

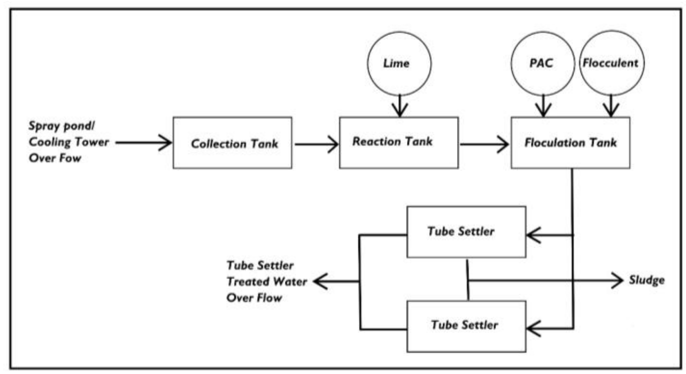

Fig 4: The layout plan to treat spray pond or cooling tower overflow with advanced tube settler technique

The concentration of total solids consists of total suspended solids (TSS) and dissolved solids (TDS). TSS and TDS were measured by gravimetric method. TSS of raw and treated effluent were analysed by filtering a known volume (100 ml) of effluent through a prepared pre-weighed glass fibers filter of a specified pore size of two micrometer. The filter paper was initially dried in the oven at 104 ± 1°C for at least one hour. After drying, the filter paper was reweighted again. The difference between the initial and final weight of the filter paper was divided by known volume of effluent filtered and measured TSS in mg/L. TDS is a measure of the dissolved combined content of all inorganic and organic substances present in the effluent. TDS was measured by evaporating a filtered effluent (100 ml) in a pre-weighed dish and then drying the residue in an oven at 103 to 105° C. The difference between the increased weight of dish was divided by a known volume of effluent filtered and measured TDS in mg/L.

An amount of oxygen consumed by microorganism present in the effluent that decomposes the organic matter of the effluent is known as biochemical oxygen demand (BOD). BOD was measured by measuring the dissolved oxygen (DO) by Winkler Method. In addition to divalent manganese solution, followed by strong alkali-iodide-azide reagent were used to fix the initial DO. The determination of initial DO on day one and after incubation period of three days at 27°C gives the value of oxygen consumed by microorganism during incubation period. Under the acidic condition, iodine liberated was titrated with standardized thiosulfate (0.025 N) solution. The quantity of effluent and difference in DO (initial and final DO values) was used for the calculation of BOD in mg/L.

COD was measured by open reflux method. Sample was refluxed in strong acid solution with a known excess of potassium dichromate ($K_2Cr_2O_7$). After digestion, the remaining unreduced $K_2Cr_2O_7$ was titrated with standard ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed and oxidisable organic matter was calculated in terms of oxygen equivalent.

A sample and precise turbidimetry method was used to determine the sulfate concentration of the sugar effluent. It was measured the turbidity formed by barium sulfate ($BaSO_4$) when an aliquot of a barium chloride-gelatin reagent was added to an acidified effluent. $BaSO_4$ suspension was measured by a spectro-photometer. The method is quite sensitive and accurate to measure sulphate concentrations of the effluent.

Mixed liquor suspended solids (MLSS) is the concentration of suspended solids in an aeration tank of the waste water treatment plant. It is mixture of activated sludge and unsettled or pre-settled wastewater within an aeration tank. MLSS is a dominant parameter of biological treatment process like ASP to ensure that there is a sufficient quantity of active biomass available to consume the present quantity of organic pollutant available in the effluent at any time. The more biomass consumed by microorganism, indicated the lower of TSS, BOD and COD in the effluent. The existing or growth of MLSS is solely responsible to remove TSS, COD as well as BOD from the effluent. MLSS was measured by filtering a known volume of the mixed liquor sample and analysis procedure is same as TSS measurement of the effluent. MLSS concentration greater than 2000 mg/L, but lower than 4000 mg/L is considered as optimum condition of ASP for efficient removal of TSS, BOD and COD of the effluent. MLSS concentration varies with sludge age, raw effluent BOD/COD ratio, tank size, temperature, pH, TDS etc. If the MLSS drops too low problem arises with flocculation, and poor quality of effluent generated. If the MLSS becomes too high, problem arises with solids separation and reduction of BOD and COD of the treated effluent.

