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Comparison of different fluid dynamics in activated sludge system for the treatment of a stimulated milk processing wastewater: Process analysis and optimization

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Abstract−Wastewater from the milk industry usually undergoes activated sludge ahead of refining treatments, final discharge or reuse. To identify the most effective bioreactor hydraulic regime for the secondary treatment of wastewater resulting from the milk industry in an activated sludge system, two lab-scale activated sludge systems characterized by a different configuration and fluid dynamics (i.e., a compartmentalized activated sludge (CAS) with plug flow regime and a complete mixed activated sludge (AS)) were operated in parallel, inoculated with the same microbial consortium and fed with identical streams of a stimulated dairy wastewater. The effect of three process and operational variables--influent chemical oxygen demand (COD) concentration, sludge recycle ratio (R) and hydraulic retention time (HRT)--on the performance of the two systems were investigated. Experiments were conducted based on a central composite face-centered design (CCFD) and analyzed using response surface methodology (RSM). The region of exploration for treatment of the synthetic wastewater was taken as the area enclosed by the COD_{in} (200, 1,000 mg/*l*), R (1, 5), and HRT (2, 5 h) boundaries. To evaluate the process, three parameters, COD removal efficiency (E), specific substrate utilization rate (U), and sludge volume index (SVI), were measured and calculated over the course of the experiments as the process responses. The change of the flow regime from complete-mix to plug flow resulted in considerable improvements in the COD removal efficiency of milk wastewater and sludge settling properties. SVI levels for CAS system (30-58 ml/g) were considerably smaller that for the AS system (50-145 ml/g). In addition, the biomass production yield could be reduced by about 10% compared to the AS system. The results indicated that for the wastewater, the design HRT of a CAS reactor could be shortened to 2-4 h.

Key words: Compartmentalized Activated Sludge (CAS) System, Process and Operational Factors, Milk Wastewater

INTRODUCTION

The dairy industry is generally considered to be the largest source of food processing wastewater in many countries. As awareness of the importance of improved standards of wastewater treatment grows, process requirements have become increasingly stringent. Although the dairy industry is not commonly associated with severe environmental problems, it must continually consider its environmental impact, particularly as dairy pollutants are mainly of organic origin [1].

The volume, concentration, and composition of the effluents arising in a dairy plant are dependent on the type of product being processed, the production program, operating methods, design of the processing plant, the degree of water management being applied, and, subsequently, the amount of water being conserved [2]. Milk has a BOD content 250 times greater than that of sewage [3]. It can, therefore, be expected that dairy wastewaters will have relatively high organic loads, with the main contributors being lactose, fats, and proteins (mainly casein), as well as high levels of nitrogen and phosphorus that are largely associated with milk proteins [4,5]. The BOD and COD for milk processing wastewater have, for instance, been established to be between 500-1,000 mg/*l* and 720-1,400 mg/*l*, respectively, with lactose being responsible for 90% of the COD and BOD contribution [6].

Dairy wastewater should most appropriately be treated by biological means, because the bulk of the pollution load from a typical dairy is organic material from whole milk, which is readily biodegradable. As a general rule, biological treatment is more economical than any other type of treatment where reasonably complete treatment is required and wherever it can be made to work successfully [2]. Different aerobic treatment systems have been applied for biological treatment of dairy wastewater [7,8]. These processes are classified as either attached growth (biofilm) or suspended growth system [9]. The treatment systems such as conventional activated sludge process, aerated lagoon, oxidation pond, sequencing batch reactor (SBR), rotating biological contactor (RBC), trickling filter, two-stage continuous flexible fiber biofilm reactor, and sequencing batch flexible fibre biofilm reactor (SBFFBR) have been examined and utilized for various types of food industries wastewaters, especially dairy effluents [10-21]. Among the abovementioned processes, the activated sludge (AS) process is widely used for the milk processing 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. Many reports show that activated sludge process has been used successfully to treat dairy industry wastes [22]. Donkin and Russell (1997) found that reliable COD removals of over 90% and 65% reductions in total nitrogen

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could be obtained with a milk powder/butter wastewater [23]. Phosphorus removals were less reliable and appeared to be sensitive to environmental changes. Despite the advantages of the AS process, its application in milk processing wastewater is still associated with several drawbacks such as long hydraulic retention time (HRT), sludge bulking and foaming. To overcome the drawbacks, providing a mixing regime close to plug flow by the reactor compartmentalization would be an economic and competent strategy.

