

Effect of MLSS, Hydraulic Loading Rate and Dissolved Oxygen on Food to Microorganism Ratio in a Submerged Membrane Bioreactor

¹S. Mohanraj, ²R. Mohanraj

¹Regional Manager Facilities, Infosys Limited, Bangalore (India)

²Department of Environmental Management, Bharathidasan University, Tiruchirappalli (India)

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*Corresponding Author

Email: mohanraj@infosys.com

ABSTRACT

Membrane bioreactor (MBR) is a technique where membranes are applied to biological wastewater treatment for biomass separation. However, their widespread application is restricted due to membrane fouling. One of the important parameter that is crucial for membrane life is that of the food to microorganism ratio in the reactor. The current investigation attempted to find the effect of mixed liquor suspended solids (MLSS), hydraulic loading rate and dissolved oxygen levels on food to microorganism (F/M) ratio. The MBR system consisted of 68 modules of Zee weed 500 ultrafiltration membrane (UF) placed inside a reactor. The results showed that the hydraulic loading rate and MLSS showed direct proportionality to f/m ratio. On the other hand, the dissolved oxygen content was found to be independent of f/m ratio, however playing a crucial role in for microorganism growth. Overall it was optimized that the plant could be maintained at f/m ratio of 0.2 when operated at MLSS of 8 kg/m³ at hydraulic loading rate of 1500 m³/day with DO levels maintained at 1.5 mg/l. Maximum BOD and COD removal was achieved in the treated water with consistent settleable sludge

1. Introduction

A desirable treated sewage is one that is free from organic, biological and mineral contaminants. In order to achieve this, treatment processes that are reliable, cost efficient and effective in removing a wide range of pollutants is required. Recent developments in membrane technology, has given the motivation to develop membrane bioreactors for various wastewater treatments. A membrane bioreactor (MBR) is a combination of membrane module and a bioreactor. The bioreactor acts as a biological treatment processor and the membrane is used as a filter in the filtration process.

Ever since the research on membrane bioreactor began over 30 years ago, the technology has undergone several changes. A brief description on the various stages of evolution of membrane bioreactors are depicted in figure 1. 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(c)). The diffusers provided the oxygen necessary for biological treatment to take place and scour the surface of the membrane to remove deposited solids. This proved efficient in tackling the membrane. However this process was restricted to small lab-scale applications. Subsequently, the invention of air-backwashing techniques for membrane de-clogging led to the development of using the membrane as a clarifier thereby eliminating the need for an additional tank. 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. This method has undergone several changes with respect to the design and in recent times two different methods are being used with regards to MBR, namely submerged MBRs and side stream MBRs. Submerged technologies are more cost effective for large scale applications. Side stream MBR technology is favored for smaller-scale applications.

