Development of a new approach to the design of a pilot plant for a modified submersible rotating biofilter

M Saied¹, N Serpokrylov² and V Nelidin³

¹ Postgraduate Student Of The Department Of Water Supply And Sanitation, Don State Technical University, Rostov-On-Don, Russia
² Professor Of The Department Of Water Supply And Sanitation Don State Technical University, Rostov-On-Don, Russia
³ Lecturer of the Department of Water Supply and Sanitation Don State Technical University, Rostov-On-Don, Russia

E-mail: e-ms-87@hotmail.com

Abstract. The Modified Submersible Rotating Biofilter (MSRB) was developed and patented for the treatment of wastewater from small settlements in Syria. A pilot plant has been developed to study the biological treatment process and its optimal parameters. In this article, on the basis of theoretical studies, a refined design methodology and calculation of the dimensions of the MSRB pilot plant are justified and proposed.

1. Introduction

Rotating biological contactors RBC are one of the most widely used wastewater treatment plants in the world [1]. In Syria, they have a priority and the prospect of being used in small settlements due to their technical and technological advantages, taking into account the climatic and geographical features of these territories [2]. The MSRB was developed to improve the aerobic biological wastewater treatment of small settlements in Syria by introducing structural modifications to the biofilter body, which allow to increase the oxygen transfer rate without the use of additional aeration devices, and as a result leads to a reduction in operating costs and an increase in process efficiency.

The study of the biological treatment process at the MSRB and the efficiency of its operation requires the creation of a pilot plant for conducting research and laboratory experiments, therefore in this article we present a new approach to the design of MSRB pilot plant, which has a modified design that is different from traditional types.

2. Materials and methods

Theoretical bases for the design of the MSRB pilot plant.

The modified submersible rotating biofilter MSRB (RF patent No. 2 720 150 C1) drum type differs from the traditional ones in the following solutions:

- Increasing the drum diameter / length ratio to 1.5, since increasing the drum diameter increases the length of the path traversed by the biomass carrier, which allows more oxygen to be captured from the air in its pores;
Creation of eight ventilation gaps in the cross section of the drum, diagonally, each gap equal to 1% of the drum perimeter. These gaps allow for uniform aeration for the biomass carrier in the inner and outer layers of the biofilter;

Creation of a ventilation gap equal to 6% of the drum length, perpendicular to the rotation shaft, so that the drum is divided into two adjacent cylinders connected by ribs. Each cylinder consists of two support rings connected by ribs in the center and along the perimeter, and bounded by a mesh. This gap allows aeration of the biomass carriers in the middle of the biofilter, which have little contact with atmospheric oxygen;

Installation of 16 scoops in the form of an open rectangular box around the perimeter of the drum with a length equal to its length. These scoops raise water and then pour it out through a flat weir as the drum rotates. This provides additional aeration of the wastewater inside the biofilter tank, thereby creating additional contact of the biomass carriers with wastewater during rotation in the atmosphere and improves the mixing of wastewater inside the filter tank, which increases mass exchange and oxygen transfer at the same time;

Division of each cylinder in the drum into eight cells, separated from each other by ventilation gaps and filled with mobile (movable) biomass carriers. The walls of each cell are made of a mesh attached to support rings and ribs. Inside each cell, a rod is mounted for mixing the biomass carriers perpendicular to the rotation shaft, which prevents clogging and agglomeration of the biomass carriers and improves the process of mass transfer and oxygen transfer to the feed material;

The use of mobile the biomass carriers with a large surface area: the first - type XEL-X (HXF13KLL +) has a cylindrical shape with a diameter of 13 mm and a length of 12 mm, a surface area of 806 m²/m³, made of recycled high density polyethylene granules HDPE. The second the biomass carrier of the XEL-X type (HEL-X flake 30) has the form of biochips with a diameter of 30 mm and a thickness of 1.1 mm, the active surface area is> 5000 m²/m³, made of primary HDPE granules.

The use of mobile biomass carriers with a small size and large surface area allows for complete mixing of the water and improves the oxygen transfer process, since these carriers have a great ability to capture oxygen. A large surface area allows a greater amount of biofilm to be fixed, thereby intensifying biological treatment and treatment of highly concentrated wastewater, reducing the number of required treatment steps and, consequently, reducing financial costs [3]. Figure (1) shows: (a) 3D view of the biofilter, (b) cross section, (c) biofilter frame.

3. Results and discussion
For the MSRB pilot plant design, a theoretical study of the RBC designing methods was carried out. When analyzing the sources of technical literature, it was noted that there is no standard algorithm for designing drum-type RBCs filled with mobile biomass carriers, although their use is not that recent [4]. As a rule, experimental observations form the basis of the calculated ratios and curves that are used to design the RBC used for the treatment of domestic wastewater and some types of industrial wastewater. The empirical models developed by RBC manufacturers cannot be adopted when designing RBC under conditions other than the experimental conditions in which these models were developed [1].

