# Performance Evaluation of Continuous Stirred Tank Reactor (CSTR)

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*Abstract*— Different studies have showed that an anaerobic treatment with the production of biogas appears to be most assuring method for the treatment of distillery spent wash. Distillery industries are one of the most highly polluting industries, generating very high strength wastewater (spent wash) which effect seriously on environment. At the time of production of alcohol, very large amount of wastewater produced. Particularly 8-15 lit of spent wash was generated on production of 1 lit of alcohol. Under various organic loading rates, ideal conditions for highest chemical oxygen demand (COD) removal and maximum biogas generation was to be found for OLR of 0.10 COD kg /d to 0.11 COD kg /d. Maximum COD removal efficiency was to be found around 73% for OLR of 9.166 kg COD/m3 /d when hydraulic retention time (HRT) decreased from 15 to 14 days. These performance evaluation figures are very important while operating the anaerobic bio digesters for the treatment of distillery spent wash. Anaerobic digestion (CSTR) can be very effective for treatment of distillery spent wash, but post-methanation spent wash still contains very high organic concentration which needs to be treated further to qualify for safe and acceptable pollution control limits for disposal.

***Keywords:*** Distillery, CSTR Start-up, OLR, HLR, Kinetic Modeling

## I. INTRODUCTION

Molasses is a byproduct of sugar manufacturing process which is used to produce alcohol in distillery [1]. A brown viscous liquid remain at the bottoms of distillery after the production of Alcohol it is called as spent wash [6]. The generation of spent wash from the distillery is about 12-15 times the production of alcohol [1]. The distillery spent wash has very high amount of biochemical oxygen demand (45000-50000mg/l) and chemical oxygen demand (110000-125000mg/l) [2]. The distillery spent wash is highly acidic in nature (pH 4.0-4.3) with highly total suspended solids (2.0-2.5kg/m3) [3]. It is harmful for surrounding environment and it also contains various nutrients like nitrogen (1600-4200mg/l), phosphorus (225-3038mg/l), and potassium (9600-17475mg/l) [4, 5].

According to the Ministry of Environment and Forests, Govt. of India the distillery industry is one of the most polluting industries [7]. According to recent survey there are around 400 distilleries currently operating in the states of India. On an average 15 liters of spent wash is produced per liter of alcohol, depending on the type of process and quality of molasses used etc [8].

According to survey, the process of production of alcohol only 12% of raw material is converted into the product and rest of all is converted into waste. There are various methods to treat this spent wash. These methods mostly comprise of recovering resources from spent wash and disposal. The secondary and tertiary methods are not technically and economically workable for mitigating the problems associated with the treatment and disposal of spent wash [9]. But there is a positive side the spent wash comprises of high BOD and COD values which can be used to produce biogas through anaerobic digestion technique. Within the available methods, anaerobic digestion is the best way for energy recovery from spent wash [10]. Anaerobic treatment of distillery spent wash with biogas recovery is most suitable method [11].

Various kinds of anaerobic bio digesters have been tested at pilot level as well as full scale operations [12]. The anaerobic bio-digestions technique usually works for spent wash because of the COD/N/P ratio which is unbalanced and works in the anaerobic bio-digestions technique which requires phosphorous and nitrogen addition [13]. Along the banks of Krishna River in South Maharashtra and North Karnataka states of India, on huge scale area sugarcane is being cultivated as it is considered as a money crop. In this area, large sugars and the distillery industries are operating and generating enormous quantity of spent wash [14].

The main purpose of the study was to assess the influence of OLR (organic loading rate) on the treatment efficiency of a continuous stirred tank reactor relating the process parameters, COD, and the biogas production The various factors affect the working of the digestion process. Activity of microorganisms, substrate utilization and biogas formation are the main factors in anaerobic digestion. The most important process parameters required to be considered are Alkalinity, VFA (Volatile fatty acid), COD exertion, and TSS (total suspended solid)[15].

