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SCIENTIFIC PAPER

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THE EFFECT OF THE SLUDGE RECYCLE RATIO IN AN ACTIVATED SLUDGE SYSTEM FOR THE TREATMENT OF AMOL'S INDUSTRIAL PARK WASTEWATER

An activated sludge aeration tank and a sedimentation basin were used to treat Amol's industrial park effluents originating from all industrial units. A continuous system was implemented and the kinetic parameters were measured. The parameters such as rate constant, substrate utilization rate constant, yield and decay coefficient were 2.12 d^{-1}, 232.4 mg l^{-1}, 0.33 g/g of substrate and 0.096 d^{-1}, respectively. The hydraulic retention times (HRT) were in the range of 9 to 27 h. The sludge recycle ratios in the range from 0.3 to 1 were considered. The COD removal, SVI and DO were determined and the optimal values were obtained. It was observed that at HRT of 16 h and the sludge recycle ratio of 0.85, the COD removal and SVI were 95 and 85 %, respectively. The sludge recycle ratio greater than 0.85 had no significant effect on the COD removal.

Key words: activated sludge; COD removal; industrial effluents; sludge recycle ratio; SVI.

The water shortage around the world is more severe and also greater attention is paid to reuse wastewater from municipalities and industrial plants [1,2]. Both municipal and industrial wastewaters are often treated aerobically by an activated sludge process [3-6]. The activated sludge process is widely used for the wastewater treatment, as it is reliable, efficient and capable of producing high quality effluent and is also, comprised of a biological reactor along with a secondary clarifier [7-11]. This process is extensively considered as a secondary wastewater treatment [12,13]. The microorganisms perform oxidation/reduction of biochemical reactions to generate the energy for the cell growth and the maintenance [13,14]. The conventional activated sludge and extended aeration have high removal efficiencies for ammonia, TSS, COD and BOD_5 and produce(d) good quality final effluents for the ultimate disposal in accordance with the discharge standard [15-17].

The performance of the activated sludge process was influenced by the sludge recycle ratio as the fresh influents were diluted with the recycle and active biomass in the aeration basin. The biomass activities were directly related to the availability of oxygen [18-20]. DO is depleted by increasing the recycle ratio. It should be considered that the power of the diffusers and agitation may act very influentially as the process was mass transfer limited [21,22]. Other potential biological processes were used for the treatment of the industrial wastewater [23-27].

The main purpose of this work was to evaluate the performance of the actual system for the biological treatment and the removal of pollutants from the industrials effluents. Two operational parameters such as hydraulic retention time (HRT) and the sludge recycle ratio were investigated.

MATERIAL AND METHODS

Amol's Industrial Park is located in the southern part of Amol in the province of Mazandaran, Iran. This Park is constructed on the 20 hectare land. It contains more than 70 industrial plants including poultry, meat, dairy product and fruit juice processing, paperboard factory, glass making, tomato cannery and many other plants. The effluents from all plants were collected by the gravity collection system and discharged to the wastewater treatment plant (WWTP). Significant variations in the composition of the wastewater arising

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from a cluster of industries have created difficulties in ensuring the efficiency and the effectiveness of the WWTP. But it is economical to have just one plant for the entire Park instead of designing and constructing a number of treatment plants for any specified industry. Most of wastewaters are readily degradable, a portion of the BOD is rapidly adsorbed and the remainder removed as a function of time and biological solids concentration [28]. The chemical industries have great potential to generate the most complex and polluted effluents. The wastes may be solid and liquid. The solids were removed from wastewater by screening and grit removal chamber. The wastewater was sent to a degreasing unit to remove oil and grease and then pumped into an equalization tank to regulate the pH level of the wastewater. Then, the wastewater was channeled to a biological unit operation. This unit consisted of two anaerobic tanks including plastic media and two aerobic tanks. The plant is using an extended aeration system in an aeration part. The conventional activated sludge and the extended aeration had higher removal efficiencies for ammonia, TSS, COD and BOD_5 and produced good quality final effluents for the ultimate disposal in accordance with the discharge standard [28]. In other resources the maximum COD removal for these sorts of plants is about 95 to 98 % [9]. After the biological treatment, the mixture is discharged to a sedimenttation tank. Sludge is settled and the treated effluent will be discharged to the chlorination tank and then to a branch of the Haraz river near the plant. A simplified scheme of the plant is presented in Figure 1. Beside the plant, a small research lab was assigned to monitor the performance of the plant. This industrial town is developing and demands for the wastewater treatment are increasing. This research was conducted in order to enhance the efficiency of the plant by decreasing its HRT and to obtain the optimum treatment by investigating the recycle ratio of the activated sludge which was not performed before. At optimum recycle ratio, a good performance with maximum efficiencies is achieved.

