Evaluation of Design Parameters for Secondary Aerobic Treatment of Anaerobically Digested Spent Wash based on Ultimate BOD

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Abstract - Spent wash is a waste water generated in distillery industry. It is a potential source of pollution if it is disposed off in streams or on land without proper treatments because of its high COD, BOD, TDS and low pH values. Present practice of spent wash treatment involves mainly anaerobic digestion , composting and incineration. The anaerobically digested spentwash also has high BOD, composting treatment is subject to availability of enough filler materials and techno economic viability is not assessed for incineration method. The secondary aerobic treatment is needed for further reduction of the pollution. Bench scale study is carried out in laboratory for the treatment of digested spentwash on the principles of extended aeration. The kinetic coefficients of the secondary treatment based on ultimate BOD are determined from the experimental study. The design parameters are evaluated based on these coefficients. The study showed optimum % BOD removal of 92 % at SRT of 18 days for HRT of 10 days with F/M ratio of 0.1. The results of the study are summarized in this paper.

Key Words:- **Spent wash, BOD, F/M ratio, MLVSS, Extended Aeration**

I. INTRODUCTION

Sugar industry is one of the major agro based industries in India. Molasses, a valuable waste / bye product of sugar industry, is fermented and alcohol is manufactured in the ancillary unit- distillery industry of almost all sugar industries. The distilleries produce a huge quantity of highly polluting waste called spentwash. Generally a distillery generates 15 litres of spent wash per litre alcohol produced [1]. The average characteristics of the anaerobically digested spent wash are shown in table **1**. Therefore, spent wash needs a further treatment for its safe disposal in the environment.

Due to very high organic content in the spent wash, favorable climatic conditions in India and methane gas recovery, anaerobic digestion is the primary treatment of spent wash. Sen and Bhaskaran [2] have reported BOD removal efficiency of 90 % for organic loading of 3.02 kg BOD/m^{3}d. However, though it has very good BOD reduction efficiency of about 80 to 87 % , the digested spentwash still has BOD of 6000 to 10000 mg/L which is much higher than the standards laid down by the pollution control boards for disposal either in streams or on land for irrigation. Huge volume of fresh water may be required for dilution of the digested spentwash to comply with the standards for disposal in streams or on land.

Composting of digested spentwash is a very good treatment as it gives almost zero liquid discharge . In this process, spentwash/ digested spentwash is mixed with filler material like press mud, bagasse cillo, rice husk, paddy straw etc maintaining suitable moisture and aerobic conditions. This mixture is converted into a very good manure, rich in N, P and K, in 20-30 days. Availability of sufficient filler material is major limiting factor in adopting this process. Besides this, it is ineffective in rainy days, needs more land and there is danger of ground water pollution due to seepage.

Concentration of spentwash to higher brix followed by incineration is another alternative treatment of spentwash. This is also called “Zero Pollution Treatment”. Inorganic dissolved solids, which cannot be removed by biological methods, get incinerated. Recovery of potassium salts from the ash which can be used as fertiliser is an additional benefit of this method. However, huge initial investments, recurring expenses and failures of machinery mainly due to clogging of boiler tubes are limitations of this method. The techno economic viability of the technology needs to be properly assessed.

In view of all above discussed methods, anaerobic digestion of spentwash, due to its energy discovery, followed by a secondary aerobic treatment on the principle of extended aeration is a rational approach to reduce pollution load. The effluent of secondary aerobic treatment may be used for irrigation with due care/ dilution.

Kinetics of biological growth plays very important role in all the biological treatments. The growth of microorganism in the reactor is directly related to the rate at which they utilize the organic matter in the waste. The kinetic coefficients and design parameters are well established for domestic waste, but not for spentwash which has very high pollution strength. Therefore, an effort has been made by conducting laboratory experiments on bench scale aeration tank reactor to determine the kinetic coefficients which are used to evaluate design parameters for the secondary aerobic treatment of anaerobically digested spentwash.