Analysis of heavy metals concentration

The treated effluent stored at lagoon as per the guidelines of CPCB, were collected at random basis (covering the total peripheral area of lagoon as well as centre) and analysed for common heavy metals (HMs) like iron (Fe), copper (Cu), cadmium (Cd) and zinc (Zn) metal normally exist in the treated effluent of the sugar industry. A total of ten samples were collected and preserved at 4^0C until further analysis was carried out. Initially samples were digested through microwave digester (model MARSXpress CEM, USA) and then further analysed through Inductively Coupled Plasma Optical Emission Spectrophotometry (model iCAP 6300DUO Thermo Fisher, USA).

All analytical (AR) grade chemicals (make: Merk Chemical Ltd., Mumbai, India) were used to analysis of HM standard metal stock solutions (1000 ppm) were used to prepare working standard. MilliQ water was used for dilution and other preparatory work. Initially, a known quantity of sample (45 ml) was digested with a concentrated acid solution (3 ml HNO_3 + 2 ml H_2SO_4) in the microwave digester. The colorless solution observed after digestion indicated the digestion was completed. The excess acid was boiled off after digestion. The dry residue was re-dissolved again in 2.5 ml of HNO_3 and 10 ml of double-distilled water by gentle heating. The final solution obtained was cooled and diluted to 100 ml in a graduated flask by triple washing with MilliQ water and then filtered. The reagent blank was also prepared using the same protocol by digesting the unexposed sample. The concentrations of HM were calculated by comparing the absorbance of the sample with standard metal solutions. The standard solution was repeatedly aspirated to ensure the calibration was within the limits of the control chart. For Quality Assurance/ Quality Control of the analysis, one-tenth of the sample was analysed in duplicate. The reproducibility test suggested the stability or the precision of the instrument was within the range of 5% of the calculated value or not. Otherwise, the standard calibration process was repeatedly performed. The unexposed sample was also repeated after ten samples of analyses.

Assessment of HM by Contamination Factor (Cf)

The contamination factor (Cf) is a diagnostic and versatile tool to identify HM pollution and contamination level both in the same environmental matrix (Devanesan et al, 2017). Cf was calculated by the following method (Hakanson L, 1980).

$$Cf = \text{frac } C_{heavymetal}/C_{background}$$

The contamination factor (Cf) is the ratio acquired by dividing each metal concentration by the background concentration. The background concentration means the selected environmental matrix was never contaminated before by any anthropogenic sources. The value of Cf < 1 indicate a low contamination; the value within the range of 1 < Cf < 3 is moderate contamination; the value within the range of 3 < Cf < 6 is considerable contamination; and if the value of Cf > 6 indicates high contamination. The minimum concentration of each HM is considered a background concentration.

