Effect of Hydraulic Retention Time, Solid Retention Time and Sludge Volume Index in the Treatment Efficiency of Micro Pollutants in Sewage

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Abstract: Conventional sewage treatment systems have limitations on the removal of Synthetic organic compounds, particularly micro pollutants such as dioxins, pharmaceuticals products, Furans and Polychlorinated phenolic compounds. Membrane Bioreactor (MBR) which couples activated sludge process and ultrafiltration (UF) membrane system has been increasingly known to be effective in removal of micro pollutants. In this study, we attempted to optimize treatment efficiency by analyzing the effect of Hydraulic Retention Time (HRT), Solid Retention Time (SRT), Sludge Volume Index (SVI) and the hydraulic plant capacity (Q) and its influence on biomass production and food to microorganism ratio. The level of biomass generation directly correlates to the removal of micro pollutants. From the statistical analysis, it was identified that HRT, SRT and SVI were inversely proportional to the production of biomass and the hydraulic plant capacity did not have a direct effect on the process. A maximum of 250 Kg/day of biomass could be obtained from the plant if it is operated at HRT and SRT of 5h, 11 days at 1500 m^3/h Hydraulic Plant capacity maintained at SVI of 50. Further a 99% reduction in micro pollutant content was seen in the plant. The results suggested the suitability of MBR process in removal of micro pollutants present in domestic sewage.

***Index Terms* – MBR, Micro Pollutants, HRT, SRT, Plant Capacity, Biomass**

I. INTRODUCTION

Efficient, cost effective and reliable treatment processes are required to produce high quality water from wastewater that can be reused without any detrimental effects. Conventional sewage treatment process such as the activated sludge process is simple and easy to construct and operate due to their low costs. This makes it more attractive to places where the budget is limited. However, these systems require frequent inspections and constant maintenance to ensure smooth operation. The various concerns include hydraulic overloading, overload of chemicals, excess biomass growth, foul odour and uncontrolled formation and release of methane into the atmosphere. Further, the effluent from the activated sludge process needs to be treated by employing additional filtration methods and disinfected before its release into the environment. This adds to the operation and equipment costs. Further, the smaller micro pollutants cannot be removed using this process. Thus, new technologies are required for complete elimination of certain micro pollutants contaminants and hence to obtain effluent acceptable for direct reuse (Tabraiz *et al*., 2017; zuthi *et al*., 2017).

Membranes are widely used in wastewater treatment since the early 1960s when Loeb and Sourirajan invented the asymmetric cellulose acetate membrane to carry out reverse osmosis (Visvanathan et al., 2000). Several combinations of membrane solid / liquid separators in wastewater treatment since. One of the most promising technologies in this area is that of membrane bioreactor (MBR). The earliest descriptions of MBR technology started in the early 1960s. A brief description on the various stages of evolution of membrane bioreactors are depicted in figure 1.

Initially when the need for water reuse arose, the conventional approach was used. The progress of membrane manufacturing technology and its applications led to the replacement of tertiary treatment steps by UF (Figure 1(1)). Subsequently, UF was developed to enforce solid liquid separation in the early biological treatment thereby eliminating the need for an additional sedimentation step. Eventually, the original process was developed and introduced by Dorr Olivier Inc. (figure 1(2)). They combined the use of an activated sludge bioreactor with a cross-flow membrane-filtration loop by pumping the mixed liquor at a high pressure into the membrane unit, the permeate passes through the membrane and the concentrate is returned to the bioreactor thereby ensuring smooth recirculation. Although, initially the idea of replacing the settling tank of the conventional activated sludge (CAS) process was attractive, it was difficult to develop f such a process because of the high cost of membranes, low economic value of the product (tertiary effluent), and the potential loss of performance due to high fouling levels. The breakthrough for the MBRs occurred in 1989 when the process involved submerging the membranes in the reactor itself and subsequent suction of the treated water through the membranes (Yamamoto et al., 1989; Kayawake et al., 1991; Chiemchaisri et al., 1993; Visvanathan et al., 1997; Arika et al., 1966; Krauth and Staab, 1988; Muller et al., 1995). In this model, the membranes were suspended in the reactor above the air diffusers (Figure 1(3)). The diffusers provided the oxygen necessary for biological treatment to take place and scour the surface of the membrane to remove deposited solids.