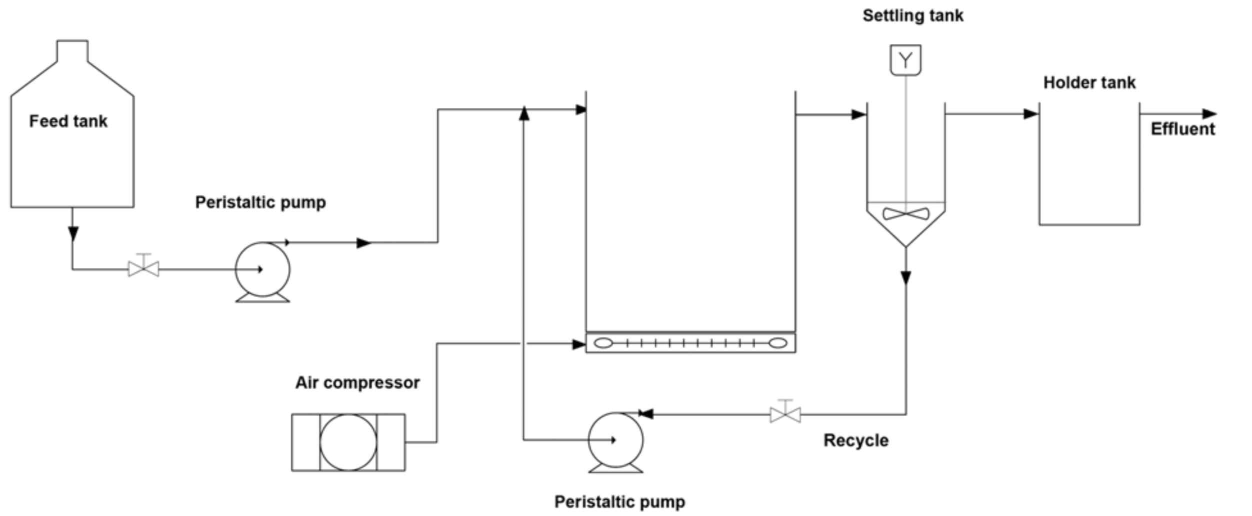
Response surface methodology (RSM) is a combination of mathematical and statistical techniques used for developing, improving and optimizing the processes, and it is used to evaluate the relative significance of several factors even in the presence of complex interactions. This methodology is widely used in chemical engineering, notably to optimize process variables. Examples of the RSM applications include fermentation of starch to lactic acid [24], analysis of the interactive effects of cell concentration and light intensity on hydrogen production by Rhodopseudomonas capsulate [25], optimization of medium for phenylalanine ammonia lyase production in *E. coli* [26], acidogenesis of cheese-whey wastewater to acetic and butyric acids [27], powdered activated carbon augmented activated sludge process for treatment of semi-aerobic landfill leachate [28], fenton and photo-fenton treatment of distillery effluent and optimization of treatment conditions [29], process modeling and analysis of palm oil mill effluent treatment in an up-flow anaerobic sludge fixed film bioreactor [30], for optimization of electrospun nanofiber formation process [31], process modeling and analysis of biological nutrients removal in an integrated RBC-AS system using response surface methodology [32].

The main purpose of this work is to compare the performance of the activated sludge (AS) system and compartmentalized activated sludge (CAS) system for the biological treatment of a synthetic milk processing wastewater. The effects of three operational factors--influent chemical oxygen demand (COD_{in}) concentration, hydraulic retention time (HRT) and the sludge recycle ratio--on the system's performance using response surface methodology were analyzed and modeled.

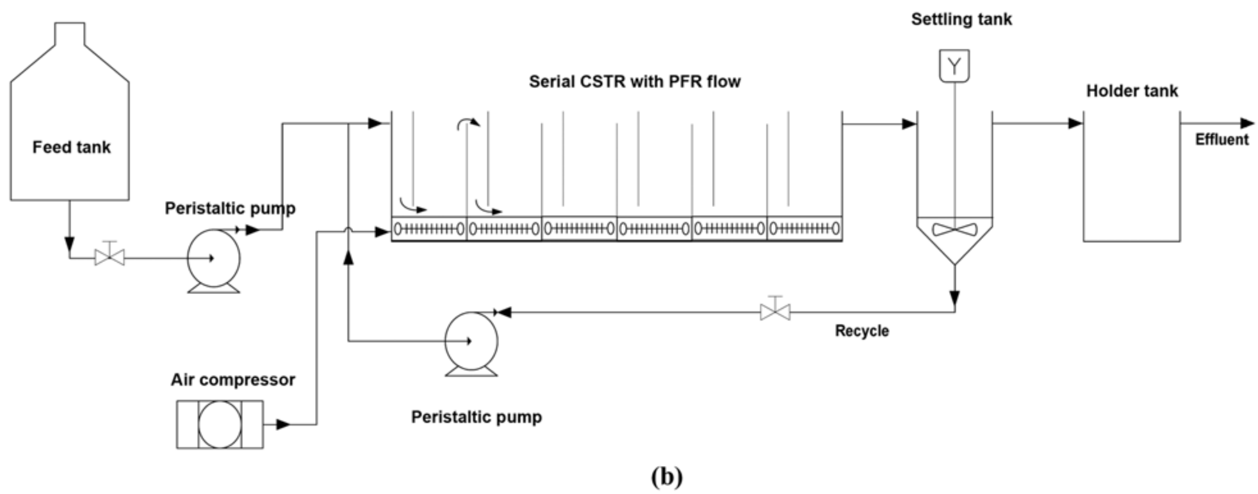
MATERIALS AND METHODS

1. Synthetic Milk Wastewater

The synthetic milk wastewater (SMW) was prepared in the laboratory using Nestle EveryDay milk powder. The used milk powder



(a)



(b)

Fig. 1. Experimental setup (a) conventional activated sludge (AS) system, and (b) compartmentalized activated sludge (CAS) system.

was composed of proteins (12.5 g/1,000 g powder), carbohydrate (54 g/1,000 g powder), fat (28 g/1,000 g powder), and inorganic matters (3 g/1,000 g powder). SMW samples were prepared based on the three different COD_{in} (200, 600 and 1,000 mg/*l*). Thus, the synthetic milk wastewaters of different organic loading have been prepared using different weight of milk powder. Furthermore, the actual COD values have been verified each time before initiation of experimental work.

2. Bioreactor Configuration and Start up

The schematic diagram of the experimental setup is shown in Fig. 1. Two integrated systems including an aeration tank and settling tank with total volume of 4 and 1 *l*, respectively, were designed and fabricated. The difference between the two systems was the configuration of the aeration tanks as shown in Fig. 1. As can be seen in the Fig. 1(b), one of the aeration tanks was compartmentalized to six identical compartments. So that, the wastewater stream passes through the unit as up and down flow. An air compressor was applied for aerating the wastewater through a circular polymeric membrane diffuser. The dissolved oxygen concentration was maintained approximately at about 4 mg/*l*. In all the experiments, the reactors were fed in parallel by two peristaltic pumps to provide the same load to each unit. Also, two peristaltic pumps were used for returning sludge from settling unit into aeration tank. The aerobic consortium used as seed culture for the two parallel bioreactors was a sample of the sedimentation sludge from a full-scale activated sludge plant treating municipal wastewater (Kermanshah, Iran). Each bioreactor was inoculated with 2 *l* of inoculums obtained from a 10 *l* sample from the mentioned wastewater treatment facility after 2 h sedimentation. To start up the systems, the both bioreactors were fed with an influent COD of 800 mg/*l* for two weeks with a constant MLVSS and HRT of 3,500 mg/*l* and 6 h, respectively. The COD removal efficiency was enhanced from 64 to 88%.