### A. *Material and Methods*

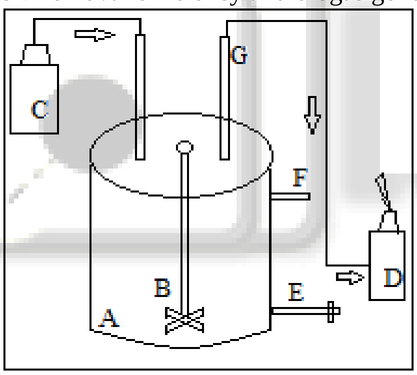
*Substrate:* For the present study spent wash and seed cultures samples were provided by Lokmalnagar sugar and the industry is located at Solapur, Maharashtra. Table no 1 shows the properties of distillery spent wash.

| Parameters | Values of Raw spent wash |
|---|---|
| pH | 3.0 – 4.5 |
| $BOD_5$ | 55000 – 65000 mg/L |
| COD | 110000 – 140000 mg/L |
| Total Solids (TS) | 90000 – 140000 mg/L |
| Total Volatile Solid (TVS) | 80000 – 100000 mg/L |
| Total Dissolved Solid (TDS) | 11000 – 14000 mg/L |
| Total Suspended Solid (TSS) | 80000 – 130000 mg/L |
| Chlorides | 7000 – 8000 mg/L |
| Phosphate | 2300 – 3000 mg/L |
| Total Nitrogen | 6000 – 8000 mg/L |

Table 1: Key properties of distillery spent wash

## II. START-UP OF THE CSTR

In the present study, a plastic tank is used as a reactor. The reactor consists of inlet, outlet, and overflow of effluent .The biogas outlet is connected to a tin lamp partially filled with water so that the biogas burns when passed through water .A Mechanical stirrer with a motor is fixed on top of the bottle. The entire apparatus was checked for any type of liquid or gas leakage. Activated seed culture is used as a seed material. To initiate the process, the seed was diluted to dilution factor 3. The important parameters of seed culture were as shown in Table 2. The spent wash was continuously feeded to the reactor at a low rate of 0.01 kg COD per day with continuous stirring of reactor liquid. Feeding process was continued till the digester parameters were stabilized. The loading of COD was increased only after steady-state conditions were achieved. The CSTR spent wash parameters were monitored and analyzed at regular intervals. After every stable condition, feeding was increased with 0.01 kg COD. The stable steady-state condition refers to very little or no variation in COD of overflow effluent, Alkalinity, or VFA of reactor effluent sample [16]. Stable VFA to alkalinity ratio also considered as a steady-state condition. This can also be checked by stable gas production [17]. The observations were recorded after 24 hrs of change in OLR. As the feeding quantity was low as compared with the volume of CSTR, the pH of the effluent was not adjusted before feeding. The gas generation was noted on the basis of the flame height. CSTR samples were checked for pH, Temperature, Suspended Solids (SS), Total Dissolved Solids (TDS), Volatile Fatty Acids (VFA), Alkalinity, COD etc. The pH was maintained at an average level of 6.5 to 7.5 to improvise the growth and activity of anaerobic bacteria throughout the study. The efficiency of the CSTR for different organic loading rates (OLRs) was evaluated on the result of COD removal efficiency and biogas generated.




[A] Anaerobic Continuous Stirred Reactor, [B] Stirrer, [C] Influent, [D] Flair Stack, [E] Outlet, [F] Overflow Effluent, [G] Biogas Outlet

Fig. 1: Diagram of aerobic continuous stirred bioreactor

| Parameter | Value |
|---|---|
| pH | 7.8 |
| Temperature | 35°C |
| VFA | 1300 mg/L |
| Alkalinity | 31000 mg/L |
| TDS | 57000 mg/L |
| TSS | 34000 mg/L |
| COD | 36000 mg/L |

Table 2: Properties of activated seed

### *A. Results and Discussions*

Properties of raw spent wash, reactor effluent and overall effluent were examined according to standard methods for the examination of water and wastewater [18]. The observed values of COD and BOD are 126000 mg/l and 57000 mg/l respectively resulting in COD to BOD ration 2.2which showed the spent wash is moistly suitable for biological digestion.