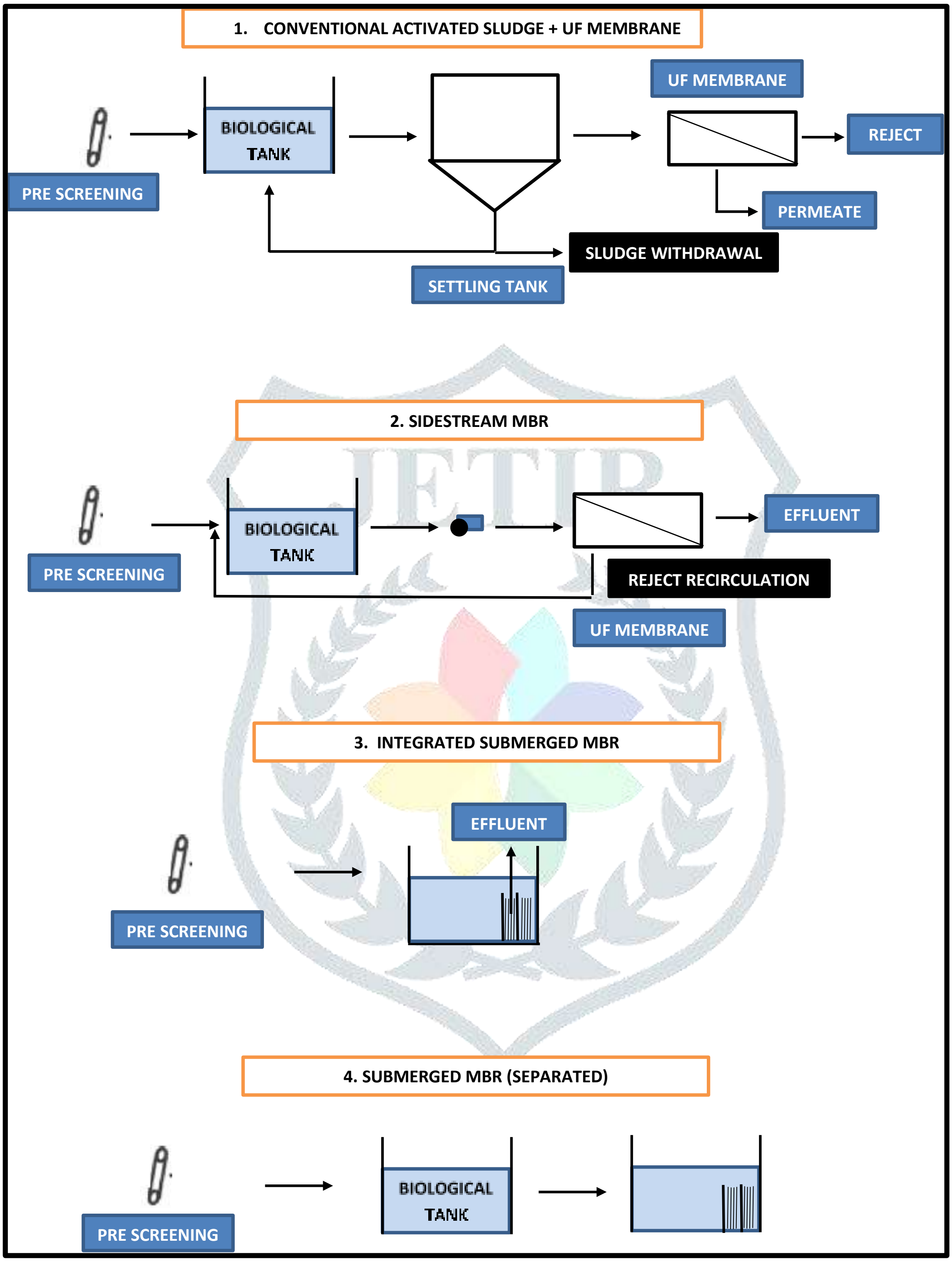

Figure 1. Evolution of MBR through the years

This proved efficient in tackling the fouling issues in the membrane. The limited amount of oxygen transfers possible with this technique, however, restricted this process only to small lab-scale applications. The invention of air-backwashing techniques for membrane de-clogging led to the development of using the membrane itself as both clarifier and air diffuser. In this approach, two sets of membrane modules were submerged in the aeration tank. While the permeate was extracted through one of the sets, the other set was supplied with compressed air for backwashing. The cycle was repeated alternatively, and the continuous airflow into the aeration tank, ensured enough aeration. In recent times two different methods are being used with regards to MBR, namely submerged MBRs and side stream MBRs. Submerged technologies tend to be more cost effective for larger scale lower-strength applications, and side stream technologies are favored for smaller-scale higher-strength applications. The side stream MBR envelope has been extended in recent years by the development of the air-lift concept, which bridges the gap between submerged and cross-flow side stream MBR. The economic viability of the current generation of MBRs depends on the achievable permeate flux, mainly controlled by effective fouling control with modest energy input (typically r^1 kW h^1 m^3 product). More efficient fouling-mitigation methods can be implemented only when the phenomena occurring at the membrane surface are fully understood.

The adaptability of MBR is that, it can be easily combined with biological treatment to remove the dissolved contaminants. Further they serve as the ideal pre-treatment to reverse osmosis. MBR systems also eliminate the need for additional secondary clarifiers and sludge recirculation process, hence reducing the space required for plant construction. Additionally, they can also handle high Mixed Liquor Suspended Solids (MLSS) content present in the sewage. The permeate produced from this wastewater treatment technology is suitable for direct reuse (Ding et al., 2017; Wang et al., 2017; Tabraiz et al., 2017). The biomass production level plays a crucial role in determining the level of removal of micro pollutants present in domestic sewage (Bolzonella et al., 2010). In light of the above, the current work aims to investigate the optimal operating conditions for MBR to achieve greater biomass production levels and hence the removal of micro pollutants.

II. MATERIALS AND METHODS

1. Study Area

The study was conducted on a currently operating MBR based sewage treatment plant (Figure 2). The plant is located in an IT campus. The sewage and canteen wash water generated from the campus are collected and treated in a centralized sewage treatment plant. The plant has a design capacity to treat 1500 m^3/day of incoming sewage.