The wastewater was characterized and the summary of the characterization is shown in Table 1. About 88 % of the effluents were originated from food processing plants. Inlet wastewater characteristics differed during the day operating period. However, the average parameters were measured for the evaluation of the plant's efficiency and also for the purpose of treating the wastewater. The average characterristics of the inlet wastewater are demonstrated in Table 2.

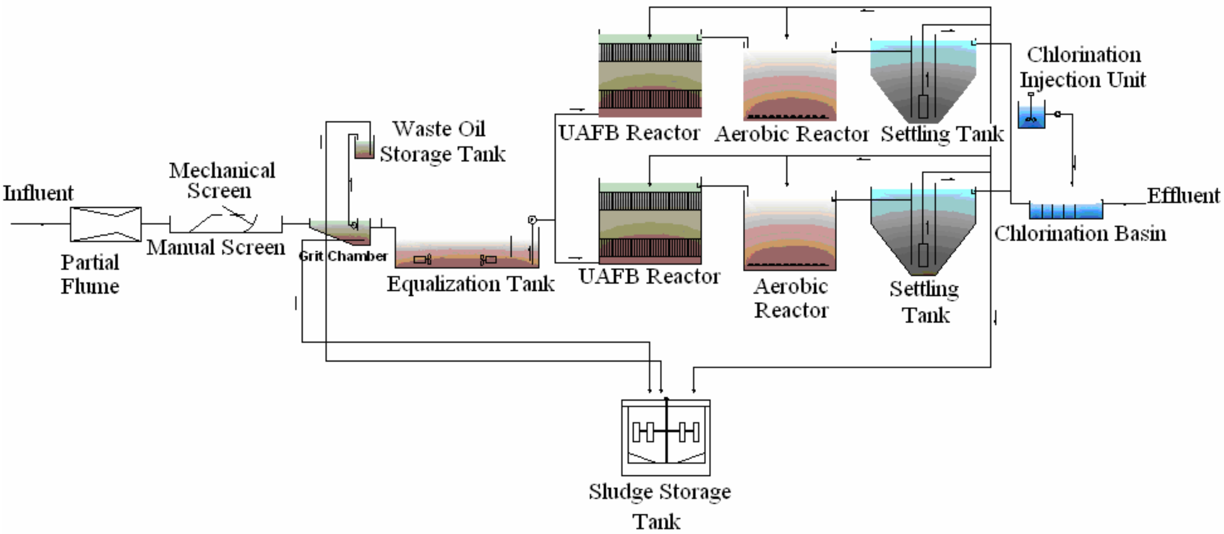

Figure 1: Amol industrial town's WWTP plant.

Table 1. The characteristics of the industrial units connected to the Amol's industrial park wastewater collection system

Industry type	Number of industries	Average flow $m^3\ d^{-1}$	Average *COD* $mg\ l^{-1}$	Total pollution $kg\ d^{-1}$	Pollution %
Chemical	15	2.65	2200	87450	4.6
Food processing	27	25	2500	1687500	88
Non metallic mineral	6	5.35	600	19260	1
Metallic	13	2.41	600	18798	1
Electronic	2	5.04	600	6048	0.4
Cellulose	5	3.06	3200	49600	3
Textile	5	7.23	1000	36150	2

Table 2. The average characteristics of the inlet wastewater

Parameter	Flow rate m^3/d	pH	*TSS* mg l^{-1}	*BOD* mg l^{-1}	*COD* mg l^{-1}
Value	450-650	4.5-6.5	400-500	1000	2000

A system of a feed tank, an aeration activated sludge tank and a sedimentation tank was used in a lab scale at WWTP. The feed tank had a working volume of 100 l, the wastewater was obtained from the plant's influent during the day and the sample was mixed and fed to the aeration tank. The wastewater was transferred to the aeration tank by a peristaltic pump which had the ability to control the wastewater flow rate. The aeration tank had the volume of 30 l which was controlled by a weir at the level of 30 l. The sedimentation tank was designed in a conical shape to collect the sludge from the treated wastewater. The sludge was recycled by another peristaltic pump in order to manage the sludge flow. The reactor was maintained at room temperature of 27 °C.