3. Experimental Design and Mathematical Model

3-1. Variables Evaluation

Biological wastewater treatment of dairy industries depends on a multitude of variables. Among these, six main factors which affect efficiency different reactors are hydraulic retention time, COD_{in}, solid retention time (SRT), biomass concentration, temperature, and pH [33-37]. In this study, COD_{in}, hydraulic retention time (HRT) and recycle ratio (R) were chosen as independent and the most critical operating factors due to the following reasons:

1. Milk wastewater is distinguished by the high BOD/COD ratio (>0.8). As the COD concentration of the industrial wastewater varies from 500 to 1,400 mg/*l*, so the study on the effect of COD_{in} on the process performance is of high importance. Therefore, in this study, efficiency of the bioreactors in milk wastewater treatment in the ranging from 200 to 1,000 mg/*l* was investigated (Table 1).

Table 1. Experimental range and levels of the independent variables

Variables	Range and levels		
	−1	0	1
COD_{in} (mg/*l*)	200	600	1000
HRT (h)	2	3.5	5
Recycle ratio	1	3	5

2. The most important parameter affecting the 'cost' of biological treatment system is retention time (HRT), because this parameter dictates the overall system volume as well as the amount of liquid held up in the system. Therefore, finding the shortest retention time to produce the required effluent quality will result in an optimality. The range studied for retention time is shown in Table 1.

3. From an operational point of view, optimization of R is of vital importance to provide the required SRT. Thus, finding the minimum R to give the maximum COD removal efficiency was determined as one of the aims in this research.

3-2. Design of Experiment

The statistical method of factorial design of experiments (DOE) eliminates systematic errors with an estimate of the experimental error and minimizes the number of experiments [38]. The RSM used in the present study was a central composite face-centered design (CCFD) involving three different factors: COD_{in}, hydraulic retention time (HRT) and recycle ratio (R).

The range and levels of the variable in coded units from RSM studies are given in Table 1. The bioreactor performance in milk wastewater treatment was assessed based on the full face-centered CCD experimental plan. The design consisted of 2^k factorial points augmented by 2k axial points and a center point where k is the number of variables. The three operating variables were considered at three levels: low (−1), central (0) and high (1). Accordingly, 20 experiments were conducted with 15 experiments organized in a factorial design (including 7 factorial points, 7 axial points and 1 center point) and the remaining five involving the replication of the central point to get good estimate of experimental error. Repetition experiments were carried out after other experiments followed by order of runs designed by DOE as shown in Table 2. To carry out a comprehensive analysis of the reactor, three dependent parameters were either directly measured or calculated as response. These parameters were COD (TCOD) removal efficiency, specific substrate utilization rate (U), and SVI.

3-3. Mathematical Modeling

After conducting the experiments, we calculated the coefficients of the polynomial model using the following equation [39]:

$$Y=\beta_0+\beta_i X_i+\beta_j X_j+\beta_{ii} X_i^2+\beta_{jj} X_j^2+\beta_{ij} X_i X_j+\cdots \quad (1)$$

Where, i and j are the linear and quadratic coefficients, respectively, and β is the regression coefficient. Model terms were selected or rejected based on the P value with 95% confidence level. The results were completely analyzed using analysis of variance (ANOVA) by Design Expert software. Three-dimensional plots and their respective contour plots were obtained based on the effect of the levels of the three factors. From these three-dimensional plots, the simultaneous interaction of the three factors on the responses was studied. The experimental conditions and results are shown in Table 2.

4. Analytical Methods

The concentrations of chemical oxygen demand (COD), total suspended solids (TSS), sludge volume index (SVI) were determined by using standard methods (APHA) [40]. For COD, a colorimetric method with closed reflux method was developed. A spectrophotometer (DR 5000, Hach, Jenway, USA) at 600 nm was used to measure the absorbance of COD samples. The dissolved oxygen (DO) concentration in wastewater was determined with a DO probe. The DO meter was supplied by WTW DO Cell OX 330, electro

Table 2. Experimental conditions and results of central composite design

Run	Variables			Response (AS system)			Response (CAS system)		
	Factor1 A: COD_{in} mg/l	Factor2 B: HRT h	Factor3 C: Recycle ratio	Total COD removal, %	SVI, ml/g	U, gCODrem/ gVSS.d	Total COD removal, %	SVI, ml/g	U, gCODrem/ gVSS.d
1	600	3.5	3	82	84.3	0.02	90	40	0.018
2	600	3.5	3	83.5	79	0.027	88	50	0.014
3	1000	5	5	93.89	172.4	0.071	95	67	0.025
4	200	5	5	94.09	66.67	0.014	93	60	0.006
5	600	3.5	3	81.1	66	0.031	88	45	0.016
6	600	3.5	3	78.3	87.5	0.028	86	45	0.018
7	600	3.5	5	88.23	75.76	0.024	97	34	0.014
8	600	3.5	3	79.4	80	0.026	88	45	0.016
9	1000	2	1	85.41	95.06	0.058	98	29	0.038
10	600	3.5	1	77.74	111.67	0.038	91	53	0.019
11	1000	3.5	3	88.15	105.65	0.04	96	33	0.027
12	600	2	3	66.4	67.14	0.025	92	25	0.02
13	200	3.5	3	75	57.27	0.011	50	36	0.003
14	200	5	1	73.28	88	0.017	59	70	0.011
15	1000	2	5	72.19	71.37	0.03	97	35	0.041
16	1000	5	1	79.95	136.36	0.04	90	52	0.03
17	600	3.5	5	74	86	0.029	88	45	0.016
18	600	5	3	95.69	94.79	0.026	97	45	0.012
19	200	2	1	54.54	58.97	0.015	48	35	0.003
20	200	2	5	30.45	42.98	0.003	83	34	0.006

DO probe, Germany. The pH meter model HANNA-pH 211 was used to measure the pH.