Table 1: Average characteristics of Anaerobically Digested Spent Wash

Sr No	**Important Characteristic**	**Value**
1.	pH	7.2 to 7.6
2.	COD	20000 to 28000
3.	BOD	5600 to 7000
4.	Total Solids	30000 to 350000
5.	Chlorides	4000 to 5000
6.	Sulphates	436
7.	Alkalinity	7675
8.	Volatile Acids	3000

Note: **All values are in mg/L except pH**

II. SECONDARY AEROBIC TREATMENT – ACTIVATED SLUDGE PROCESS

2. It is a biological treatment process that takes place in presence of oxygen. In this process, the microorganisms in suspension are responsible for conversion of organic matter in the waste to gases and new cell. Of many suspended growth aerobic treatments, activated sludge process (ASP) is the most commonly used method for secondary treatment of waste water. Arden and Locket [3] were the first to work with a biomass resembling what is presently known as activated sludge. They found that a well oxidised effluent could be obtained with aeration time of 6 to 9 hours. Although an attempt was not made to formulate aeration tank loading based on the waste strength, two very important principles were noted

(a) A higher strength waste required a longer time than lower strength waste to achieve the same effluent quality.

(b) An increase in the concentration of biomass decreased the aeration tank required to produce the desired effluent quality.

2.1 Various Design Parameters Of Activated Sludge Process

2.1.1 Aeration Time

Till 1940 only aeration time was considered in the design of aeration tank. Metcalf and Eddy[4] and other researchers have presented a direct relationship between the aeration time and BOD removal and had recommended an aeration time of 4 to 10 hours for domestic waste treatment. But the use of aeration time as a design parameter fails to consider organic loading and amount of biomass present in the reactor.

2.1.2 Organic Loading Per Unit Volume

This parameter had originated in Germany around 1930 by Karl Imhoff [3]. In 1943, Greeley[3] presented a relationship between organic loading (gm BOD/ m^3 d) and BOD removal. As the organic loading increased from 640 gm BOD/ m^3 d to 3800 gm BOD/ m^3 d the BOD removal decreased from 90 to 40 %. This parameter did not consider the amount of biomass in the reactor.

2.1.3 Organic Loading Per Unit Biomass

It is expressed as gm BOD/gm MLSS per day. Some references use MLVSS (Mixed Liquor Volatile Suspended Solids) in place of MLSS. This parameter attempts to relate the organic loading to the number of micro organisms available for the stabilization of the waste and is often referred to as food to micro organism ratio (F/M). In 1940 Sawyer [3] found that increasing MLSS concentration from 800 to 3200 mg/L caused BOD removal to increase from 84 to 97 % at a constant aeration time. In 1944 Okun [3] noted that the use of MLVSS data provided a better correlation between F/M ratio and BOD removal than the MLSS data. This parameter is generally considered to be more representative of the actual conditions in the reactor than other parameters.

2.2 Extended Aeration

Extended aeration is the modification of activated sludge process in which, the organic matter which is converted into new cells is also oxidised. The auto oxidation of the new cells is called 'Endogenous Respiration'. This process is used for certain industrial wastes having high organic strength like spent wash which otherwise may remain partially treated due to less aeration. The advantages are better quality effluent, less sludge production and no requirement of sludge treatment.

III. EXPERIMENTAL WORK

3.1 Materials And Methods

The experimental studies were carried out in a laboratory on bench scale aeration tank of 6.5 litres capacity. The photograph of experimental set-up is as shown in fig 1. The effluent from anaerobic digester was brought from Rajarambapu Patil Sahakari Sakhar Karkhana (RPSSK) Ltd Sakhrale, Dist Sangli, and was used as feed for its secondary aerobic treatment. The aeration was achieved by two fish aerators. The rate of oxygen transfer of the two aerators was experimentally determined and was found out to be 40.75 mg/hr.

Initially the reactor was filled with 5 liters of domestic sewage and was aerated for 24 hrs. Then, 2.5 liters of the sewage was replaced by 2.5 liters of the feed. After 5 days of aeration, 50 ml loading of the feed was started for 15 days keeping constant volume of 5 liters in the reactor. By this time there was enough growth of biomass which was acclimatised to the digested spentwash. The reactor was then operated over a range of organic loadings and F/M ratios to study COD and BOD reduction.