## III. Organic and Hydraulic Loading Rates

The organic loading rates (OLR) rate from 0.01kgCOD/d to 0.16kgCOD/d was applied with an increase in 0.01kg COD. Hydraulic loading rate can be applied as per required organic loading rate (kg/d). The hydraulic loading rate and equivalent hydraulic retention time for continues stirred tank reactor (CSTR) model were shown in table 3.

| Influent COD (kg/l) | Hydraulic Loading Rate (l/d) | Organic Loading Rate COD (kg/d) | Hydraulic Retention Time (d) |
|---|---|---|---|
| 0.122 | 0.08 | 0.01 | 146.4 |
| 0.122 | 0.16 | 0.02 | 73.2 |
| 0.122 | 0.25 | 0.03 | 48.8 |
| 0.122 | 0.33 | 0.04 | 36.6 |
| 0.130 | 0.38 | 0.05 | 31.2 |
| 0.130 | 0.46 | 0.06 | 26.0 |
| 0.130 | 0.54 | 0.07 | 22.3 |
| 0.130 | 0.62 | 0.08 | 19.5 |
| 0.130 | 0.69 | 0.09 | 17.3 |
| 0.128 | 0.78 | 0.1 | 15.4 |
| 0.128 | 0.86 | 0.11 | 14.0 |
| 0.128 | 0.94 | 0.12 | 12.8 |
| 0.128 | 1.02 | 0.13 | 11.8 |
| 0.119 | 1.18 | 0.14 | 10.2 |
| 0.119 | 1.26 | 0.15 | 9.5 |
| 0.119 | 1.34 | 0.16 | 8.9 |

Table 3: Influent COD and OLR details

### *A. Effect of OLRs on CSTR parameters*

The pH in the reactor is maintained in a range between 6.5 to 8 because of Methanogenesis is sensitive for both high and low pH. The stability and efficiency of the anaerobic treatment process are greatly affected by temperature so that the temperature of reactor was constantly observed from the beginning of the process [20]. The area know to be affected by temperature are reaction rate, the dominance of certain biochemical pathways and microbial activity [21]. The small temperature variation can considerably affect the performance of reactor and biogas production hence constantly observing the reactor temperature is very important [22].

## IV. Kinetic Modeling

The thesis related to kinetic model proposed by Stovere Kincannon relates the organic substance utilization rate as a function of OLR at steady-state conditions. Equation I

$$\frac{dS}{dt} = \frac{Q(S_e - S_i)}{V} \tag{I}$$

The original stovere kinacannon model is as in Equation II

$$\frac{dS}{dt} = \frac{Q(S_e - S_i)}{V} = \frac{U_{max}\left(\frac{QS_i}{V}\right)}{K_b + \left(\frac{QS_i}{V}\right)} \tag{II}$$

Rearrangement of equation gives the relationship

$$\left(\frac{dS}{dt}\right)^{-1} = \frac{V}{Q(S_i - S_e)} = \frac{K_b V}{U_{max} QS_i} + \frac{1}{U_{max}} \tag{III}$$

The model applied to the reactors data where S is digester substrate concentration (kg COD /m$^3$ in the Eq. (III), dS/dt is substrate removal rate ($kg/m^3/d$), $U_{max}$ is maximum removal rate constant ($kg/m^3/d$), Kb is saturation value constant ($kg/m^3/d$).

If (dS/dt) −1 is considered as V/Q ($S_i$ -$S_e$ ), which is the inverse of the loading removal rate, and this is represented and plotted with the inverse of the total loading rate V/ ($QS_i$ ), it will produce a straight line. The slope of the lines is Kb/Umax and the intercept of these lines is $1/U_{max}$, respectively. Figure 4, demonstrates the results on the graphs respectively. The graph shows $QS_i/V$ Vs Q ($S_i$ - $S_e$)/V for all the HRT considered for the study. Table D shows, Stover and Kincannon model table showing values for X-axis and Y-axis for the Continuous stirred tank reactor lab model. The maximum removal rate constant Umax ($kg/m^3$ /d) and is a saturation value constant Kb ($kg/m^3/d$) was determined as below.