RESULTS AND DISCUSSION

1. Statistical Analysis

As various responses were investigated in this study, different degree polynomial models were used for data fitting (Table 3). The regression equations obtained are presented in Table 3. To quantify the curvature effects, the data from the experimental results were fitted to higher degree polynomial equations, i.e., two-factor interaction (2FI) and quadratic. In the Design Expert software, the response data were analyzed by default. The ANOVA results for all responses are summarized in Table 3. The model terms in the equations are after elimination of insignificant variables and their interactions. Based on the statistical analysis, the models were highly significant with very low probability values (<0.0001). It was shown that the model terms of independent variables were significant at the 99% confidence level. The square of correlation coefficient for each response was computed as the coefficient of determination (R^2). It showed high significant regression at 95% confidence level. The predicted versus actual plot for the three responses in the both systems (AS and CAS) is shown in Fig. 2. It shows that the actual values are distributed close to the straight line (y=x) with relatively high values of R^2. The model's adequacy was tested through lack-of-fit F-tests [41]. The lack of fit F-statistic was not statistically sig-

Table 3. ANOVA results for the equations of the design expert 6.0.6 for studied responses

Type of system	Response	Modified equations with significant terms	Probability	R^2	Adj. R^2	Adeq. precision	SD	CV	PRESS	Probability for lack of fit
AS	COD removal	$80.35+9.22A+12.79B-5.32C^2-8.27AB+9.01BC$	<0.0001	0.9170	0.8874	4.97	5.72	6.40	729.83	0.1295
	SVI	$86.34+26.70A+22.27B+11.20AB$	<0.0001	0.8104	0.7748	15.827	13.48	16.02	5694.19	0.0660
	U	$0.029+0.018A+0.0085BC$	<0.0001	0.8150	0.7932	19.185	7.106E-3	24.80	1.436E-3	0.0510
CAS	COD removal	$89.6+14.3A+7.9C-8.7A^2+8.13AC$	<0.0001	0.8205	0.7726	12.997	7.22	8.47	1488.41	0.0512
	SVI	$43.9+13.6B$	<0.0001	0.6499	0.6305	11.562	7.44	16.95	1249.27	0.0900
	U	$0.018+0.013A-0.0024B-0.004AB$	<0.0001	0.9279	0.9144	25.143	3.06E-3	17.24	2.85E-4	0.1382

A: first variable, COD_{in} (mg/l), B: second variable, HRT (h), C: third variable, recycle ratio R^2: determination coefficient, Adj. R^2: adjusted R^2, Adeq. Precision: Adequate precision, SD: standard deviation, CV: coefficient of variation, PRESS: predicted residual error sum of squares