The feed flow rate (Q_f), hydraulic retention time (*HRT*) and the sludge recycle ratio (*R*) varied during the various sets of experiments. The expressions for the sludge recycle ratio and *HRT* are given below [5]:

$$R = \frac{Q_r}{Q_f} \tag{1}$$

where Q_r is the recycle sludge flow (l h^{-1}). The hydraulic retention time is defined as:

$$HRT = \frac{\text{Volume of aeration tank}}{\text{Feed flow rate}} \tag{2}$$

The details for experimental runs, the reactor *HRT* and the sludge recycle ratio are summarized in Table 3. During each experimental run, a continuous system was operated for two to three folds of the *HRT* value in order to obtain the steady state condition and then samples were withdrawn to perform the analysis [21]. The experiments were carried out for sufficient data collection. Each set of the experiment was involved with a variable sludge recycle ratio. The sludge recycle ratios varied from 0.3 to 1.1 while the *HRT* was fixed, and then the *HRT* values varied from 8 to 28 h, with the fixed sludge ratio. The performance of the activated sludge system was evaluated by the following process parameters [5]:

$$\text{Removal efficiency (\%)} = \frac{100(S_0 - S)}{S_0} \tag{3}$$

Table 3. The details of experimental runs

HRT / h	Recycle ratio, *R*	*COD* / mg l^{-1}		Removal, %	*MLSS* / mg l^{-1}	*SVI*	*DO* / mg l^{-1}
		Influent	Effluent				
Set 1							
9	0.3	1800	300	83	3700	82	5.5
9	0.5	1740	163	90.6	5000	108	4.5
9	0.8	1690	125	92.6	5320	141	4.4
9	0.9	1761	109	93.8	5800	155	4.2
9	1	1583	94	94	5900	164	3.8
Set 2							
11	0.3	1850	203	89	4100	73	5.2
11	0.5	1900	160	91.5	5068	77	4.5
11	0.8	1780	120	93.2	7672	89	2.5
11	0.9	1820	110	93.9	7900	95	2
11	1	1800	95	94.7	8010	102	1.5
Set 3							
16	0.3	1750	172	90.2	5120	63	4.5
16	0.5	2050	170	91.7	5760	67	4.2
16	0.8	1950	100	94.8	5900	75	3.5
16	0.9	1900	95	95	7560	86	2.2
16	1	1800	75	96	7900	90	1.6
Set 4							
23	0.3	1750	140	92	6050	79	3.2
23	0.5	1785	90	95	6116	90	3.2
23	0.8	1806	88	95.1	6300	103	3
23	0.9	1850	75	95.9	6700	107	2.8
23	1	1650	60	96.3	7050	111	2.7

$$SVI = \frac{1000V}{MLSS} \quad (4)$$

where the variable V stands for the volume of the sludge settled during 30 min in a 1000 ml of Imhoff cone (ml); the S_0 is influent concentration of the pollutant (mg l^{-1}) and $MLVSS$ is the mixed liquor suspended solid in an aeration tank (mg l^{-1}). The specific substrate utilization rate (mg COD mg^{-1} X d^{-1}) is expressed in the following equation:

$$U = \frac{S_0 - S}{\theta_H X} \quad (5)$$

where the variable θ_H stands for the hydraulic retention time (HRT, d) and X is the biomass concentration or it may represent(s) the mixed liquor volatile suspended solids ($MLVSS$, mg l^{-1}). To make the data fit in to the linear equation, the double reciprocal form of the specific growth is written by the following equation [5]:

$$\frac{1}{U} = \frac{k_s}{kS_e} + \frac{1}{k} \quad (6)$$

where the S_e is the effluent concentration of the pollutant (mg l^{-1}); k_s is the saturation constant for COD removal (mg l^{-1}) and k is the maximum specific rate constant for COD removal (d^{-1}). The sludge retention time is expressed as a function of the process yield, as shown in Equ. (7):

$$\frac{1}{SRT} = Yu - k_d \quad (7)$$

where Y is the maximum growth yield coefficient (g X g^{-1} S) and k_d is the death rate constant (d^{-1}). This equation is applied either in recycle or for the system of non-recycled aeration tank [12,13].