Intercept = 0.0584

$U_{max} = \frac{1}{\text{Intercept}}$ = 0.0584 $kg/m^3/d$

Slope = 1.9547

$K_b$ = Slope*$U_{max}$ = 33.471 $kg/m^{3/}d$

| V ($m^3$ ) | Si (kg $COD/m^3$) | Se (kg $COD/m^3$) | Q ($m^3/d$) | V/(QSi) ($m^3d/kg$) | V/Q (Si-Se) (kg $COD/m^3$) |
|---|---|---|---|---|---|
| 0.012 | 122 | 58 | 0.00008 | 1.230 | 2.344 |
| 0.012 | 122 | 57 | 0.00016 | 0.615 | 1.145 |
| 0.012 | 122 | 55 | 0.00025 | 0.393 | 0.716 |
| 0.012 | 122 | 53 | 0.00033 | 0.298 | 0.527 |
| 0.012 | 130 | 52 | 0.00038 | 0.243 | 0.405 |
| 0.012 | 130 | 49 | 0.00046 | 0.101 | 0.322 |
| 0.012 | 130 | 45 | 0.00054 | 0.171 | 0.261 |
| 0.012 | 130 | 40 | 0.00062 | 0.149 | 0.215 |
| 0.012 | 130 | 39 | 0.00069 | 0.134 | 0.191 |
| 0.012 | 128 | 35 | 0.00078 | 0.120 | 0.165 |
| 0.012 | 128 | 35 | 0.00086 | 0.109 | 0.150 |
| 0.012 | 128 | 37 | 0.00094 | 0.100 | 0.140 |
| 0.012 | 128 | 36 | 0.00102 | 0.092 | 0.128 |
| 0.012 | 119 | 36 | 0.00118 | 0.085 | 0.123 |
| 0.012 | 119 | 37 | 0.00126 | 0.080 | 0.116 |
| 0.012 | 119 | 38 | 0.00134 | 0.075 | 0.111 |

Table 4: Stover and kincannon model table showing values for X-axis and Y-axis for CSTR lab model

The most important characteristic of the plot is the gradual loss in efficiency with increased organic loads. The kinetic constants Umax and Kb can be calculated as 17.123 $kg/m^3/d$ and 33.471 $kg/m^3/d$ respectively from Fig. 4. The regression line had an $R^2$ of 0.9995, verifying the accuracy of Eq. (II).

The obtained values of $U_{max}$ and $K_b$ can be used to find the reactor volume to reduce the organic matter from $S_i$ to $S_e$ . It is also used to find $S_e$ (effluent concentration) for known or given V and $S_i$.

Mass balance for an anaerobic reactor can also be written as

{Mass in X volume of media} = {Mass out X volume of media} + {Mass biodegraded}

$$QS_e = QS_i + V\left(\frac{dS}{dt}\right) \quad \text{(IV)}$$

Further, in the above relationship ds/dt can be replaced

$$QS_i = QS_e + V\left(\frac{U_{max}\left(\frac{QS_i}{V}\right)}{K_b + \left(\frac{QS_i}{V}\right)}\right) \quad \text{(V)}$$

The above equation can be further simplified for the calculation of volume required for anaerobic reactor or concentration of effluent.

$$V = \frac{QS_i}{\left(\frac{U_{max}S_i}{S_i - S_e}\right) - K_b} \quad \text{(VI)}$$

$$S_e = S_i - \frac{U_{max}S_i}{K_b + \left(\frac{QS_i}{V}\right)} \quad \text{(VII)}$$

Above Eq. (VII) can be used to calculate concentration in effluent from known influent concentration and Organic loading rate for the CSTR. Table E shows the equivalent effluent concentrations predicted using the above equation and observed values during the study, which verifies the applicability of the model.

| Q ($m^3/d$) | Si (kg COD /$m^3$) | Observed Se (kg $COD/m^3$) | $U_{max}$ ($kg/m^3/d$) | $K_b$ ($kg/m^3/d$) | Predicted $S_e = S_i - \frac{U_{max}S_i}{K_b + \left(\frac{QS_i}{V}\right)}$ |
|---|---|---|---|---|---|
| 0.00008 | 122 | 58 | 17.123 | 33.741 | 58.00 |
| 0.00016 | 122 | 57 | 17.123 | 33.741 | 57.06 |
| 0.00025 | 122 | 55 | 17.123 | 33.741 | 54.98 |
| 0.00033 | 122 | 53 | 17.123 | 33.741 | 52.99 |
| 0.00038 | 130 | 52 | 17.123 | 33.741 | 51.81 |
| 0.00046 | 130 | 49 | 17.123 | 33.741 | 48.97 |
| 0.00054 | 130 | 45 | 17.123 | 33.741 | 44.94 |
| 0.00062 | 130 | 40 | 17.123 | 33.741 | 40.14 |
| 0.00069 | 130 | 39 | 17.123 | 33.741 | 39.03 |
| 0.00078 | 128 | 35 | 17.123 | 33.741 | 34.62 |
| 0.00086 | 128 | 35 | 17.123 | 33.741 | 34.62 |
| 0.00094 | 128 | 37 | 17.123 | 33.741 | 36.94 |
| 0.00102 | 128 | 36 | 17.123 | 33.741 | 36.18 |
| 0.00118 | 119 | 36 | 17.123 | 33.741 | 36.07 |
| 0.00126 | 119 | 37 | 17.123 | 33.741 | 36.07 |
| 0.00134 | 119 | 38 | 17.123 | 33.741 | 38.05 |

Table 5: Observed and predicted values of effluent organic concentration (Se) for CSTR lab model.