Fig 1. Photograph of Bench Scale Aeration Tank

The sludge removal and recycling was done only to maintain a constant MLSS in the reactor. The COD, pH of the influent and effluent was determined every day. The BOD of influent and effluent and MLSS of the reactor were analyzed at a regular interval of 5 to 6 days.

IV. RESULTS AND DISCUSSIONS

4.0 The average reactor monitoring data of aeration tank in the descending order of HRT is presented in table 2.

Table 2. Average reactor monitoring data in the descending order of HRT.

Sr No	HRT	INFLUENT CHARACTERISTICS				REACTOR CHARACTERISTICS				EFFLUENT CHARACTERISTICS			% REMOVAL	
	(Θ)	pH	COD	BOD	BOD	MLSS	MLVSS(X)	SVI	F/M	COD	BOD	pH	COD	BOD
	D		mg/L	mg/L	Kg/m^3.d	mg/L	mg/L			mg/L	mg/L			
1	20	7.3	22070	6250	0.3	6380	3509	29	0.15	9570	438	7.7	56.6	93
2	16.66	7.4	30353	6950	0.42	8120	4466	30	0.15	11548	520	8.5	62	92.5
3	14.28	7.3	24818	5600	0.42	5156	3094	23	0.15	12918	356	8.5	47.9	93.6
4	13.33	7.6	29407	6600	0.525	6243	3746	23	0.15	13754	603	8.6	53.2	90.9

5	10	7.6	28295	7300	0.7	6263	3758	13	0.2	15284	1103	8.8	46	84.9
6	6.66	7.4	28000	6800	1.05	7917	4354	25	0.3	15400	1100	8.4	45	83.8
7	6	7.2	19756	5950	1	7287	4008	11	0.3	11533	1183	8.5	41.6	80.1

4.1 Determination of Kinetic Coefficients k , Ks , Y and kd

Kinetic equations give an idea of the pattern of substrate removal or microbial growth. The equations of mass balance of microorganisms and substrate for completely mixed activated sludge process can be written as under [4, 6] ,

$$X\Theta / (So - S) = (Ks/ k) (1/S) + 1/k \quad \ldots. \quad (1)$$

and,

$$1/ \Theta = [Y (So - S) / X\Theta] - kd \quad \ldots. \quad (2)$$

Where,

X = Concentration of microorganisms in the reactor, MLVSS

Θ = Hydraulic Retention Time (HRT)

Θc = Solids Retention Time (SRT)

So and S = Substrate concentration of influent and effluent respectively, mg / L

Ks = Substrate concentration at half the maximum growth rate

K = Maximum rate of substrate utilization, per unit mass of microorganisms

Y = Maximum yield coefficient, Mass of cell formed per mass of substrate consumed.

Kd = Endogenous decay coefficient, per day

The computations required for determination of the kinetic coefficients on Ultimate BOD basis are done and are tabulated in table 3 .

Table 3. Computation Table To Determine Kinetic Coefficients Ks,k, Y and kd On Ultimate BOD Basis

Sr No	INFLUENT BOD		EFFLUENT BOD		So – S	XΘ	XΘ /(So-S)	$^1/_S$	$^1/_\Theta$
	BOD_5	BOD L	BOD_5	BOD L					
		(So)		(S)					
	mg/L	mg/L	mg/L	mg/L	mg/L	mg d /L	d	$(mg/L)^{-1}$	d^{-1}
1	6250	9191	438	644	8547	70180	8.21	0.0016	0.0500
2	6950	10220	520	765	9455	74403.56	7.87	0.0013	0.0600
3	5600	8235	356	524	7711	44182.32	5.73	0.0019	0.0700
4	6600	9706	603	887	8819	49934.18	5.66	0.0011	0.0750

5	7300	10735	1103	1622	9113	37580	4.12	0.0006	0.1000
6	6800	10000	1100	1618	8382	28997.64	3.46	0.0006	0.1502
7	5950	8750	1183	1740	7010	24048	3.43	0.0006	0.1667

From the computation table and equation (1), if the term XΘ / (So – S) is plotted against the term 1/S as shown in fig 2, Ks/ k will be equal to the slope of the curve and 1/k will be equal to the ordinate intercept .