III. RESULT AND DISCUSSION

The physic-chemical characteristic of the raw and treated effluent quality varies from one to another industry due to differences in the sugar manufacturing processes, a type of sugarcane crop, soil quality on which sugarcane crop was cultivated, quality and quantity of water used and overall the efficiency of the biological treatment plant (Macarie et al, 2006). The characteristic of the effluent before the installation of the tube settler unit had been studied for three months (November 13, 2018, to March 24, 2019). The parameters like pH, TSS, TDS, BOD, COD and sulphate were assessed to evaluate the performance evaluation of ASP. The characteristic of raw and treated effluent before installation of tube settler unit is shown in **Table 1**. The effluent samples were collected twice a week and a total of thirty five (35 nos) of composite samples (8 hourly basis) were collected and analysed. All the selected parameters were analysed as per the American Public Health Association guidelines (APHA, 2017). The characteristic of the treated effluent for selected parameters like pH, TSS, TDS, BOD, COD and sulphate varied from 7.2 to 7.7, 36 to 78, 1454 to 2435, 70 to 138, 273 to 402 and 864 to 910 mg/litre respectively. Till date sulphate has not been included as a criteria pollutant in the CPCB standard but sulphate plays an important role in the performance of ASP especially for sugar industry effluent. The characteristic of the raw and treated effluent after installation of tube settler unit in additional in ASP process had been studied for three months (November 13, 2019, to March 24, 2020). The effluent of spray pond overflow/cooling tower was initially treated through the tube settler unit then treated overflow/cooling tower effluent was mixed with the effluent of other processing units. The characteristic of raw and treated effluent after installation of tube settler unit is shown in **Table 2**. The characteristic of the treated effluent for selected parameters like pH, TSS, TDS, BOD, COD and sulphate varied from 7.2 to 8.3, 15 to 27, 1046 to 1530, 19 to 28, 195 to 242 and 233 to 372 mg/litre respectively. Before the installation of tube settler unit, the removal efficiency of ASP for selected parameters like TSS, TDS, BOD, COD and sulphate were 69, 42, 79, 75 and 20% respectively. But after the installation of tube settler unit in ASP, the removal efficiency of the selected parameters was 87, 63, 94, 85 and 64% respectively. The removal efficiency of the criteria pollutants had been increased after the installation of tube settler unit. The treatment of effluent through only ASP could not meet the discharge standard prescribed by CPCB because spray pond overflow/cooling tower effluent contain maximum TDS which affects to maintain the mixed liquor suspended solids (MLSS) concentrations in the aeration tank of ASP. Sugar industry effluent is treated by ASP and the removal efficiency of pollution load with respect to BOD and COD are mainly dependent on the concentration of MLSS i.e., growth of aerobic bacteria in the aeration tank. A tendency of incremental TDS concentration of the effluent could adversely affect the aerobic oxygen intake of microorganism. As a result aerobic mechanism of aeration tank is disturbed and ultimately leads to failure of ASP (Wu et al, 2018). As such, the maximum concentration of MLSS could be maintained upto 2000 mg/litre without installation of tube settler unit. However, with the installation of tube settler unit, the concentration of MLSS could be maintained within an average 2500 to 3600 mg/litre respectively. The higher concentration of MLSS indicates the maximum removal efficiency of pollution load.

TABLE 1

The characteristic of raw and treated effluent before installation of tube settler unit

S. No	Parameter	Raw Effluent	Average	Treated Effluent	Average	% Removal	CPCB Standard, 2016
1.	pH	5.5-6.9	6.5	7.2-7.7	7.4	-	5.5-8.5
2.	TSS	122-263	202	36-78	63	69	30 disposal in surface water 100 disposal on land
3.	TDS	1970-3898	3163	1454-2435	1826	42	2100
4.	BOD	253-602	430	70-138	92	79	30 disposal in surface water 100 disposal on land
5.	COD	667-2665	1532	273-402	386	75	250
6.	Sulphate	979-1108	1005	864-910	807	20	-

pH measured in pH scale

Except pH, concentrations of other selected parameters were measured in mg/litre.

BOD was measured in three days at 27^0C

TABLE 2

The characteristic the raw and treated effluent after installation of tube settler unit

S. No.	Parameter	Raw Effluent	Average	After Tube Settler	Aver age	Treated Effluent	Aver age	% Removal	CPCB Standard 2016
1.	pH	5.4-7.3	6.6	10.4-11.7	10.8	7.2-8.3	7.4	-	5.5-8.5
2.	TSS	100-252	199	32-104	72	15-27	26	87	30 disposal in surface water 100 disposal on land
3.	TDS	2020-3970	3230	1620-3260	2248	1046-1530	1188	63	2100
4.	BOD	264-688	404	208-542	316	19-28	25	94	30 disposal in surface water 100 disposal on land
5.	COD	940-2680	1577	400-1920	1081	195-242	229	85	250
6.	Sulphate	798-1083	908	432-664	496	233-372	328	64	-

pH measured in pH scale

Except pH, concentrations of other selected parameters were measured in mg/litre.