Similar experiment was done by Bhavik K. Acharya in his study of Kinetic modeling, and microbial community assessment study of anaerobic biphasic fixed-lm bioreactor treating the distillery spent wash [19]. High strength distillery effluent was treated through biphasic continuous mode, up-Flow Fixed film reactor having a volume of 3L.

Process kinetics, anaerobic digestion process, microorganisms' community structure was the main focus of the study. By using the Stovere Kincannon model to the digester, the saturation value constant ($K_b$) and maximum removal rate constant ($U_{max}$ ) and was found and observed to be 1.69 $kg/m^3/d$ and 2 $kg/m^3/d$ respectively.

The results, observations and calculations are a clear indicator of how suitable Stovere Kincannon kinetic model to the anaerobic CSTR, capable to reduce 50–75% COD at various OLR. The most appropriate result indicates that $R^2$= 0.9997 which are very close to unity and indicates the acceptability of model data. The significant difference in the maximum removal rate constant ($U_{max}$) ($kg/m^3$ /d) and the saturation value constant ($K_b$) ($kg/m^3/d$) values of this study and previous studies are observed. The difference may be due to the substantial variation in confined conditions between both the studies.

Moreover, these constants may have different values for various OLRs, HRTs, and other operating conditions of the digester. We can avoid the problem of process stability by adopting proper process models and consideration of microbial communities concerned in the removal of complex organic matter from wastewater. The quality microbiological assessment study plays a vital role in the design and control of the treatment process of spent wash digestion.