Feed samples and the filtered effluent from the clarifier were collected for analytical purposes. The COD of the collected samples was analyzed by the closed reflux method. The cell optical density and the cell dry weights were measured for the biomass concentrations. All the analyses were based on standard methods for the examination of wastewater [29].

RESULTS AND DISCUSSION

The activated sludge system was implemented for the removal of organic pollutants from the influents of Amol Industrial Park. The wastewater used for the present research, was obtained from the plant's inlet wastewater. Kinetic parameters for the activated sludge process and the sludge recycle ratio with respect to HRT were obtained. The COD removal, DO and SVI were experimented for the designed experimental aeration basin.

A linear model fitted for the experimental data obtained by the activated sludge system implemented for the Amol's Industrial Park influents (Figure 2). The double reciprocal plot for the specific growth and organic pollutants are perfectly fitted according to the expression stated in Eq. (6). The HRT was in the range of 8 to 28 h and SRT was set at 10 d. From the slope and the intercept of the best fitted line, the rate constant and the Monod constant were found to be 2.12 d^{-1} and 232.4 mg l^{-1}, respectively. The large values of k_s shows that either the biomass grown on the wastewater has low affinity for the substrate or that the rate expression can be simplified and may lead to the first order [28]. To determine the optimum value, charts of COD removal values versus HRT values and SVI values *versus HRT* values were depicted.

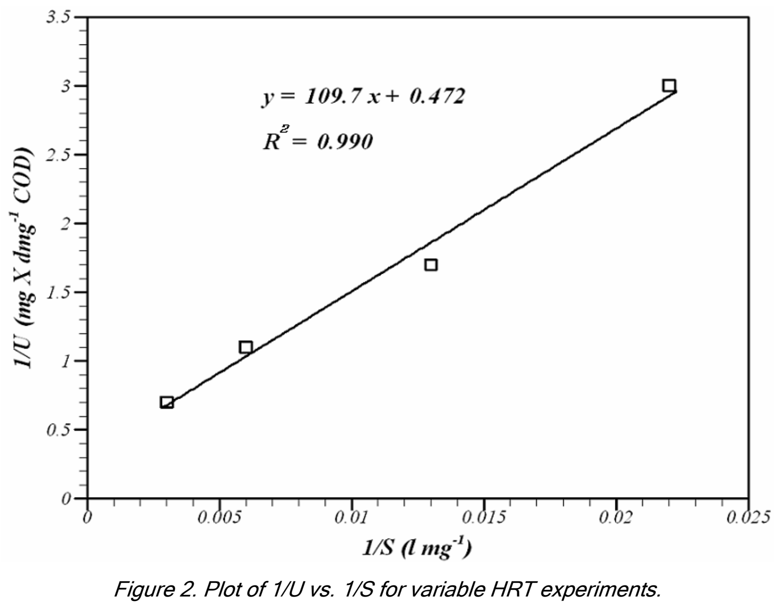

Figure 2. Plot of 1/U vs. 1/S for variable HRT experiments.

Similarly, the experimental data obtained with variable *SRT* in the range of 5 to 30 d at constant *HRT* (12 h) were plotted in form of $1/\theta_c$ versus *U* according to Eq. (7) and the following constants were determined from the slope and the intercept of the best fitted line (Figure 3). The yield, *Y*, was defined (0.33 gX g^{-1} S) and the decay coefficient was 0.096 d^{-1}. The kinetic parameters for the domestic wastewater were experimented [28]. The results showed that the k_s, *k*, *Y* and k_d were 85.5 mg/l, 1.71 d^{-1}, 52 % and 0.06 d^{-1}, respectively [15].