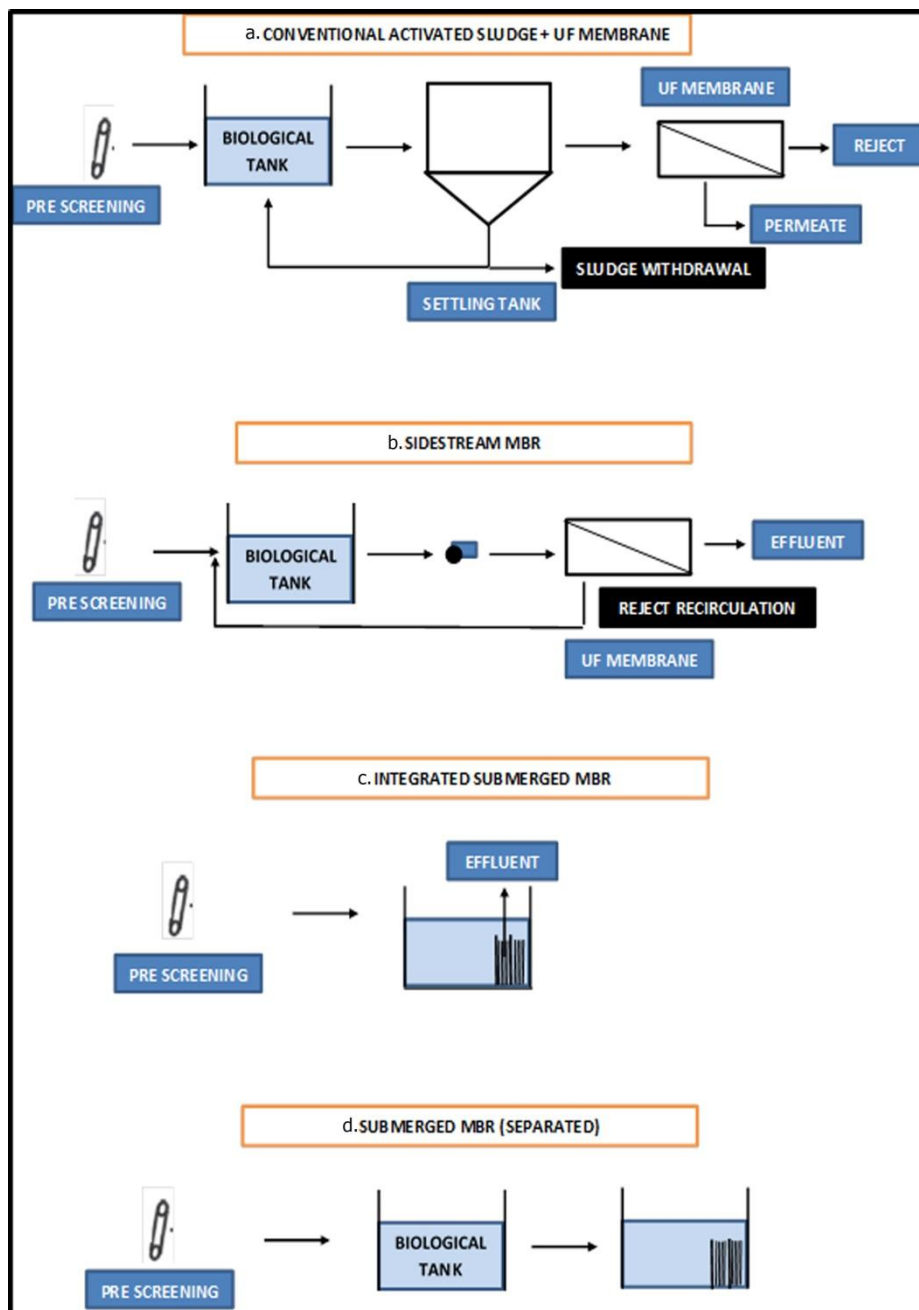


Figure 1. Evolution of MBR through the years

According to the global market for MBR, the growth rate and demand is over 10% due to the effectiveness of the process in removing the contaminants and micro-pollutants present in waste water. Further, the cake can be easily removed from the MBR system compared to other methods indicating its suitability in the industrial scale (Tabraiz et al., 2017; zuthi et al., 2017). Despite its reliability, high costs, membrane maintenance and fouling issues have slowed down the interests on MBR. [17]

The food to microorganism (F/M) ratio is one of the significant design and operational parameters of membrane bioreactor systems. It plays a crucial role in affecting the nature of sludge formed and hence forms the major determinant of membrane fouling. A high F/M indicates higher BOD and COD contents leading to formation of inadequately digested biological sludge. This can lead to poor separation of sludge from the effluent. On the other hand, if F/M ratio is at

low levels, the bacteria begin to form a thick slime layer losing their motility. As a result, a slimy floc is formed that settles down in the tank. The sludge hence cannot be separated from the effluent leading to choking of the tank and hence leads to membrane fouling.