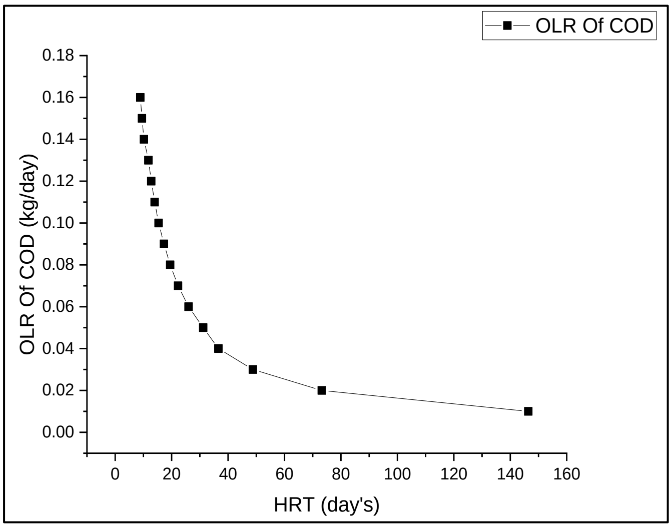



Fig. 2: Effect of HRT on OLR of COD

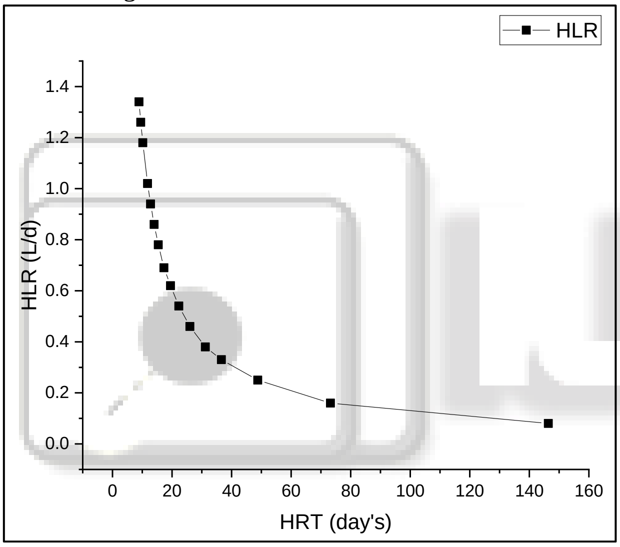



Fig. 3: Effect of HRT on HLR

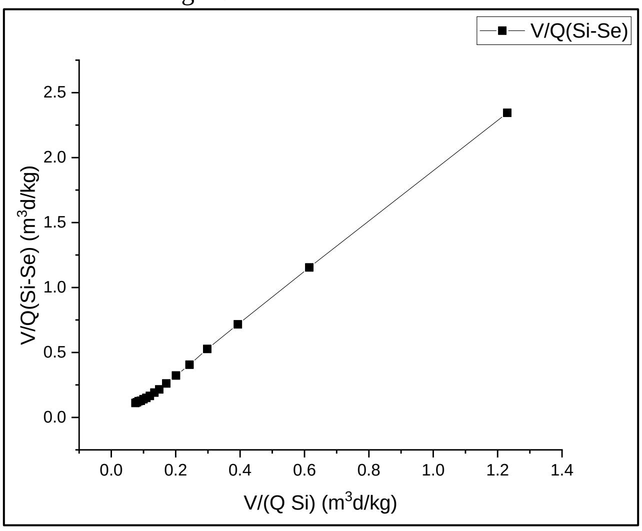



Fig. 4: Effect of Organic loading rate on rate of COD removal for CSTR Lab model

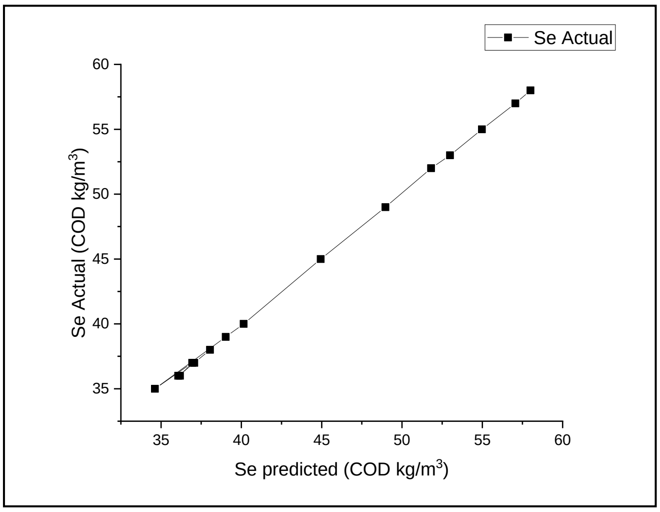



Fig. 5: The distinguish between (Se) Predicted and (Se) Actual

## V. CONCLUSION

The treatment of the spent wash can be very effectively be carried out by CSTR. If we operate in the favorable pH ranges the maximum COD removal was guaranteed to be 73%.The most favorable conditions for COD removal and biogas generation were found to be for OLR 0.10 kg/d to 0.11 kg/d, at 14d HRT, and VFA to Alkalinity ration around 0.12.The Optimum biogas generation with a conversion coefficient of 0.405 was observed to be around 30L/d for steady-state conditions. From the experiment carried out the efficiency of the Stovere Kincannon model to the reactor which is applicable to remove 70–75% COD at different OLR. Methanation effluent after the process is completed needs to be treated properly. The performance towards COD reduction and Biogas formation can further be enhanced by increasing the buffering capacity of the reactor. Using the improved Stovere Kincannon kinetic model, the maximum removal rate constant ($U_{max}$) and saturation value constant (Kb) were observed to be 17.123 kg/m$^3$/day, and 33.471 kg/m$^3$/day. The result shows that how the Stovere Kincannon model is helpful for anaerobic CSTR. The results of the digester can further be improved by adding micronutrients to the reactor; hence a study of seed culture at a microbiological level needs to be conducted to analyze the performance.