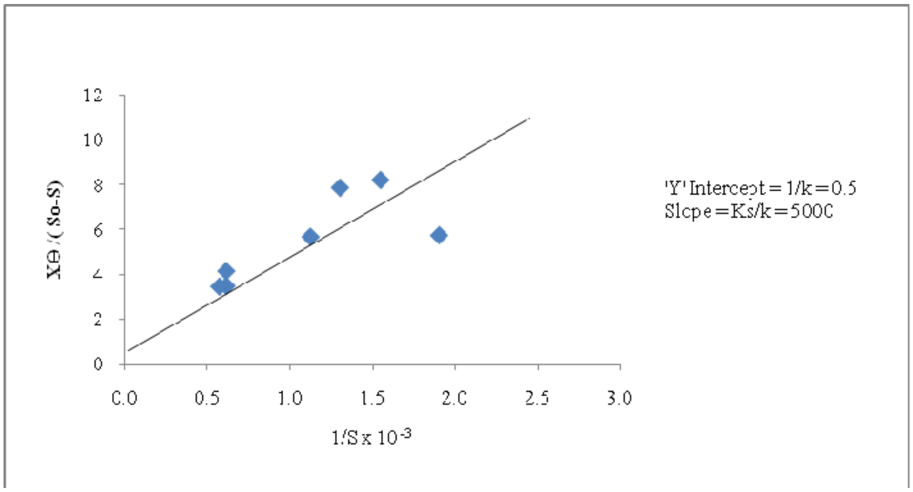

Fig 2 . Plot of Experimental Data to Determine the Kinetic Coefficients Ks and k

From fig 2., 1/ k = 0.5 and Ks/k = 5000

Therefore, k = 2 per day and Ks = 10000 mg/L

From equation (2), if the term 1/Θ is plotted against the term (So-S)/ XΘ as shown in fig 3, Y will be equal to the slope of the curve and kd will be equal to the ordinate intercept .

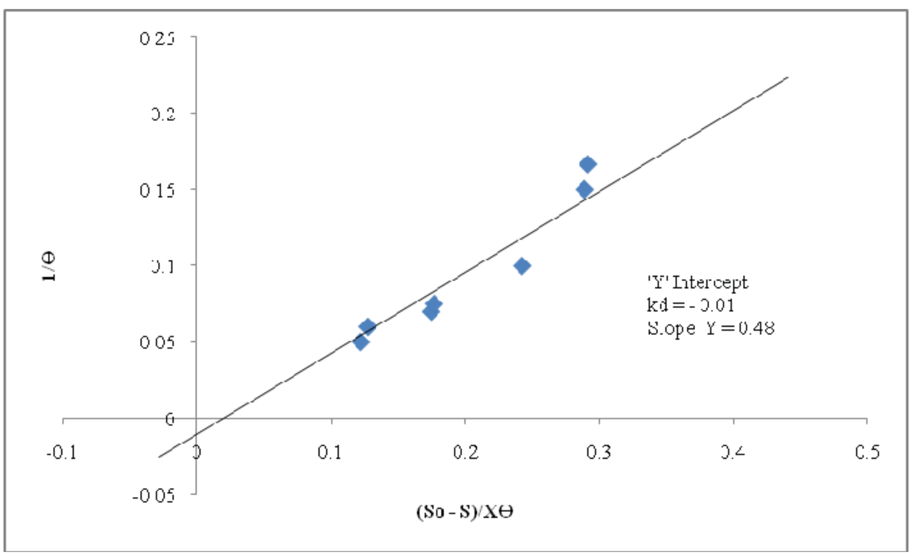

Fig 3. Plot of Experimental Data to Determine the Kinetic Coefficients Y and kd

From fig 3. Y = slope of the curve = 0.48 and kd = ordinate intercept = 0.01 per day

