HANDLING SHOCK LOADS OF BOD IN WASTEWATER TREATMENT

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1.Introduction:

Generally, the performance of any wastewater treatment system is heavily influenced by the ability of the treatment system to remove the BOD, which largely depends on the kinetics of microbial growth and system operating parameters such as HRT, SRT and F/M. However, shock loads[1] have the potential to upset the performance of the wastewater treatment plant. The reason being that, even well equalised effluent may pose shocks to the treatment system – since conventional equalisation is mainly designed to handle variations in flow. Flow equalisation does not consider variability in the influent concentration of BOD. Shock loads arise from two different sources where i) the level of BOD changes without a significant change in the nature of the organics present in the effluent; ii) the nature of organics present in the effluent changes but the level of BOD does not vary much. A well-designed treatment system should be able to handle both these scenarios. Shock loads are quite common in any wastewater treatment plant, and care should be taken to avoid plant upsets.

It is possible to construct an equalising tank where sufficient time is given for the effluent parameters to shed-off their fluctuations and settle down to some background value to which the biological treatment unit is optimised to operate. But, in a treatment facility where more than one industrial unit discharges the effluent (like in the case of collective treatment of effluent in a Common Effluent Treatment Plant), the time profile of effluent BOD shall go on changing. Under such a scenario, two different cases can be considered: i) there is a surge (single pulse) in the concentration of a constituent and that vanishes after a very short time; ii) a damp (single pulse) that appear momentarily. The problem shall become more complex if we have multiple pulses. However, in order to have a basic understanding here I consider only two simple scenarios.

1 Shock is classified here as *surge* and *damp; surge* is a sudden increase in the concentration of constituents in the influent whereas *damp* is a sudden decrease in the concentration of the constituents.

1.1 Single pulse surge:

Assume that at time t=0, the wastewater in a *continuous flow equalisation tank*[2] is completely mixed and remain homogeneous. Let the concentration of BOD in the tank to be Δ (mg/L). At this moment, a *surge*[3] occurs in the feed quality that tends to change the concentration of BOD in the wastewater being equalised. Provided that influent is instantly mixed in the equalisation tank[4], the effect of *surge* on the quality of the effluent can be given by the following equation:

$$(C + \nabla) = C_o \exp(-t/\tau) \qquad (1.1)$$

where,

∇	=	Background steady-state concentration of BOD (mg/L) in the equalisation tank before the shock occurred[5].
C	=	Concentration of BOD remaining in the equalisation tank after time *t* (mg/L).
C_o	=	Initial concentration of BOD in the equalisation tank after the *surge* occurred (mg/L) [Note: instantaneous complete-mixing is a pre-condition here].
t	=	Time elapsed after the *surge* (*hour*)
τ	=	Theoretical detention time in hours (=V/Q; where V = volume of the equalisation tank (L) and Q = volumetric flow rate (L/hour).

Now, looking at Table-1, it is understood that when the elapsed time $t < \tau$ (the theoretical detention time) - most of the constituent supplied during the *surge* remains within the

2 Continuous flow equalisation tank is defined here as the one where inflow and outflow remains equal and constant with time.

3 As already mentioned, *surge* is defined here as an increase in the concentration of anyone of the constituents in the influent within a short span of time, where after it disappears. Thus, this is a transient process. For the following mathematical description, it is necessary that this constituent should be *non-reactive* (*i.e.*, *conservative*) within the equalisation tank. For all practical purposes, TDS can be considered conservative; pH, BOD and COD can be considered conservative only if the detention time in the equalisation tank is minimal so that the effect of microbial growth on their levels remain insignificant.

4 Instantaneous mixing is practically impossible to achieve. However, for simplification here I consider the case of instantaneous mixing within equalisation tank. Albeit, a good design should incorporates multiple injection points inside the equalisation tank at a fixed depth to achieve fast and homogeneous mixing.