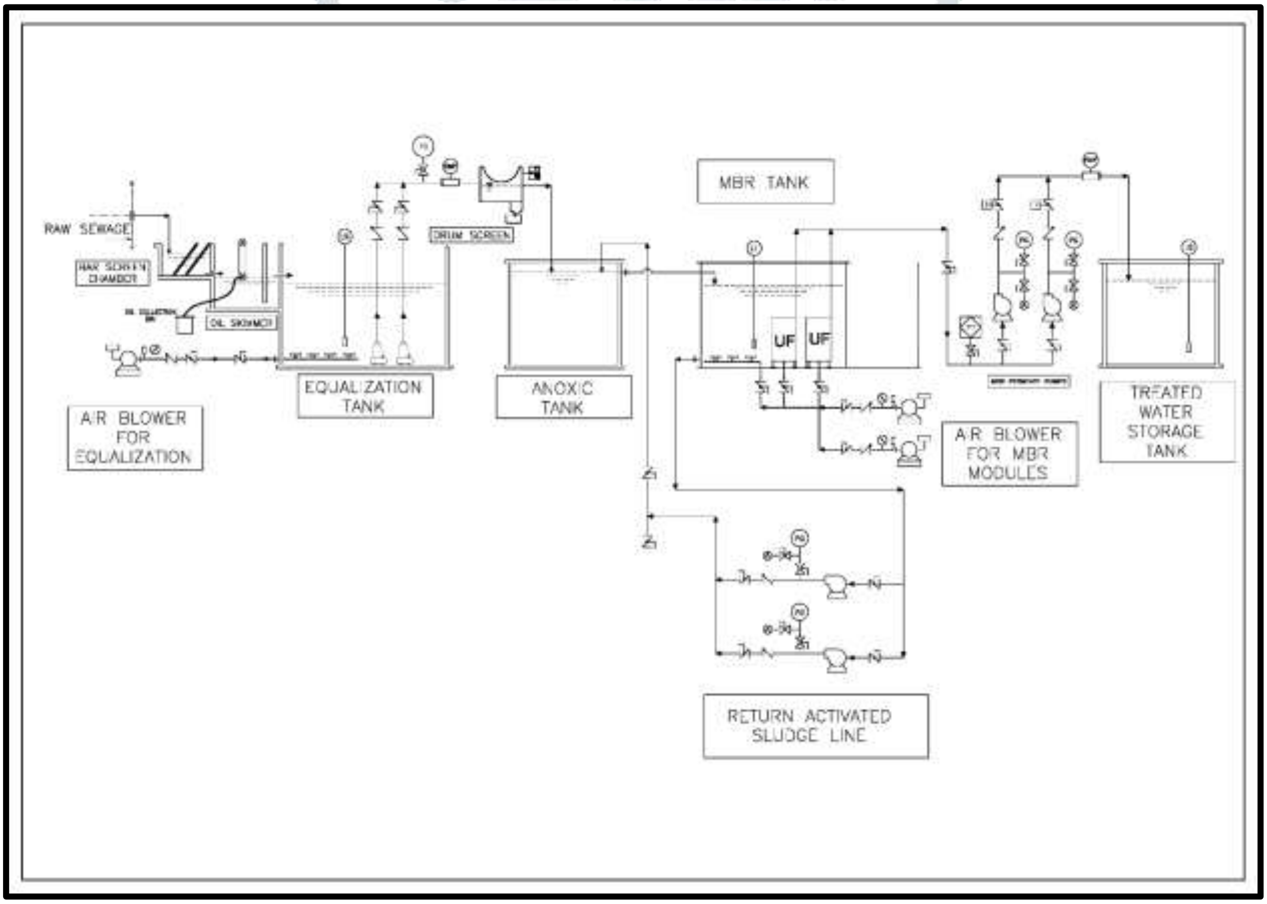

Figure 2. MBR based sewage treatment plant scheme

The incoming sewage was received in screen chamber to trap debris and large particulate material. The sewage then collects in a collection cum equalization tank. The tank was provided with an air mixing grid to mix and equalize the coming sewage. The equalized sewage is then passed through a drum type fine screen of 2mm. This screen ensures complete removal of fibrous material, seeds etc. This was followed by nitrification reaction in an anoxic tank. The nitrification process is intended to be a controlled ammonia reduction process in the section and can be described by the following equation,

$$NH_4^+ \Longrightarrow NO^{2-} \Longrightarrow NO^{3-}$$

The second step denitrification is intended to convert the residual Nitrates to nitrogen

$$NO^3 \Longrightarrow N_2$$

The reaction is achieved by generation of chemoautotrophic bacteria that is sustained by the carbon source from the recirculated activated sludge and incoming raw sewage. Subsequently, activated sludge process was carried out in the presence of recirculated biomass produced.

III. Study Data

a) Incoming Sewage Characteristics

A typical trend of the physical and chemical parameters of feed and treated water samples are summarized below:

S. No	Parameter	Unit of measurement	Value
1.	pH		6.68
2.	BOD	mg/l	370
3.	COD	mg/l	1190
4.	TDS	mg/l	1450
5.	TSS	mg/l	110
6.	Total Ammoniacal Nitrogen	mg/l	56
7.	Total Kjeldahl's Nitrogen	mg/l	60
8.	Ibuprofen	mg/l	1.65
9.	Diclofenac	mg/l	9.70
10.	Sulfamethoxazole	mg/l	0.15
11.	Estrone	mg/l	0.10
12.	Estriol	mg/l	1.52