4.2 Evaluation of the Design Parameters

Considering the BOD of digested spentwash as 6000 mg/L and taking values of all the kinetic coefficients that are determined from the experiments as **K= 2 per day, Ks= 10000mg/l, Y=0.48 and Kd=0.01 per day,** the BOD removal efficiency is computed theoretically at different values of SRT (Θc). The MLVSS required for the same at different values of HRTs (Θ) are also calculated as per equations (3 , 4 & 5) . All the computations , required for evaluating the optimum value of important design parameter Θc and other dependent parameters, are shown in the table 4.

$$X = \Theta c \,.\, Y (So - S)/ [\Theta (1 + Kd\, \Theta)] \qquad \ldots(3)$$

Where,

$$S = U\, Ks \;/\; (K - U) \qquad \ldots (4)$$

and

$$U = (Kd\, \Theta c + 1) \;/\; (Y\, \Theta c) \qquad \ldots(5)$$

Table 4: Computations required for evaluation of Design Parameters

SRT	U	S	% Efficiency	X in mg /L at various HRT (Θ) days								XΘ
				4	6	8	10	12	14	16	18	at Θ=10 d
8	0.2813	1636	81	6633	4338	3194	2508	2053	1729	1487	1299	25080
10	0.2292	1294	85	8686	5681	4182	3285	2689	2264	1947	1701	32850
12	0.1944	1077	88	10724	7014	5163	4056	3319	2795	2404	2100	40560
14	0.1696	927	89	12754	8342	6141	4823	3948	3324	2859	2498	48230
16	0.1510	817	91	14778	9666	7116	5589	4574	3852	3312	2894	55890
18	0.1366	733	92	16800	10989	8089	6354	5200	4379	3766	3290	63540
20	0.1250	667	92	18820	12310	9061	7117	5825	4905	4218	3686	71170
22	0.1155	613	93	20838	13630	10033	7881	6450	5431	4671	4081	78810
24	0.1076	569	94	22855	14949	11004	8643	7074	5957	5123	4476	86430
26	0.1010	532	94	24871	16268	11975	9406	7698	6483	5574	4871	94060
28	0.0952	500	94	26886	17586	12945	10168	8322	7008	6026	5266	101680
30	0.0903	473	95	28901	18904	13915	10930	8946	7533	6478	5660	109300

For evaluating the design parameters of the secondary aerobic treatment, following constraints are imposed

i) BOD removal should be optimum
ii) MLVSS is restricted to 6500 mg/L so as to keep the problem of sludge bulking in control.

In view of the above imposed constraints, all the combinations of parameters Θ and Θc for which the computed values of MLVSS are beyond 6500 mg/L (shown in red) in the table 4, are not desirable and hence are not considered. The parameter SRT (Θc) can be determined for HRT Θ of 10 days. The variation of % BOD removal with respect to XΘ and SRT (Θc) are shown in fig 4 and fig 5 respectively.