The kinetic and stoichiometric constants determined for this wastewater are comparable with the literature reports where *k* is between 1 and 5 d^{-1}, k_s is 100-300 mg\l^{-1}, *Y* is 0.2-0.5 g X g^{-1} S and k_d is 0.01--0.15 d^{-1} [22].

Figure 4 shows the percentage of the *COD* removal with respect to *HRT* while the sludge recycle ratio varied from 0.3 to 1.1. The maximum percentage of the *COD* removal was obtained while the value of *HRT* was 1.1. As the sludge recycle ratio was increased from 0.3 to 1.1, the *COD* removal was improved by 12 %.

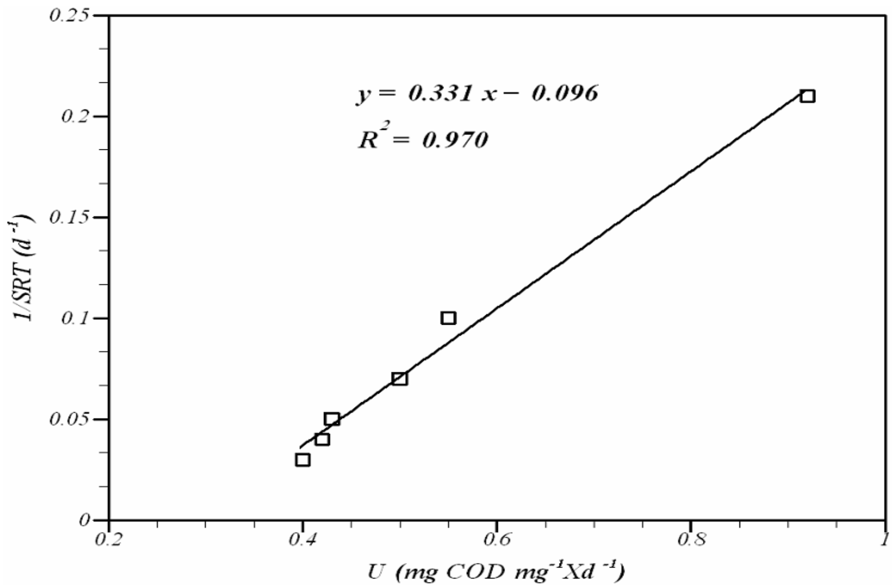

Figure 3. Plot of 1/SRT vs. U for variable SRT experiments.

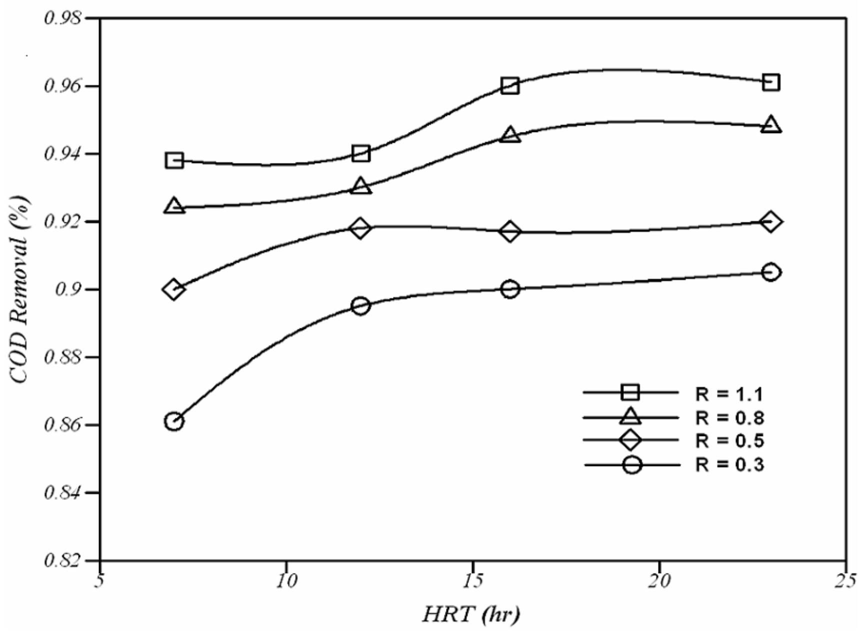

Figure 4. The effect of HRT on COD removal for various sludge recycle ratios at averaged COD, 27 °C, 30 l aerated vessel.