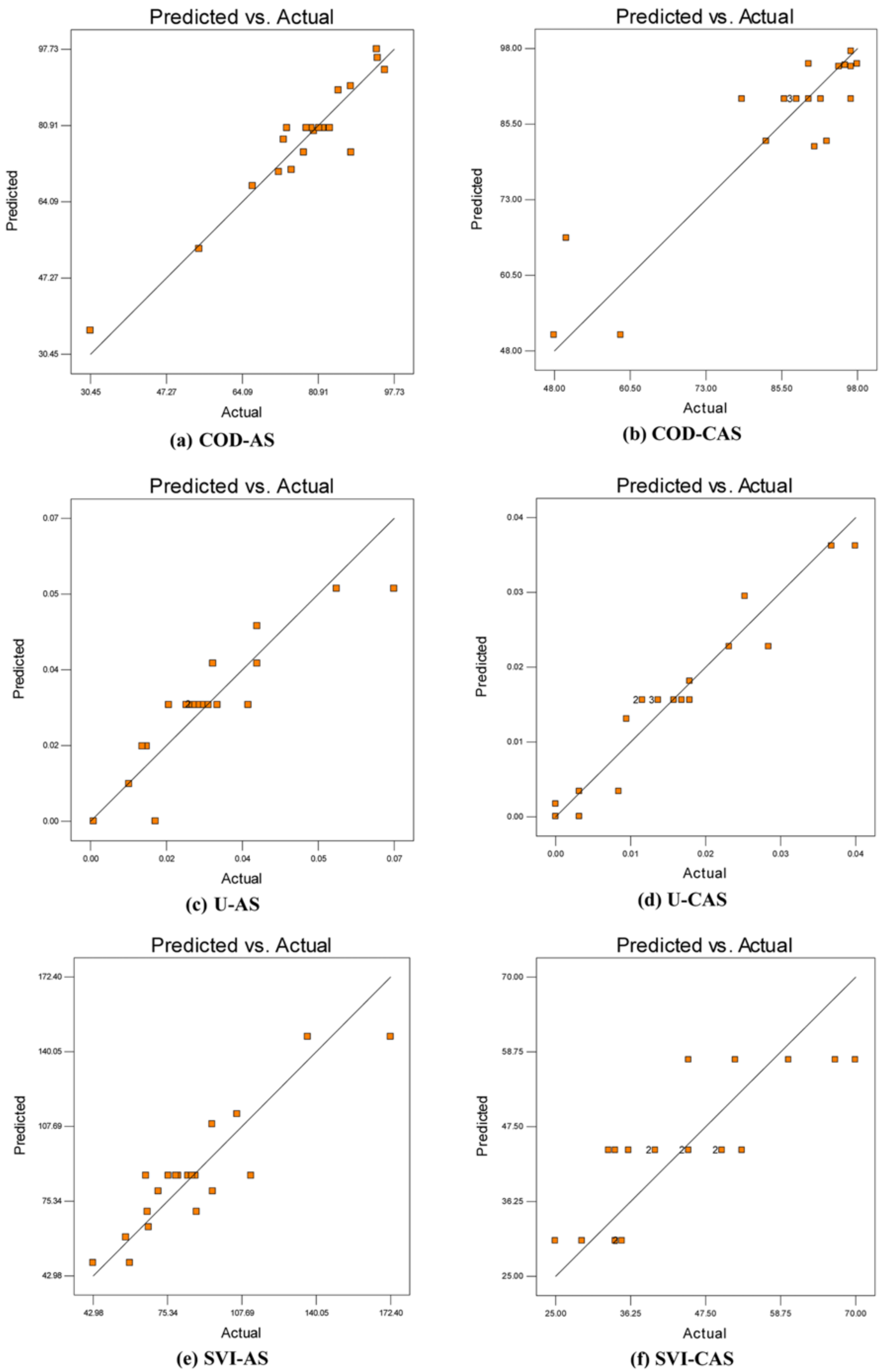


Fig. 2. Predicted versus to actual values for the variables studied in the AS and CAS systems.

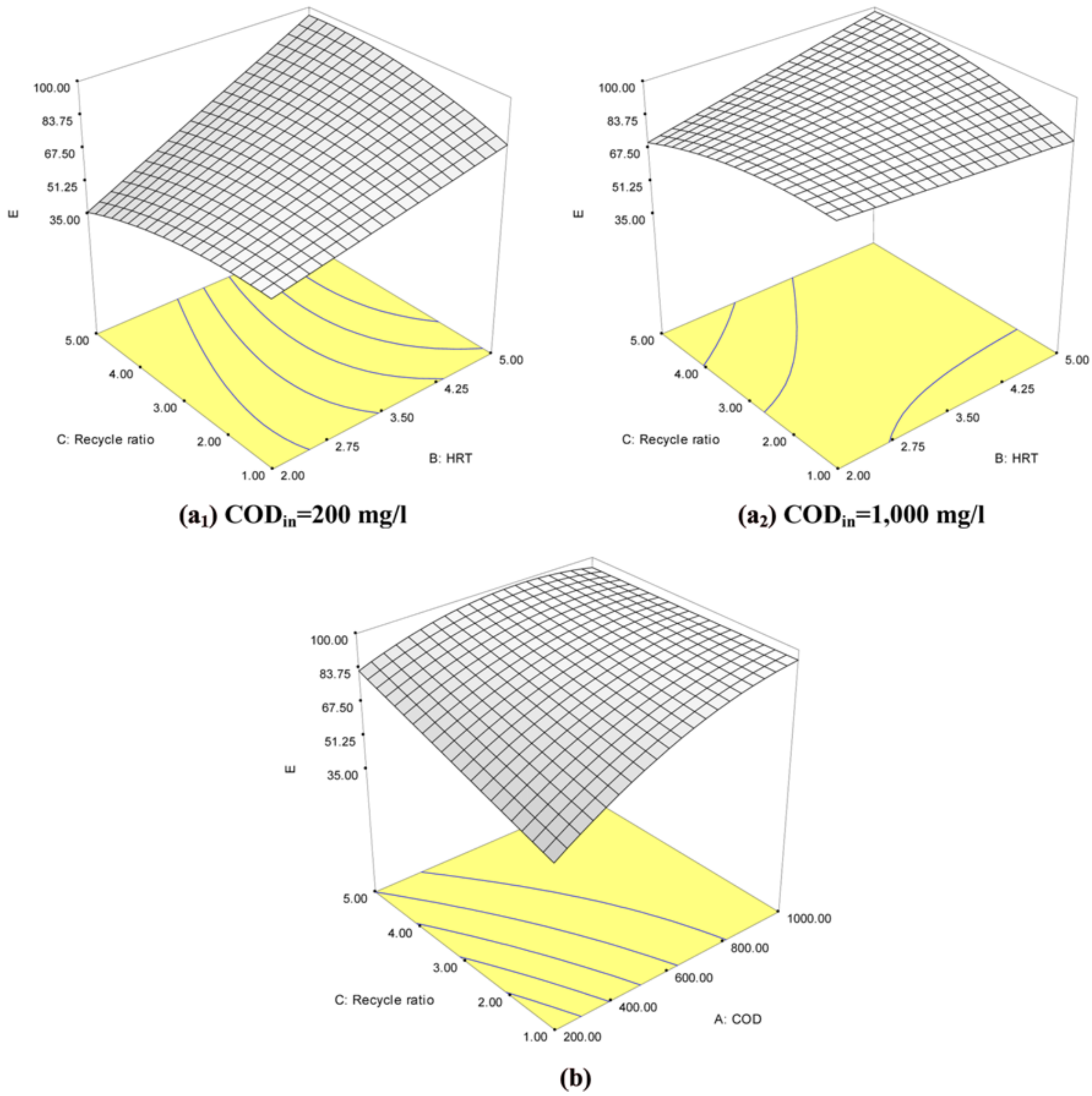


Fig. 3. Response surface plots for COD removal efficiency; (a_1) and (a_2) AS bioreactor, (b) CAS bioreactor.

nificant as the P-values were greater than 0.05.