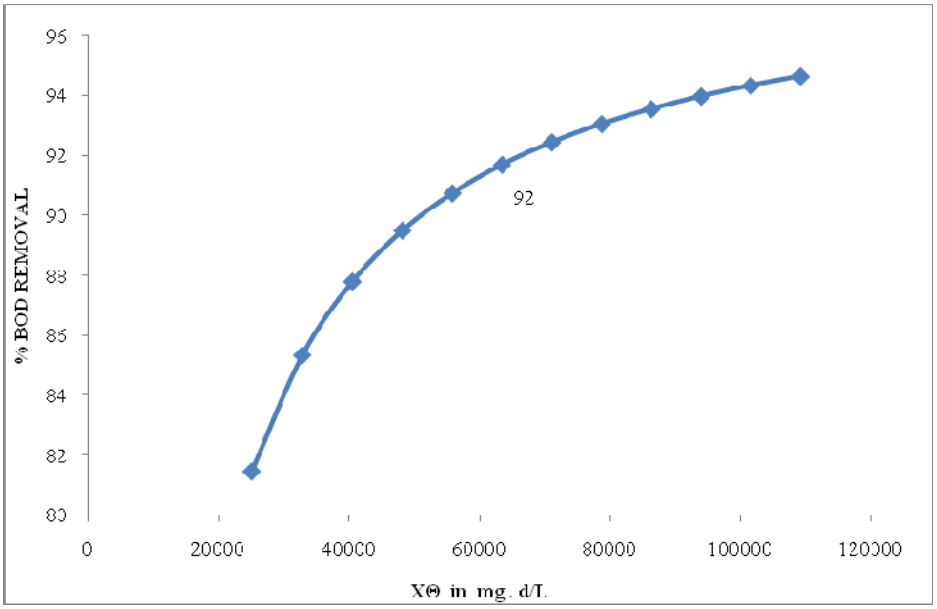

Fig 4 : Variation of % BOD removal with XΘ

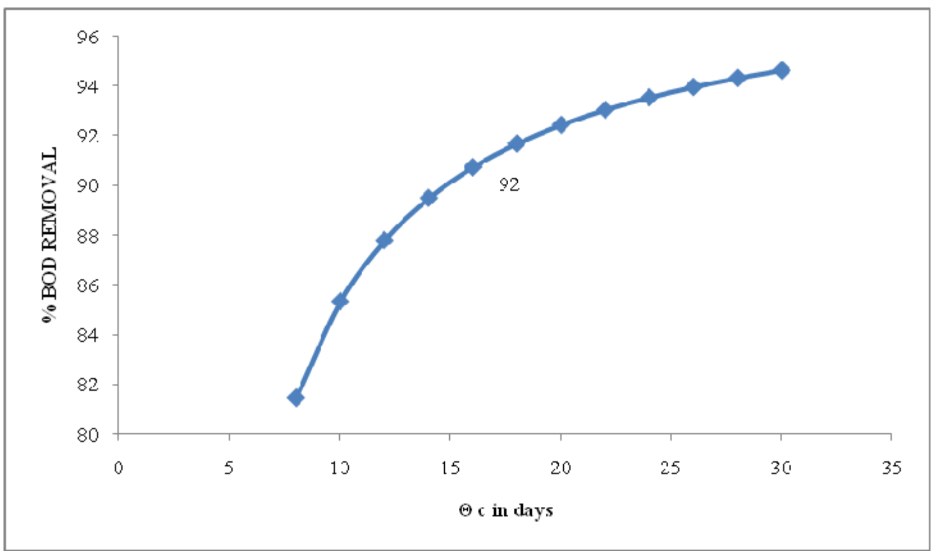

Fig 5 : Variation of % BOD removal with Θc

i) It is seen from the fig 4 that the optimum % BOD removal is 92 % because, with any further increase in XΘ, there is very small increment in % BOD removal.
ii) The SRT for optimum % BOD removal of 92 % is 18 days as seen from fig 5.
iii) The actual % BOD removal and theoretical % BOD removal are comparable as seen from table 2 and table 4.

Considering the BOD of digested spentwash as 6000mg/L and MLVSS as 6000mg/L, the design parameters for the secondary aerobic treatment are as follows

i) MLVSS	=	6000 mg/L
ii) F/M kg BOD/kg MLVSS	=	0.1
iii) Hydraulic Retention Time Θ	=	10 days
iv) Solids Retention Time Θc	=	18 days

V. CONCLUSIONS

1 The kinetic coefficients for anaerobically digested spentwash obtained from the experiments(on ultimate BOD basis) are k = 2 per day , Ks = 10000 mg/L , Y = 0.48 and kd = 0.01 per day
2 These kinetic coefficients are used for evaluating the design parameters for the secondary aerobic treatment of anaerobically digested spentwash . They are MLVSS = 6000mg/L, F/M = 0.1, HRT = 10 days and SRT = 18 days.
3 The actual and theoretical % BOD removal are comparable with variation of % BOD removal in the range of 80 % to 93% with SRT between 8 days to 30 days. However the optimum % BOD removal is 92 % at SRT of 18 days.
4 The anaerobically digested spentwash can be treated on the principles of extended aeration in secondary aerobic treatment. Though the BOD of the effluent after the secondary aerobic treatment is still slightly higher than the disposal standards for BOD [7], it can be used for irrigation with dilution.
5 Two stage activated sludge system may be used with bigger $\Theta c/\Theta$ ratio in the second stage for further reduction of BOD .

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