5 Due to variability in the nature of the influent, ∇ may vary from time to time. For all practical purposes, the mean concentration of the constituent in the equalisation tank can be taken. It is not necessary that ∇ should have any value greater than zero. It may even be equal to zero. If ∇ is zero at time *t*=0, then it's value after certain period represents the built up of the constituent in question due to the effect of a surge that brought this particular constituent to the equalisation tank.

equalisation tank. At one τ period, about 63% of the constituent is removed and within 3τ period, 95% of the constituent in the equalisation tank is removed. If HRT of the BOD removal unit is less than 3τ, the shock shall be passed out. Instead, if the HRT of the BOD removal unit is higher than 3τ, then the shock is properly handled by the BOD removal process.

1.2 Single pulse damp:

If the shock is to bring a sudden decrease in the concentration of any constituent (*damp*) then, the concentration of the constituent in the equalisation tank returns to normal according to the equation (1.2):

$$C = C_o\,[1 - \exp(-t/\tau)] \qquad (1.2)$$

where,

C	=	Concentration of BOD remaining in the equalisation tank after time *t* (mg/L).
C_o	=	Concentration of BOD in the equalisation tank just after the *damp* occurred (mg/L).
t	=	Time elapsed after the *damp* (*hour*)
τ	=	Theoretical detention time in hours (=V/Q; where V = volume of the equalisation tank (L) and Q = volumetric flow rate (L/hour).

After a damp, the BOD concentration returns to 63% of its earlier value within one τ period; within 3τ period, the concentration of the constituent is restored to 95% of its value before the *damp* occurred. But these things apply only when influent concentration of BOD returned to the steady-state concentration of BOD in the equalisation tank before the surge/damp occurred. But, in practise, the concentration of the BOD in the influent is expected to vary. Then, the time profile of BOD does exhibit fluctuations and it dose not follow a simple equation. Such kind of uncertainty can be solved if we have two equalisation tanks operating in cycles to collect the effluent in batch mode. The calculations given here are a first approximation to solve the problems associated with shock loads. A realistic picture of the situation can be obtained by considering the kinetics of biodegradation of organics in the BOD removal unit along with the equalisation process.

It should be noted here that removal of shock load of BOD is only dependent on the V/Q ratio and not tank size[6]. Thus, for any equalisation tank, if the V/Q ratio (τ) is small, then the ability to dampen the surge is lower. On the contrary, if the V/Q ratio (τ) is large, the constituent that arrived to the equalisation tank in a surge is retained for a longer time.

There is a remarkable advantage in setting up equalisation tanks in series as illustrated in Table-2. For example, assume a BOD surge of 100 mg/L above the background value at time t_0. If equalisation tank detention time is 1 hour and instantaneous mixing is assumed, at a time of $t_{(0+1)}$ hour, the concentration of BOD in the first equalisation tank effluent (outlet) is 63 mg/L in excess of the background value. Similarly, at the end of 1 hour since the occurrence of shock, the concentration profiles of excess BOD in the effluent of 2nd, 3rd, 4th and 5th tanks are 40, 25, 16 and 10 mg/L, respectively. The concentration profiles of BOD in the equalisation effluent for various times are provided in Table-3 for $\tau = 1$ hour, and depicted in Fig.1. It takes 5 hours to pass around 95% of the shock to the treatment system. Since shock loads are delayed, the BOD removal unit shall have more time to digest excess BOD. Thus, process upset can be avoided.

For all practical purposes, the surge frequency (S_f) should be lesser than $1/3\tau$ so that 95% of the constituent is removed before any other surge occurs (Table-1)[7].

$$S_f \leq 1/3\tau \qquad (1.3)$$

In order to ensure that such a *surge* or *damp* occurs at a frequency lesser than $1/3\tau$, preliminary study should be conducted in the receiving end by collecting the influent samples at specific sampling interval (i). This sampling interval (i) should never be greater than τ – but most ostensibly it is required to have the condition $i \leq ½\ \tau$ being met to ensure that no *surge/damp* has gone undetected[8].

6 This concept provide an opportunity to design a compartmentalised equalisation tank, where each compartment is connected in series. Each compartment receives equalised effluent from the previous tank, suppress the surge/damp and pass on it to the next compartment. In this way the variability of the quality of equalised effluent at the end is highly minimised. Any building up or, diminishing levels of any constituent after equalisation is only gradual. Thus, short-term variability is minimised while long-term variability still remains the same. It should be mentioned here that total volume of all such compartments is still equal to a single high capacity equalisation tank – but control on variability is higher with compartmentalised equalisation tank whereas it is very low with a single equalisation tank.