Figure 5 shows the effect of *HRT* on *SVI* values. The sludge index was gradually decreased with respect to *HRT*. The *SVI* was minimized with *HRT* at 16 h.

Figure 6 shows that the *COD* removal was based on the sludge recycle ratio. As the recycle ratio increased gradually the percentage of the *COD* removal was increased. While collecting the above data, the *HRT* was fixed at 16 h.

Figure 7 presents the sludge volume index (*SVI*) with respect to the sludge recycle ratio. The *SVI* increased with gradually increase of the recycle ratio. At high value of the sludge recycle ratio, the retained sludge in the aeration basin was also higher. The *SVI* value higher than 200 and the return sludge concentration lower than 8000 mg/l is a sign of the poor settle ability of the sludge and may cause bulking in clarifier [14].

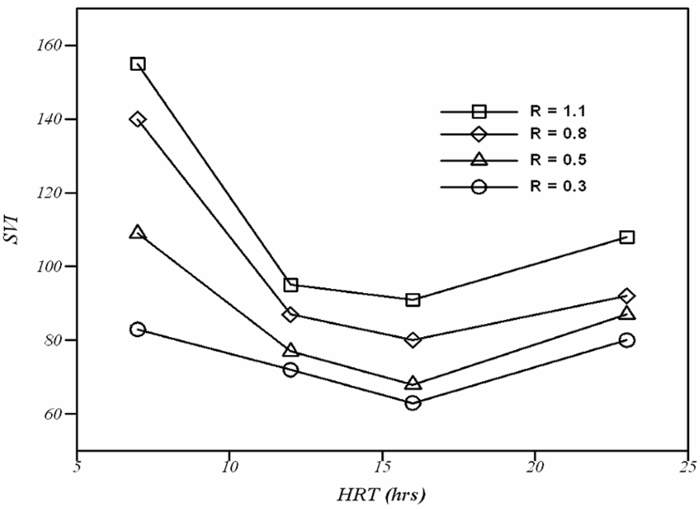

Figure 5. The effect of the HRT increase on SVI values at averaged COD, 27 °C, 30 l aerated vessel.

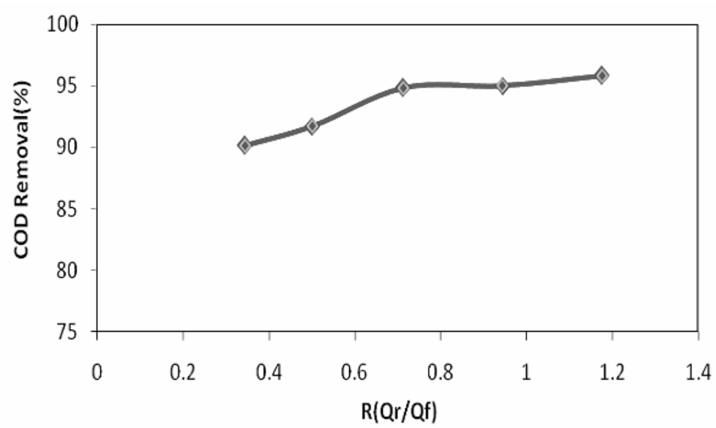

Figure 6. The effect of the sludge recycle ratio on COD removal at averaged COD, 27 °C C, 30 l aerated vessel.

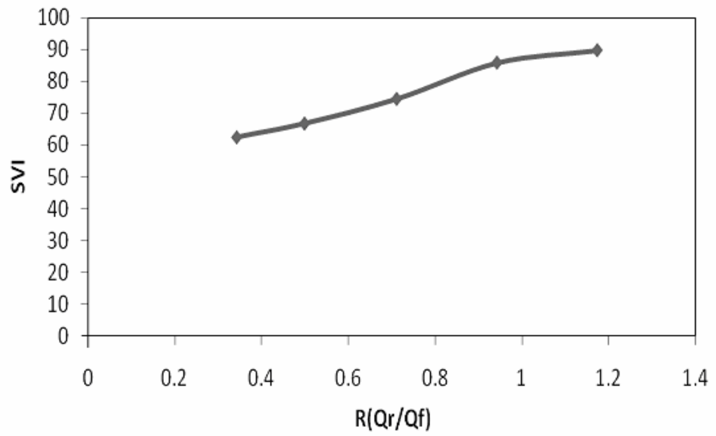

Figure 7. The effect of the sludge recycle ratios on SVI values at averaged COD, 27 °C, 30 l aerated vessel.