Adequate precision is a measure of the range in predicted response relative to its associated error or, in other words, a signal-to-noise ratio. Its desired value is 4 or more [42]. The value was found desirable for all models. Simultaneously, low values of the coefficient of variation (CV) (6.4-24.8%) indicated good precision and reliability of the experiments as suggested by Kuehl [38] and Khuri and Cornell [39]. Detailed analysis of the models is presented in the following sections.

2. Performance of the Systems Studied

2-1. COD Removal

2-1-1. AS System

To investigate the effects of the variables studied on the biological treatment process, dependency of COD removal efficiency to the variables was analyzed and modeled. The regression equation after the analysis of variances (ANOVA) gave the level of COD removal as a function of the influent COD concentration (A), hydraulic retention time (B) and recycle ratio (C) (Table 3). By applying multiple regression analysis on the experimental data, the experimental results of the CCD design were fitted with a modified quadratic model. From the table, first-order main effects of A and B, second order of C, and interaction effects of AB and BC were significant model terms. Fig. 3(a_1) and (a_2) represent COD removal efficiency as a function of HRT and recycle ratio at constant value of influent COD concentration (200 and 1,000 mg/*l*, respectively). As can be seen in the figures, at high HRT, the COD removal efficiency increased with an increase in recycle ratio. It was attributed to more SRT, favoring food to microorganism ratio (0.5-1 g COD_{in}/g VSS.d). In contrast, a decreasing impact of the recycle ratio (at the values more than 3) on the response was found at HRTs lower than 3.5 h. It was because of very high biomass content (>10,000 mg/*l*) which generates more soluble microbial products (SMPs) [9]. Greater COD removal efficiency was obtained at higher COD_{in} (74-98% at COD_{in}=1,000 mg/*l* versus 40-97% at COD_{in}=200 mg/*l*), implying high removal capacity of the system. Similar findings were reported by Hosseini and his co-workers [43].

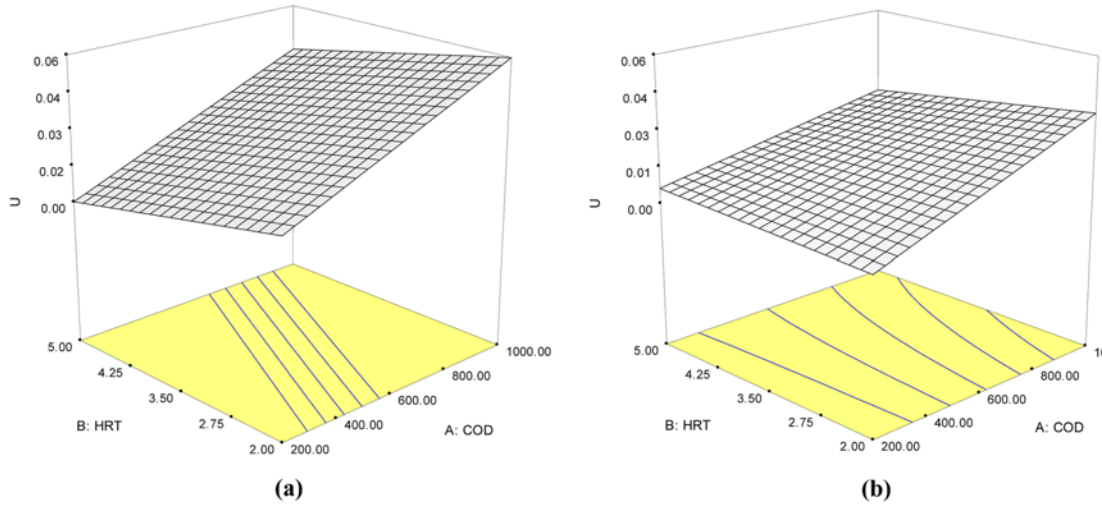


Fig. 4. Response surface plots for specific substrate utilization rate (U); (a) AS bioreactor, (b) CAS bioreactor.

2-1-2. CAS System

The ANOVA values for the COD removal efficiency are shown in Table 3. As presented in the table, the main effect of A, second order effects of A^2 and the interactive effect of AC were significant model terms. HRT showed no significant impact on the response in the range studied (2-5 h), implying that the two-hour retention time has been sufficient, achieving high COD removal efficiency. From the regression equation, initial COD concentration was the most effective factor in COD removal efficiency. Fig. 3(b) represents COD removal efficiency as a function of COD_{in} and R. As can be seen in the Fig, simultaneous increase in the variables (COD_{in} and R) caused an increase in the response. It should be noted that the COD removal efficiency was more than 83% except the condition with minimum COD_{in} and R (200 mg/*l* and 1), which was about 52%. R had almost no effect on the response at COD_{in} higher than 800 mg/*l*. The response slightly increased with an increase in R at a constant COD_{in} (at the values lower than 800 mg/*l*). It was due to increase in MLVSS content of the system, favoring food to microorganism ratio (less than 1 g COD_{in}/g VSS.d). Similar findings were reported by Chakraborty and his co-workers [44]. The maximum COD removal was modeled to be 98% at the highest value of recycle ratio and COD_{in} about 800 mg/*l*. This study showed that the CAS was more efficient compared to AS at the same operating condition due to its flow regime (semi plug flow), proving that the order of biochemical reactions (n) occurred has been ≥1 [45]. Therefore, to reduce the required reactor volume (especially for the wastewaters with high slowly biodegradable COD), compartmentalization is an economic and effective solution. In addition, by providing a plug flow regime in the system, the removal capacity is increased.