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## REFERENCES

[1] Shankaran K, Divakar S, Nagarajan S. Vadanasundari V. 2011. Analysis on biodegradation and colour reduction of distillery euent spentwash. Asian journal of science and technology, 2(3) 015- 021.
[2] Chidanand P., P. B. Kalburgi, Mugdha Ghorpade,. "Performance and Evaluation of Sugar & Distillery Euent Treatment Plant. 2015. International Research Journal of Engineering and Technology. 2(3) Loading

[MathJax]/jax/output/CommonHTML/jax.js Page 16/23 1456-1460.
[3] Tapas N., Sunita Shastry, S. N. Kaul. 2002. Wastewater management in a cane molasses distillery involving bioresource recovery. Journal of Environmental Management. 65(1)25-38. doi:10.1006/jema.2001.0505
[4] Pankaj C., Nawaz Khan and Ram Naresh Bharagava. 2018. Distillery Wastewater: it's Impact on Environment and Remedies. Environmental Analysis & Ecology Studies.1(2) 14-17
[5] Satyawali Y., M. Balakrishnan. 2008. Wastewater treatment in molasses-based alcohol distilleries for COD and color removal: A review. Journal of Environmental Management,: 86(3) 481–497.
[6] Prof. Yogesh. S. Khandekar , Dr. Narendra. P. Shinkar Treatment Methods of Distillary Spent Wash: A Review. International Journal of Engineering Science Invention (IJESI) 2018.
[7] Mrityunjay Singh Chauhan and Anil Kumar Dikshit. 2012. Indian Distillery Industry: Problems and Prospects of Decolourisation of Spentwash. International Conference on Future Environment and Energy. IPCBEE, IACSIT Press, Singapoore. Vol. 28.
[8] 2017. Draft Guidelines For Co-Processing Of Distillery Spent Wash Concentrate In Cement Industry. (Ministry of Environment & Forests, Govt. of India).
[9] Sowmeyan R., G. Swaminathan . "Effluent treatment process in molasses-based distillery industries: A review." Journal of Hazardous Materials, 2008: 152(2) 453–462.
[10] Rajeshwari K., M. Balakrishnan, A. Kansal, Kusum Lata. "State-of-the-art of anaerobic digestion technology for industrial wastewater treatment." Renewable and Sustainable Energy Reviews, 2000: 2(4), 135-156.
[11] CPCB, India. "Guidelines on Techno–Economic Feasibility of implementation of zero liquid discharge for water polluting industries". http://www.indiaenvironmentportal.org.in /files /file/Final-ZL, 2015.
[12] Ravikumar R., R.Saravanan, N.S.Vasanthi, J.Swetha, N.Akshaya, M.Rajthilak and K.P. Kannan. "Biodegradation and decolourization of biomethanated distillery spentwash." Indian Journal of Science and Technology, 2007: 1(2) 1-6.
[13] Moletta R. 2005. Winery and distillery wastewater treatment by anaerobic digestion. Water Science and Technology. 51 (1): 137-144.
[14] . D. Mohite, S. S. Salimath. 2019. Performance Optimization of Anaerobic Continuous Stirred-Tank Reactor Operating on Distillery Spent Wash. Journal of Environmental Engineering, 145(9): 04019054-1-5.
[15] Bhavik K. Acharya, Sarayu Mohana, Datta Madamwar. 2008. Anaerobic treatment of distillery spentwash – A study on upow anaerobic xed lm bioreactor. Bioresource Technology. 99(11) 4621–4626.
[16] Prakash N., V. Sockan. V. S. Raju,. 2014. An aerobic digestion of distillery spent wash,. APRN Journal of science and technology, 4(3) 2225 -7217
[17] . Patel H., Madamwar, D. 2002. Effects of temperatures and organic loading rates on biomethanation of acidic petrochemical wastewater using an anaerobic upow xed-lm reactor. Bioresource Technology, 82(1) 65–71.
[18] APHA . 2005. Standard Methods for the Examination of Water and Wastewater. 21st Edition, American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC
[19] Bhavik, K and Acharya, Hilor Pathak , Sarayu Mohana , Yogesh Shouche, Vasdev Singh. 2011. Kinetic modelling and microbial community assessment of anaerobic biphasic xed lm bioreactor treating distillery spent wash. Water Resarch, 45(14) 4248-4259.
[20] . Chapleur O., Mazie L, Gordon J, Bouchez T. 2016. Asymmetrical response of anaerobic digestion. Applied Environmental Microbiology. 100:1445–1457.
[21] Appels L., Baeyens J, Degréve J, Dewil R. 2008. Principles and potential of the anaerobic digestion of waste-activated sludge. Progress in Energy and Combustion Science. 34(6) 755-781.
[22] Muzaffar A., Athar Hussain and Chanchal Verma. 2016. Design considerations and operational performance of anaerobic digester: A review. Cogent Engineering.