The performance of the activated sludge process is limited by the availability of oxygen [12,13]. Another parameter which was discussed is the *DO* level during the experiment and its depletion by increasing the recycle ratio. It should be considered that the power of the diffuser was constant during the experiments. Figure 8 presents the concentration of dissolved oxygen (*DO*) with respect to the sludge recycle ratio. As the recycle ratio increased, the *DO* concentration gradually decreased. At the low value of the recycle ratio, of about 0.3, the *DO* level was about 4.5 mg l^{-1} as the recycle ratio increased to 1.2, the *DO* value dropped to about 2 mg l^{-1}. In an additional investigation at the same site, it was found out that by adding urea and phosphate to the aerobic tank, there was a 5 % increase in the total removal efficiency [4].

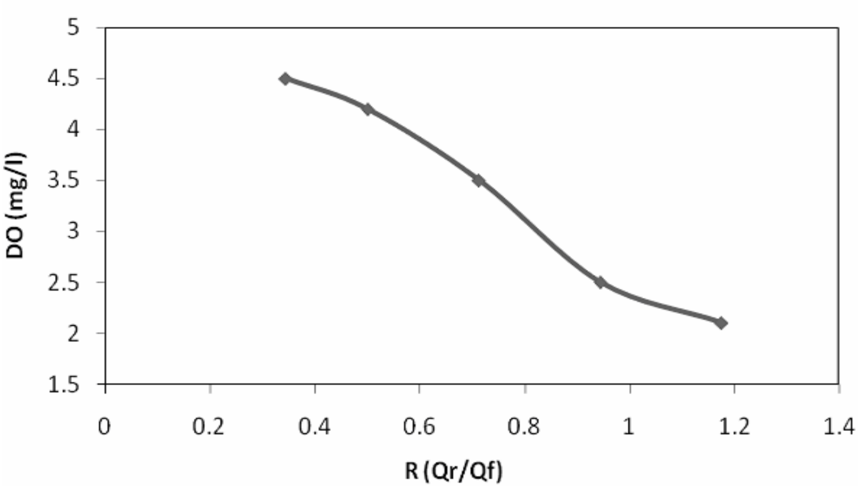

Figure 8. The effect of the sludge recycle ratio on DO level in aeration tank at averaged COD, 27 °C, 30 l aerated vessel.

CONCLUSION

The effects of *HRT* and the sludge recycle ratio were studied as a parameter affected the removal efficiency of *COD* and *SVI* value in an aerobic activated sludge system. The *HRT* values beyond 16 h had no significant effect on the *COD* removal efficiency. At *HRT* of 16 h the minimum value of *SVI* was obtained. The same results were also achieved for the sludge recycle ratio. The *COD* removal was increased with an increase of the recycled sludge ratio.

The *SVI* values were increased by increasing the recycle sludge. And it may reach 100 which could cause the bulking effects of the sludge. To avoid such phenomena the *SVI* was minimized.

DO depletion may cause a problem during the increase of the sludge recycling. But at the recycle ratio of 0.75, *DO* was obtained as 3 mg l^{-1}, which was suitable for the activated sludge process.

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Nomenclature

Q - Flow rate, l/d
V - Working volume of the aerated vessel, l
S_0 - Initial substrate, mg l^{-1}
S - Final substrate, mg l^{-1}
τ - Hydraulic retention time, d
K - Rate constant, d^{-1}
K_s - Monod constant, mg l^{-1}
E - Treatment efficiency, %
X - Biomass concentration, mg l^{-1}
F/M - Food to microbe ratio, dimensionless
Y - Biomass yield, dimensionless
U - Substrate utilization rate, d^{-1}
θ_c - Mean cell residence time, d
K_d - endogenous decay coefficient, d^{-1}.

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