b) Treatment Plant Design and Capacity

S. No	Parameter	Unit	Value
ORGANIC LOAD TO THE AERATION BASIN			
1.	BOD Load	Kg/d	285
2.	Total Kjeldahl Nitrogen Load	Kg/d	90
3.	Recirculation Flow Rate	M^3/h	250
4.	Inert Compounds Loading	Kg/d	3.72
5.	Endogenous Decay Constant		0.05
SLUDGE GENERATION CONSIDERATIONS			
6.	Observed Biomass Yield	Kg VSS/ Kg BOD Removed	0.51, 0.14
AERATION BASIS			
7.	Oxygen Required for BOD	Kg	1.25
8.	Air Flow Rate	m^3/h	481, 727

c) Membrane Bio Reactor

The Sewage Treatment plant has Zee weed 500, 68 Modules located in two tanks. Each tank has 34 modules set of modules operate parallel to each other.

The current operating cycle of the MBR modules are as follows,

Service : 8 mins

Backwash : 40 secs.

Membrane air scouring : 250 m^3/hr
Operating Flux : 28 lmh

2. Process Modelling

Identification of Parameters

In order to optimize and model the biomass production and f/m ratio, a number of factors such as inlet MLSS, hydraulic retention time, solid retention time, sludge volume index and plant capacity were identified. Statistical optimization procedure is used simultaneously to estimate the overall main parameter effects and interactive effect of the parameters on the biomass production and food to microorganism ratio. Two levels were set for each parameter as represented in table 1. The air supply level and feed capacities were adjusted accordingly to achieve the design parameter levels. F/M ratio and biomass concentration were considered the response factors.

Table 1 Experimental ranges and levels of factors used in the process modelling

Parameters	Range and level	
	+1	-1
Plant Hydraulic loading – m3/day	1500	800
Aeration tank Hydraulic Retention Time (HRT) – in hrs	12	5
MLSS (kg/m^3)	12	8

IV. CALCULATIONS

a) Biomass Concentration

$$Biomass\ Concentration\ (X) = \frac{SRT}{HRT}\{\frac{Y(S_0 - S)}{1 + K_d SRT}\}$$

Where, X is the Biomass Concentration (Kg/m^3), SRT is the Solid retention Time (days), HRT is the Hydraulic Retention Time (Days), Y is Observed Biomass Yield (Kg Vss/ Kg BOD), K_d is the endogenous decay constant, S_0 is MLSS (Kg/m^3) and S is the limiting substrate concentration (Metcalf & Eddy, 2003).

Analytical Methods

Micro pollutant levels in terms of pharmaceutical pollutants (Ibuprofen, Dochlofenac etc.,) in the raw sewage was analysed in accordance to previously validated methods (Munoz et al., 2009). Extraction of the compounds was carried out by solid-phase extraction according to Camacho-Munoz et al., 2009. Chromatographic analysis was performed using an HPLC instrument. This was carried out by gradient elution with acetonitrile and a 25 mM potassium dihydrogen phosphate solution.

V. RESULTS AND DISCUSSION

Effect of Hydraulic Retention time, solid retention time and Sludge Volume Index on Production Analysis of Variance

Table 2 summarizes the effect of process parameters on biomass concentration. The main focus of this study was to determine the effect induced by the process parameters including HRT, SRT and SVI on the production of biomass. The results indicated that the main effects of HRT, SRT and SVI showed negative effect on the biomass concentration as indicated by the coefficients. However, the two level interactive effects of all the process parameters showed positive correlation. This indicated that all the parameters were crucial in determining the formation of biomass. The P-value plays a major role in determining the significance of the factors and their interactions. Factors and their interactions exhibiting P-value less than 0.05 are considered as significant. The remaining insignificant parameters were eliminated from the model as they showed no effect on the process. Considering the co-efficient of significant parameters, biomass concentration was modelled using the following equation:

Biomass Concentration = 226.53 – 46.72(HRT) – 25.59 (SRT) – 31.52 (SVI) + 9.66 (HRT * SRT) + 12.98 (HRT * SVI) + 7.11 (SRT * SVI)

The R-Squared value of 99% showed a 1% deviation from the linear model applied to the biomass production level.