Thus, in light of the above, the current investigation aimed to provide an understanding of the factors that affect the F/M ratio.[17]

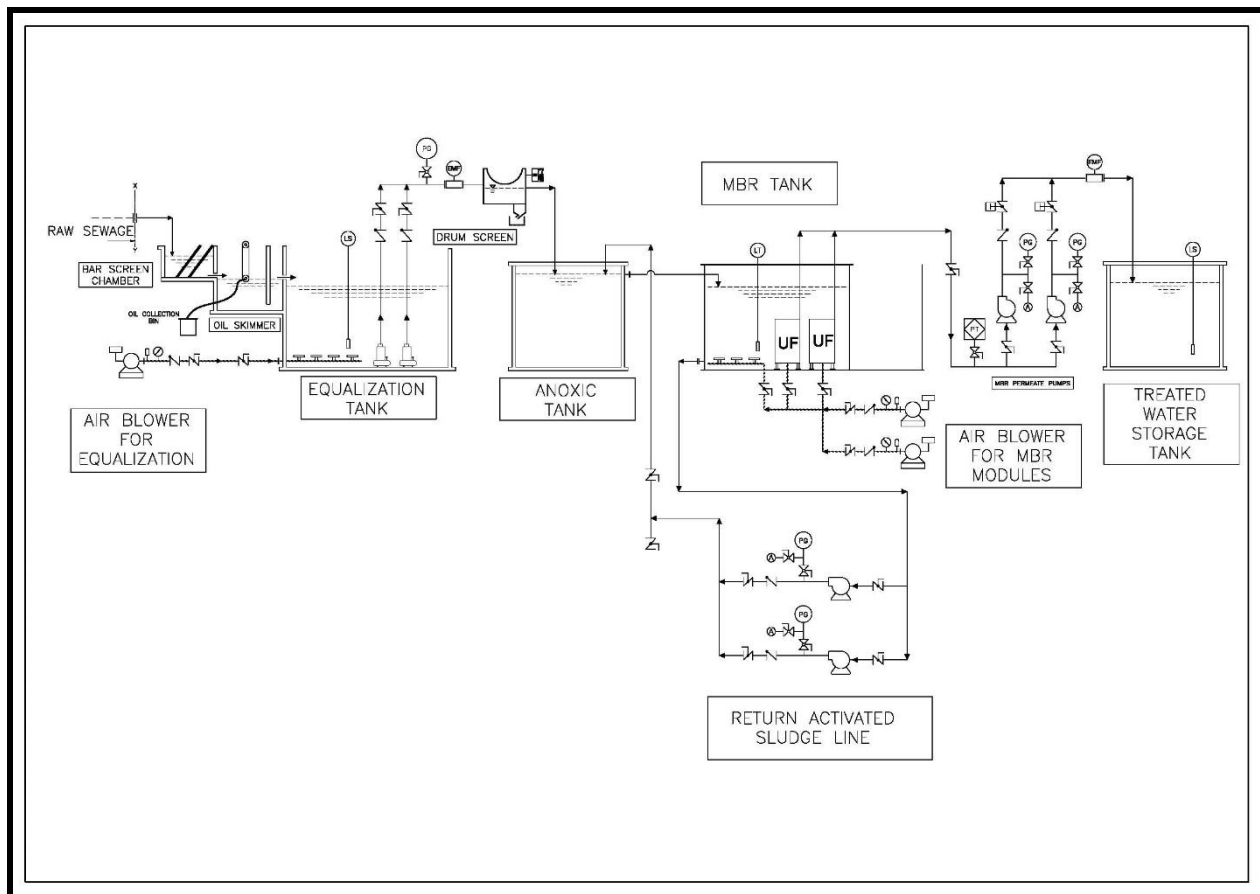
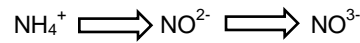
2. Materials and Methods

2.1 Study Area

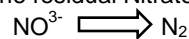
The study was conducted on a currently operating MBR based sewage treatment plant (Figure 1). The plant is located in an IT campus. The sewage and canteen wash water generated from the campus are collected and treated in a centralised sewage treatment plant. The plant has a design

capacity to treat 1500 m³/day of incoming sewage. The incoming sewage was received in screen chamber to trap debris and large particulate material. The sewage then collects in a collection cum equalisation 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,



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



a) Incoming Sewage Characteristics

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.