2-2. Specific Substrate Utilization Rate (U)

Specific substrate utilization rate (U) indicates the capacity treatment of the process [9]. As it is clear from the regression equations presented in Table 2, A is the most effective factor while B and C did not have a significant effect on the response. Fig. 4 illustrates U as a function of COD_{in} and HRT at a constant R (middle level). As can be seen in the Fig., in the both systems, the response has been changed with a same trend but different intensity. So that, the increasing effect of COD_{in} on the response became less as HRT in-

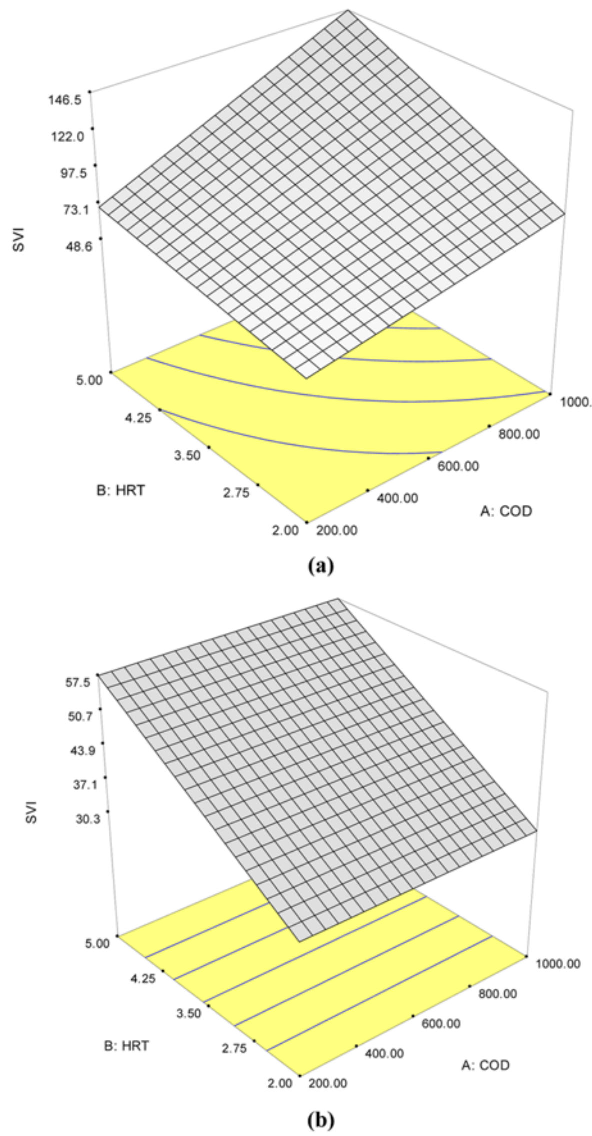


Fig. 5. Response surface plots for SVI; (a) AS bioreactor, (b) CAS bioreactor.

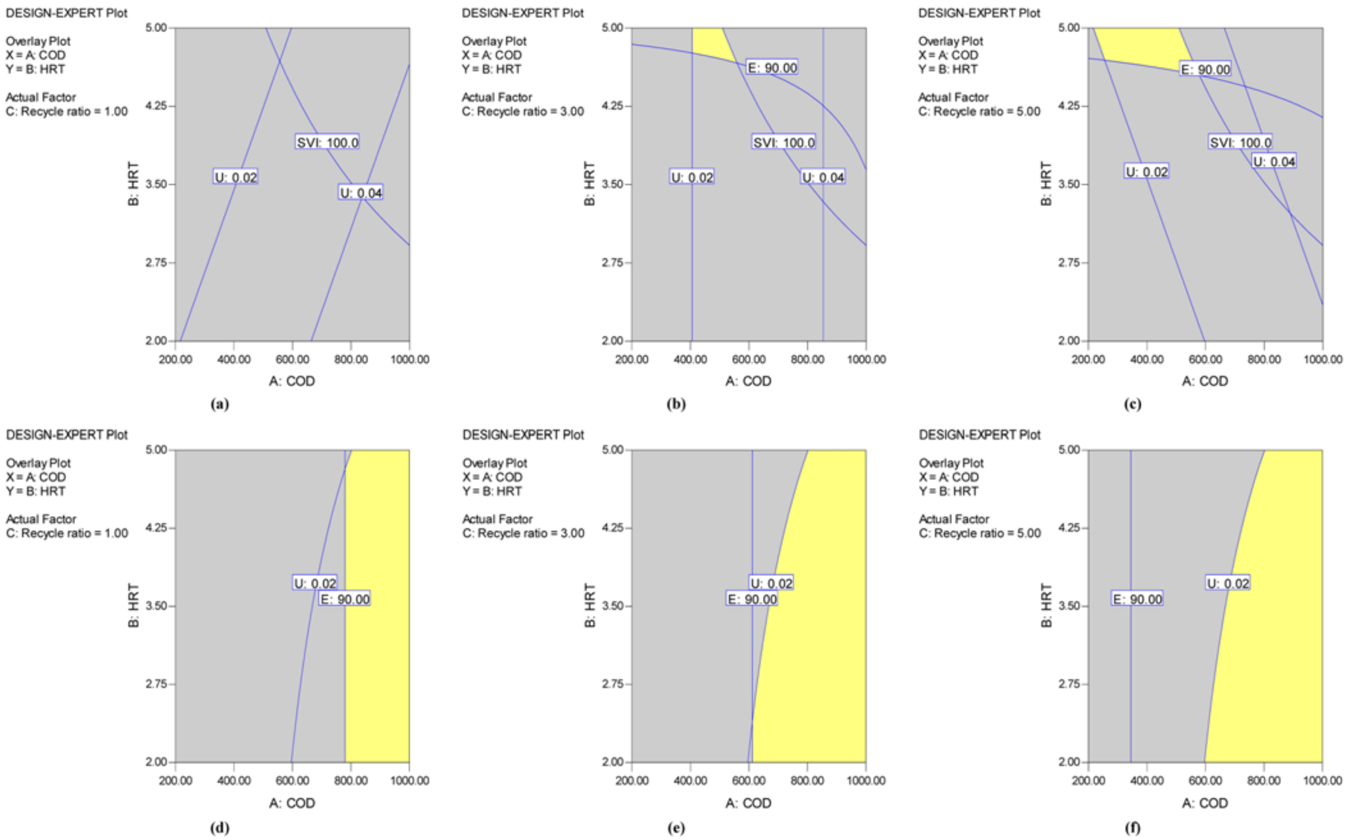


Fig. 6. Overlay plot for the optimal region; (a)-(c) AS system, (d)-(f) CAS system.