Table 2 ANOVA Table to evaluate the Effect of Hydraulic Retention time, solid retention time and Sludge Volume Index on Biomass Concentration

Source	Co-Efficient	Sum of Squares	F- Value	P- Value
Constant	113.46			
HRT	-46.72	116977	3952.552	0
SRT	-25.59	109437	1186.10	0
SVI	-31.52	31043	1043.28	0

HRT * SRT	9.66	18555	200.02	0
HRT * SVI	12.98	5263	176.89	0
SRT * SVI	7.11	4924	53.06	0
R-Sq	99%			

Normal Probability Plot

The type of effect induced by the significant parameters on biomass production was confirmed using the normal probability plot [Palanikumar et al., 2006]. The points close to the fitted line does not exhibit any significant effect on the model. Points away from the line represent the significant effects on the model [Palanikumar et al., 2006]. The position of points representing the significant effects determines the type of effect induced on purity. On analysing the normal probability plot for biomass production (Fig. 3), it was found that the main effects of HRT, SRT and SVI showed negative correlation effect of approximately 50%. Hence it was concluded and confirmed that the parameters should be maintained at permissible low levels to achieve greater biomass production and hence the removal of the same as sludge.

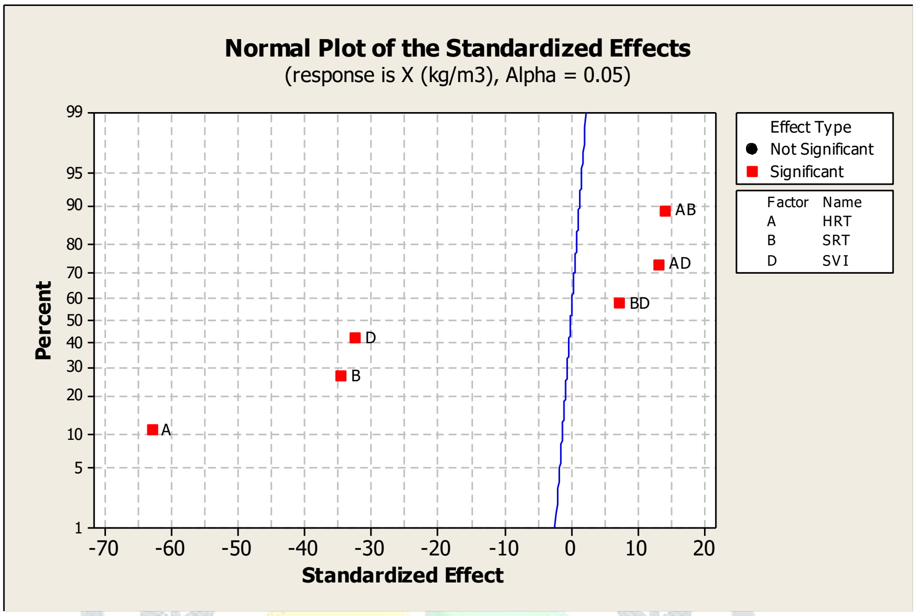

Figure 3 Normal plot to find the nature of Effect induced by Hydraulic Retention time, solid retention time and Sludge Volume Index on Biomass Concentration

Optimization of Response Parameters for the Biomass Production

Optimization of the factors on Biomass production was carried out using desirability function (D) [Palanikumar et al., 2006]. Desirability function is used to find the optimal condition that provides the most desirable response value. The main objective of this work is to enhance the biomass production and hence the removal of micropollutants from the sewage. Based on the results of ANOVA table and normal probability plot, the factors were set at different ranges using response optimizer to achieve maximum desirability. The combination that gave maximum desirability is represented in the response optimization plot (Fig. 4). It was found that a maximum of 250 Kg/m^3 of biomass content is achievable when hydraulic retention time is maintained at 5h, SRT is maintained at 11 days and at SVI of 100 keeping the feed capacity constant at 1500 m^3/day.