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

2.2 Study Data

| S. No | Parameter | Unit of measurement | Value |
|-------|---------------------------|---------------------|-------|
| 1. | pH | | 6.68 |
| 2. | BOD | mg/ltr | 370 |
| 3. | COD | mg/ltr | 1190 |
| 4. | TDS | mg/ltr | 1450 |
| 5. | TSS | mg/ltr | 110 |
| 6. | Total Ammoniacal Nitrogen | mg/ltr | 56 |
| 7. | Total Kjeldahl's Nitrogen | mg/ltr | 60 |

a) Study Area Design

| S. No | Parameter | Unit | Value |
|-------------------------------------------|------------------------------|-------------------|-------|
| ORGANIC LOAD TO THE AERATION BASIN | | | |
| | BOD Load | Kg/d | 285 |
| | Total Kjeldahl Nitrogen Load | Kg/d | 90 |
| | Recirculation Flow Rate | m ³ /h | 250 |
| | Inert Compounds Loading | Kg/d | 3.72 |
| | Endogenous Decay Constant | | 0.05 |
| SLUDGE GENERATION CONSIDERATIONS | | | |
| | Biomass Concentration | Kg/m ³ | 250 |
| AERATION BASIS | | | |
| | Oxygen Required for BOD | Kg | 1.25 |
| | Air Flow Rate | m ³ /h | 500 |

b) 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 | : 28lmh |

3. Process Modelling

3.1 Identification of Parameters

In order to optimize and model f/m ratio, a number of factors such as inlet MLSS, hydraulic loading rate and dissolved oxygen level were identified. 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 was 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 – m ³ /day | 1500 | 800 |
| Dissolved oxygen (mg/l) | 1.5 | 2 |
| MLSS (kg/m ³) | 12 | 8 |

4. Calculation

a) F/m ratio

$$F/M = \frac{Q \times S_0}{V \times X}$$

Where, X is the Biomass Concentration (Kg/m³), So is the MLSS concentration (Kg/m³), V is the tank volume and Q is the hydraulic loading rate (m³/day).

5. Results And Discussion

5.1 Analysis of Variance (ANOVA)

The anova table showed that f/m ratio was influenced by the main effects of feed capacity, MLSS. The dissolved oxygen concentration and 2nd level effects of the parameters did not show any direct significance in affecting the f/m ratio. This showed that hydraulic loading and MLSS was crucial for determining the f/m ratio. The nature of effect induced by the parameters was analysed using the normal probability plot. An R-Squared value of 96% showed a 4% deviation on the model.

Table 1 ANOVA Table to evaluate the Effect of feed capacity, MLSS and biomass concentration on Biomass Concentration

| Source | Co-Efficient | Sum of Squares | F- Value | P- Value |
|-----------------------|--------------|----------------|----------|----------|
| Constant | 0.061 | | | |
| Hydraulic Loading | 0.018 | 0.0027 | 125 | 0.001 |
| S _o (MLSS) | 0.012 | 0.0012 | 53.98 | 0.001 |
| R-Sq | | 96% | | |

Considering the co-efficients of significant parameters, biomass concentration was modelled using the following equation:

$$f/m = 0.061 + 0.018 (\text{hydraulic Loading}) + 0.012 (\text{MLSS})$$

5.2 Normal Probability Plot

The nature of effect induced by the individual parameters was identified using the normal probability plot [Palanikumar et al., 2006]. The position of points representing the significant effects determines the type of effect induced on f/m ratio. From figure 1, it was found that the main effect of the hydraulic

loading and MLSS was directly proportional to the f/m ratio. Any change in the loading, impacted the MLSS level and hence the f/m ratio. Hence the result showed that the parameters had to be maintained at optimum levels in order to effect constant and consistent sludge formation. The dissolved oxygen concentration was deemed as out of fit as it was found

to have no direct significance on the f/m ratio. However, the parameter proved crucial for growth of microorganisms.