7 The remaining 5% constituent shall build up in the equalisation tank. However, the damps that follow each surge is expected to nullify the effect of this accumulation.

8 This condition is necessary if no surge should escape detection under blind sampling (*blind sampling* is a

Table-1: The relationship between elapsed time, time constant (τ = V/Q) and % of constituent remaining in the equalisation tank after the surge occurred.

S.No	Time (t)	τ (V/Q)[9]	Exponent	% past	% retained	τ / t
1	0.000	1	1.000	0	100	Undefined
2	0.250	1	0.779	-22.12	77.88	4.00
3	0.500	1	0.607	-39.35	60.65	2.00
4	0.750	1	0.472	-52.76	47.24	1.33
5	1.000	1	0.368	-63.21	36.79	1.00
6	1.250	1	0.287	-71.35	28.65	0.80
7	1.500	1	0.223	-77.69	22.31	0.67
8	1.750	1	0.174	-82.62	17.38	0.57
9	2.000	1	0.135	-86.47	13.53	0.50
10	2.250	1	0.105	-89.46	10.54	0.44
11	2.500	1	0.082	-91.79	8.21	0.40
12	2.750	1	0.064	-93.61	6.39	0.36
13	3.000	1	0.050	-95.02	4.98	0.33
14	3.250	1	0.039	-96.12	3.88	0.31
15	3.500	1	0.030	-96.98	3.02	0.29
16	3.750	1	0.024	-97.65	2.35	0.27
17	4.000	1	0.018	-98.17	1.83	0.25
18	4.250	1	0.014	-98.57	1.43	0.24
19	4.500	1	0.011	-98.89	1.11	0.22
20	4.750	1	0.009	-99.13	0.87	0.21
21	5.000	1	0.007	-99.33	0.67	0.20
22	5.250	1	0.005	-99.48	0.52	0.19
23	5.500	1	0.004	-99.59	0.41	0.18
24	5.750	1	0.003	-99.68	0.32	0.17

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method whereby the moment of occurrence of an event to be observed is unknown before sampling is carried out; the chances are that such an event could have happened at any moment before sampling commenced). Consider an example where the sample is taken just after the traces of a surge have vanished from the equalisation tank. If the sampling frequency (S_f) is equivalent to 1/τ, then the next sample shall be taken when the next surge have just disappeared. However, shocks in effluent characteristics are random processes, and can not be assumed to occur at equal intervals, which is the assumption of the above discussion. For more robust discussion, a good reading on S*ampling Theory* is essential along with good exposure to *Probability.*

9 Please note that the actual value of τ =V/Q may be different from 1; However, here I consider time (t) as a fraction or multiple of τ; so, the value given by V/Q is taken as unity, and time is measured as a fraction or, multiple of τ.