creased. It was due to the lower organic loading rate at higher HRTs. In AS (Fig. 4(a)), the change in the response is more compared with CAS (Fig. 4(b)) (0.04 respect to 0.03 g COD_{rem}/g VSS.h). It was because of more MLVSS content of the CAS provided by the reactor configuration as well as the hydraulic regime, causing a smaller U for CAS. Yee Shian Wong's investigations confirm the result and show that the values of specific substrate utilization rate are between 10 and 60 days of HRT [46]. Maximum U was obtained at HRT of 2 h and COD_{in} of 1,000 mg/*l* which was 0.054 and 0.038 g COD_{rem}/g VSS.h (1.3 and 0.9 g COD_{rem}/g VSS.d) for the AS and CAS systems, respectively.

To estimate the biomass production yield (Y) and biomass decay coefficient (K_d), the relationship between the inverse SRT and the specific substrate utilization rate (U=[(−dS/dt)/X] for both systems was investigated and the biomass production yield (Y) for AS system obtained 0.57 which was greater than that for CAS system (0.45), implying more microbial death rate in CAS system (K_d=0.033 d^{-1}) caused by the semi plug flow regime. By compartmentalizing the reactor, in addition of achieving a higher COD removal efficiency at a low HRT, the biomass production yield could be reduced by about 10% compared to the AS system.

2-3. Solid Volume Index (SVI)

Settleability of the sludge is of crucial importance in the operation of AS processes, particularly when MLSS is high. The return sludge pumping rate is set based on the sludge settleability, which is approximately equal to the percentage ratio of the volume occupied by the settleable solids from the aeration tank effluent to the volume of the clarifies liquid (supernatant) after settling for 30 min in a 1,000-ml graduated cylinder. Therefore, SVI is an effective parameter to control the rate of return sludge pumping.

Fig. 5(a) and (b) represent variations of SVI as a function of the variables for AS and CAS, respectively. From the models in Table 3, the main effects of the two factors (A and B) and the two-level interaction (AB) of the variables are significant model terms for the AS, while in CAS, B is the only significant term. In the both systems, HRT showed an increasing effect on the response owing to decrease in F/M ratio. Comparison of Figs. 5(a) and 5(b) shows that SVI levels for CAS system (30-58 ml/g) were considerably smaller that for AS system (50-145 ml/g). Typical SVI values for good settling sludge in activated sludge system are between 50 and 170 ml/g.

In a hydrodynamic sense, a column-type upflow reactor and CMTR have very different hydrodynamic behaviors in terms of interactive patterns between flow and microbial aggregates. The reactor configuration in CAS (as shown in Fig. 1) provides an up-flow pattern in the system which leads to more compact, denser, rounder, and stronger aerobic flocs with smaller SVI [47]. In addition, in the CAS the bacteria are subjected to a periodic feast-famine regime as a kind of microbial selection pressure that may alter the surface properties of cells, conducting the microbial aggregation [47,48].

3. Process Optimization

With multiple responses we need to find regions where requirements simultaneously meet the critical properties, the "sweet spot". The best compromise can visually be searched by superimposing or overlaying critical response contours on a contour plot. Graphical optimization produces an overlay plot of the contour graphs to

Table 4. The optimization criteria for the responses studied

Response	Limit	Unit
COD removal	≥90	%
U	0.02-0.04	g COD_{rem}/gVSS.h
SVI	<100	ml/g

display the area of feasible response values in the factor space. The graphical optimization results allow visual inspection to choose the optimum operating conditions. The optimum region was identified based on the responses (COD removal, U and SVI), whose criteria were adopted as shown in Table 4. The shaded areas on the overlay plots in Fig. 6 are the regions that meet the proposed criteria. As demonstrated in the Fig. 6(a)-(c) (for AS system), the effect of R on the optimum region is observed. So no optimum region was found at R=1 that could meet the criteria. Whereas an optimum region was appeared as R increased to 3 and 5 (Figs. 6(b) and (c)), indicating the positive impact of R on the process performance in AS system. The region is covered by HRT of 4.5-5 h and COD_{in} smaller than 600 mg/*l*. Conversely, R was not a significant factor for CAS system. The results (Fig. 6(d)-(f)) showed that the optimization criteria could be met even at R=1, COD_{in}≥800 mg/*l* and any HRT in the range studied (2-5 h).

CONCLUSION

The compartmentalization of the activated sludge (AS) system is an economic, efficient and reliable strategy to promote the system treatment capacity. The response surface methodology results demonstrated the effects of the studied variables as well as their interactive effects on the responses. The HRT and R were determined to be the most effective operational factors on the system performance treating milk wastewater. By compartmentalizing the reactor, in addition of achieving a higher COD removal efficiency at a low HRT, the biomass production yield could be reduced by about 10% compared to the AS system. The optimum conditions for treatment of the milk wastewater in the AS were determined as HRT of 4.5-5 h and COD_{in} smaller than 600 mg/*l*, while in the CAS system it was COD_{in}≥800 mg/*l* and any R and HRT in the range studied, respectively. As a conclusion, compartmentalization is an economic and effective solution to reduce the required reactor volume (especially for the wastewaters with high slowly biodegradable COD).

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