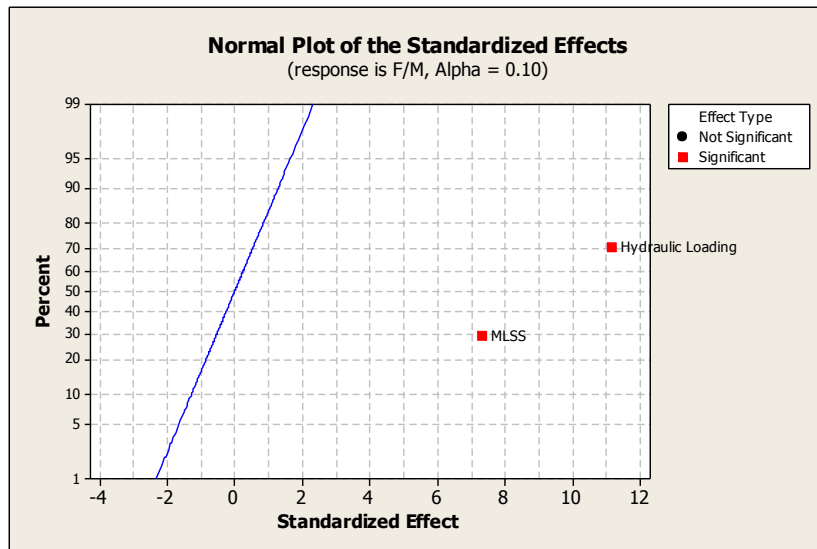


Figure 1. Normal plot to find the nature of Effect induced by hydraulic loading rate, biomass concentration and MLSS on F/M ratio

5.3 Main Effects Plot for F/M Ratio

Main effects plot helps to determine the optimum levels of each process parameter in order to achieve the desired f/m value [Palanikumar et al., 2006]. From figure 2, it was identified that the plant could be maintained at f/m ratio of 0.2 when the it was maintained at loading rate of 1500 m³/day at MLSS of 12 kg/m³ with biomass levels maintained constant at

250 kg/m³. Further, the plot also indicated that dissolved oxygen levels were independent and affected the microorganism growth. Hence it was concluded that DO needs to be maintained at status quo level based on the incoming feed levels.

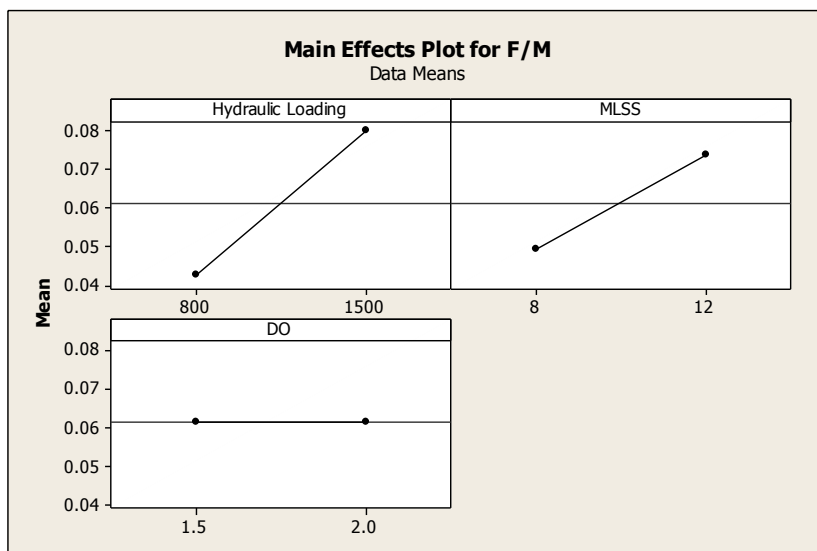


Figure 2 Desirability Plot to find the optimal levels in order to achieve maximum biomass production

The plant was operated in accordance to the main effects plot and an f/m ratio of 0.2 was achieved.

6. Conclusions

A study on the effect of hydraulic loading rate, MLSS and dissolved oxygen on the f/m ratio was studied. The results suggested that the plant needs to be operated at hydraulic loading rate of 1500 m³/day at MLSS of 12 kg/m³ to achieve optimal f/m ratio of 0.2. Further, the results showed that Dissolved oxygen did not have any direct significance in affecting the f/m ratio. However, the parameter proved to be crucial for survival of microorganisms and hence for the

consumption of BOD and COD. It was inferred from the study that f/m was crucial to prevent membrane fouling. If f/m went above 0.2, the sludge diluted resulting in improper filtration. On the other hand, if it was below 0.15, the sludge thickened leading to membrane fouling. Overall, it was concluded that MBR is an efficient technology compared to conventional methods as it can handle heavy load of MLSS. However, the f/m ratio should be periodically monitored in order to sustain the purification levels.

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