Table-2: Shock handling by single and multiple stage equalisation tanks fot t = 1 hour.									
		Single stage		Multiple stages in series					
τ (=V/Q)	exp (-t/τ)	Shock	Shock	Shock passed					Total shock
HRT		retained	passed	C_1	C_2	C_3	C_4	C_5	retention
(hours)		C (%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1	0.37	36.79	63.21	63.21	39.96	25.26	15.97	10.09	89.91
2	0.61	60.65	39.35	39.35	15.48	6.09	2.40	0.94	99.06
3	0.72	71.65	28.35	28.35	8.04	2.28	0.65	0.18	99.82
4	0.78	77.88	22.12	22.12	4.89	1.08	0.24	0.05	99.95
5	0.82	81.87	18.13	18.13	3.29	0.60	0.11	0.02	99.98
6	0.85	84.65	15.35	15.35	2.36	0.36	0.06	0.01	99.99
7	0.87	86.69	13.31	13.31	1.77	0.24	0.03	0.00	100.00
8	0.88	88.25	11.75	11.75	1.38	0.16	0.02	0.00	100.00
9	0.89	89.48	10.52	10.52	1.11	0.12	0.01	0.00	100.00
10	0.90	90.48	9.52	9.52	0.91	0.09	0.01	0.00	100.00
11	0.91	91.31	8.69	8.69	0.76	0.07	0.01	0.00	100.00
12	0.92	92.00	8.00	8.00	0.64	0.05	0.00	0.00	100.00
13	0.93	92.60	7.40	7.40	0.55	0.04	0.00	0.00	100.00
14	0.93	93.11	6.89	6.89	0.48	0.03	0.00	0.00	100.00
15	0.94	93.55	6.45	6.45	0.42	0.03	0.00	0.00	100.00
16	0.94	93.94	6.06	6.06	0.37	0.02	0.00	0.00	100.00
17	0.94	94.29	5.71	5.71	0.33	0.02	0.00	0.00	100.00
18	0.95	94.60	5.40	5.40	0.29	0.02	0.00	0.00	100.00
19	0.95	94.87	5.13	5.13	0.26	0.01	0.00	0.00	100.00
20	0.95	95.12	4.88	4.88	0.24	0.01	0.00	0.00	100.00
21	0.95	95.35	4.65	4.65	0.22	0.01	0.00	0.00	100.00
22	0.96	95.56	4.44	4.44	0.20	0.01	0.00	0.00	100.00
23	0.96	95.75	4.25	4.25	0.18	0.01	0.00	0.00	100.00
24	0.96	95.92	4.08	4.08	0.17	0.01	0.00	0.00	100.00
25	0.96	96.08	3.92	3.92	0.15	0.01	0.00	0.00	100.00

Table-3: Retention of BOD in multiple stage equalisation tanks in series (τ = V/Q = HRT = 1 hour)

	1st stage		2nd stage		3rd stage		4th stage		5th stage	
Time (t) (hour)	Retained (%)	Left (%)	Retained (%)	Left (%)	Retained (%)	Left (%)	Retained (%)	Left (%)	Retained (%)	Left (%)
0.00	100	0	0	0	0	0	0	0	0	0
0.08	92	8	7.36	0.64	0.59	0.05	0.05	0	0	0
0.17	84.65	15.35	13	2.36	1.99	0.36	0.31	0.06	0.05	0.01
0.25	77.88	22.12	17.23	4.89	3.81	1.08	0.84	0.24	0.19	0.05
0.33	71.65	28.35	20.31	8.04	5.76	2.28	1.63	0.65	0.46	0.18
0.42	65.92	34.08	22.46	11.61	7.65	3.96	2.61	1.35	0.89	0.46
0.50	60.65	39.35	23.87	15.48	9.39	6.09	3.69	2.4	1.45	0.94
0.58	55.8	44.2	24.66	19.53	10.9	8.63	4.82	3.82	2.13	1.69
0.67	51.34	48.66	24.98	23.68	12.16	11.52	5.91	5.61	2.88	2.73
0.75	47.24	52.76	24.92	27.84	13.15	14.69	6.94	7.75	3.66	4.09
0.83	43.46	56.54	24.57	31.97	13.89	18.07	7.86	10.22	4.44	5.78
0.92	39.98	60.02	24	36.02	14.4	21.62	8.64	12.97	5.19	7.79
1.00	36.79	63.21	23.25	39.96	14.7	25.26	9.29	15.97	5.87	10.09
1.50	22.31	77.69	17.33	60.35	13.47	46.89	10.46	36.42	8.13	28.3
2.00	13.53	86.47	11.7	74.76	10.12	64.65	8.75	55.9	7.56	48.33
2.50	8.21	91.79	7.53	84.26	6.92	77.34	6.35	70.99	5.83	65.16
3.00	4.98	95.02	4.73	90.29	4.5	85.8	4.27	81.52	4.06	77.46
3.50	3.02	96.98	2.93	94.05	2.84	91.21	2.75	88.46	2.67	85.79
4.00	1.83	98.17	1.8	96.37	1.77	94.61	1.73	92.87	1.7	91.17
4.50	1.11	98.89	1.1	97.79	1.09	96.7	1.07	95.63	1.06	94.57
5.00	0.67	99.33	0.67	98.66	0.66	97.99	0.66	97.33	0.66	96.68

Fig.1: Propagation of BOD shock in serially connected equailisation tanks.