BOD was measured in three days at 27°C

The HM concentration of the treated effluent collected from lagoon is given in **Fig 5**. The concentration of selected HMs namely, Fe, Cu, Cd, and Zn of total ten (10 nos) of lagoon samples were 0.36±0.14, 0.18±0.08, 0.17±0.06, and 1.33±0.31mg/litre respectively. The average concentration of Fe, Cu, and Cd of effluent exceeded the permissible limit of Indian standard (IS 10500, 2012).The only Zn concentration was within the permissible limit of Indian standard (IS 10500, 2012). Zn is considered as an indispensable micro nutrient for plants growth metabolism and human body but excess may cause vascular shock, nausea and vomiting tendency (Juned and Bhosle et al, 2010). Fe and Cu are also an essential micro nutrient for the growth and development of plants and humans. But beyond the permissible limit of Cu may cause chlorosis and necrosis, stunting, leaf discoloration, and inhibition of root growth etc. Surplus Fe may lead to genetic and metabolic diseases. Cu is one of the major constituents of sewage fertilizer and pesticide residues and excess Cu accumulation to the human body causes hypertension and can be root the cause for brain and bone tissue damage (Begum et al, 2009). Cd is considered as the most dangerous pollutant as it has adverse health effects like renal disease and skeletal problems etc. (Jarup et al, 1998). The result of the present study showed that Cf value of the selected metals was considerably high. The Cf value of Zn varied from 1.0 to 2.43 with an average value of 1.68 which falls under the category of moderate contamination. Cf value of other metals like Fe, Cu, and Cd were varied from 1.0 to 4.21, 1.0 to 10.43, and 1.0 to 4.0 with an average value of 2.56, 5.91 and 2.8 respectively. Based on the average value of Cf, Fe and Cd falls under the category of moderate contamination but Cu fall under the category of considerable contamination.

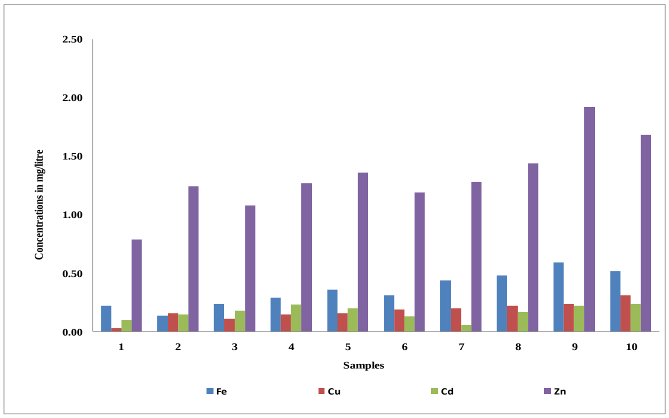

Fig 5: The HM concentration of the treated effluents collected from lagoon

IV. CONCLUSION

The performance evaluation of effluent treatment plant (ETP) of M/S. DCM Shriram Limited Sugar Unit- Loni, Hardoi study indicated that the conventional treatment process, the removal efficiency of ETP for selected parameters like TSS, TDS, BOD, COD and sulphate were 69, 42, 79, 75, and 20% respectively. But after the installation of the tube settler unit in additional in the ETP, the removal efficiency of the selected parameters like TSS, TDS, BOD, COD, and sulphate were increased from 69 to 87%, 42 to 63%, 79 to 94%, 75 to 85%, and 20 to 64% respectively. The high TDS concentration suppresses the growth of microorganism which ultimately reduces the removal efficiency of pollution load in terms of TSS, BOD, and COD. This type of problem arises when cooling tower effluent and process effluent is treated together. But after treating the cooling tower effluent separately through tube settler unit, if the total generation of effluent (process effluent and treated cooling tower effluent) is treated through ASP, removal efficiency of TSS, TDS, BOD, and COD are quite high and can meet both discharge norms (surface waters and land disposal) of CPCB, 2016. This study revealed that the installation of a tube settler unit can be one of the sustainable solutions to improve the treated effluent quality. The evaluation of HM concentrations of lagoon samples by contamination factor (Cf) suggested that Zn, Fe and Cd falls under the category of moderate contamination whereas Cu fall under the category of considerable contamination.

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