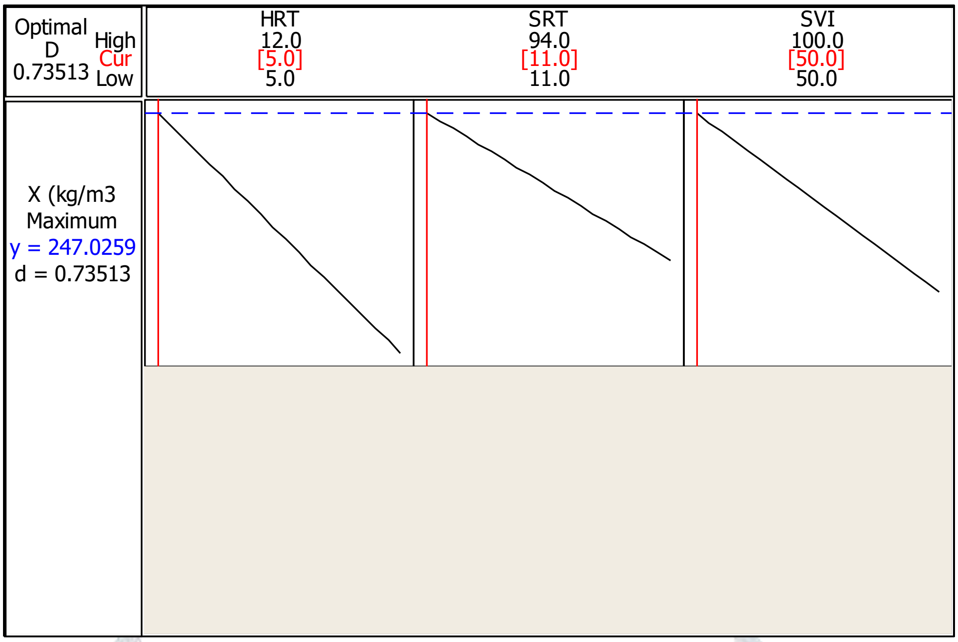

Figure 4 Desirability Plot to find the optimal levels in order to achieve maximum biomass production

Based on the response optimization, the plant was operated at HRT of 5h at 11 days of SRT and sludge volume index of 50. This was achieved by gradually increasing the plant hydraulic loading rate from 800 m3/day to 1500 m3/day over a period of 6 months. All the chemical parameters and micro pollutant levels were monitored in the raw and treated samples after achieving the optimal conditions. Their levels and removal efficiency of the MBR are summarized in below table.

S. No	**Parameter**	**Unit of measurement**	**Raw Sewage**	**Treated Sample**	**Removal Efficiency (%)**
1.	pH		6.68	7.00	-
2.	BOD	mg/l	370	5	99
3.	COD	mg/l	1190	38	97
4.	TDS	mg/l	1450	1160	80
5.	TSS	mg/l	110	<1.0	99
6.	Total Ammoniacal Nitrogen	mg/l	56	1.40	0.025
7.	Total Kjeldahl's Nitrogen	mg/l	60	<5	92
8.	Ibuprofen	mg/l	1.65	<0.05	~ 99
9.	Diclofenac	mg/l	9.70	<1	~ 99
10.	Sulfamethoxazole	mg/l	0.15	<0.05	~ 99
11.	Estrone	mg/l	0.10	<0.01	~ 99
12.	Estriol	mg/l	1.52	<0.1	~ 99

Overall, considering the removal of micro pollutants in the system, a 99% removal efficiency was seen. The results confirmed the suitability of the MBR in removal of the micropollutants that enter the system through domestic sewage.

VI. CONCLUSIONS

A study on the removal of micro pollutants as biomass from the MBR plant was conducted. A maximum of 250 Kg/day of biomass could be obtained from the plant if it is operated at HRT and SRT of 5h, 11 days at 1500 m^3/h Hydraulic Plant capacity maintained at SVI of 50. Effectively, 87% of biomass production was obtained when plant was run using the optimized process parameters. Further, a 99% efficiency in removal of major micro pollutants was achievable with the plant. Overall, it was concluded that MBR is an efficient technology compared to conventional methods as it can handle heavy load of MLSS and can yield treated water free of micro pollutants and fecal coliforms. However, new technologies are required in this area to reduce the operation and maintenance costs of the plant.

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