When developing innovative types of RBC, researchers rely on experimental laboratory models, the dimensions of which are postulated in a first approximation, and subsequently the results of their research are compared and the optimal parameters for their work are determined [5-8]. Russian technical literature gives some design parameters of this type of biofilters according to Yakovlev and Voronov, but without a clear algorithm for their calculation [9]. The most clear one is the algorithm for calculating drum-type RBC according to German standards ATV-DVWK-A 281E [10], which is adopted in our study for calculating and designing a the MSRB pilot plant.
Calculation of the MSRB pilot plant dimensions.
Our proposed method for calculating the MSRB pilot plant is divided into two stages:

- First stage of the calculation: initial design and calculation of a conventional drum type RBC pilot plant without any modifications in accordance with German standards ATV-DVWK-A 281E [10]. This stage is used to determine the initial data and dimensions required for the design of the MSRB pilot plant.

The initial values of the wastewater composition are taken as at the wastewater treatment plant of small settlements (Al-Ruemiya) in Latakia city, Syria [11]. To calculate the biofilter, we assume using mobile biomass carriers with a surface area of 280 m²/m³. (table 1) shows the design values of the wastewater flow rate Q_in; BOD₅ of incoming wastewater L_en,с; TN of incoming wastewater L_en, N.

| Q_in l/h | L_en,с mg/l | L_en,N mg/l |
|----------|-------------|-------------|
| 4        | 400         | 65          |

Table 1. Design values for pilot plant parameters.
According to the German standards for biological wastewater treatment with nitrification, theoretically three stages are taken for an organic loading rate for BOD5 $B_{A,BOD} \leq 8 \text{ g/m}^2\text{.day}$ and TKN loading rate $B_{A,TKN} 1.1 \text{ g/m}^2\text{.day}$ [10].

The required surface area $ARC$ is calculated according to equations (1, 2, 3).

\[
ARC, C = \frac{B_{A,BOD} \times 1000}{B_{A,BOD}} = \frac{400+424}{8+1000} = 4.8 \text{ m}^2
\]  

\[
ARC, N = \frac{B_{A,TKN} \times 1000}{B_{A,TKN}} = \frac{65+424}{1.1+1000} = 5.673 \text{ m}^2
\]  

\[
ARC = ARC, C + ARC, N = 4.8 + 5.673 = 10.47 \text{ m}^2 \approx 10.5 \text{ m}^2
\]  

Surface area required for each stage:

\[
ARC, 1 = \frac{ARC}{3} = \frac{10.5}{3} \approx 3.5 \text{ m}^2
\]

Volume corresponding to the calculated surface area for the required biomass carriers:

\[
X = \frac{(3.5 \times 1 \times 1000)}{280} = 12.46 \text{ l} \approx 12.5 \text{ l}
\]

Suppose this volume is equivalent to 75% of the drum size, and therefore the drum volume is:

\[
V_B = X \times 1.25 = 12.5 \times 1.25 = 15.625 \text{ l} = 15625 \text{ cm}^3
\]

Suppose that the drum diameter is $D = 30 \text{ cm}$, therefore, the drum length $LB$ is:

\[
LB = \frac{4 \times V_B}{\pi D^2} = \frac{4 \times 15625}{\pi \times 30^2} = 22.08 \text{ cm} \approx 22 \text{ cm}
\]

The calculated drum length is about 73% of the diameter, which helps to increase the oxygen transfer rate, that increases with increasing diameter.

Drum perimeter:

\[
W_B = \pi D = \pi \times 30 = 94.25 \text{ cm}
\]

The second stage of the calculation: making modifications to the initial calculation of the conventional drum type RBC pilot plant to determine the dimensions of the MSRB pilot plant.

The first modification: the creation of eight ventilation gaps in the cross-section of the drum diagonally, the width of each gap is equal to 1% of the drum perimeter $= 1 \text{ cm}$, thus, we obtain a new perimeter of the MSRB pilot plant:

\[
W_{MB} = W + [1 \times 8] = 94.25 + 8 \times 1 = 102.25 \text{ cm}
\]

New diameter of MSRB:

\[
D_M = \frac{W_{MB}}{\pi} = \frac{102.25}{\pi} = 32.55 \text{ cm} \approx 32 \text{ cm}
\]

The second modification: creation of a ventilation gap, perpendicular to the rotation shaft, width $= 1 \text{ cm}$, it is approximately equal to 6.25% of the drum length. New length of MSRB pilot plant:

\[
L_{MB} = L_B + 1 = 22 + 1 = 23 \text{ cm}
\]

The third modification: installation of 16 scoops in the form of an open box around the drum perimeter with a length equal to the drum length, 4 cm wide and 2 cm high. The volume of water carried by the scoop is equal to:

\[
Q_s = L_{MB} \times 4 \times 2 = 23 \times 4 \times 2 = 184 \text{ cm}^3 = 0.184 \text{ l}
\]

We take the dimensions of the MSRB tank as follows: the length of the tank is 33 cm, the width is 36 cm, and the height is 20 cm.
The fourth modification: the use of mobile biomass carriers with a large surface area. The first biomass carrier is type XEL-X (HXF13KLL +), its protected surface area is 806 m$^2$/m$^3$. The second biomass carrier is type XEL-X (HEL-X flake 30), its active surface area is > 5000 m$^2$/m$^3$. Filling the drum with these two biomass carriers allows to study the effect of changing the surface area of the virtual biomass carriers used for the initial design of the pilot plant on the number of stages required for treatment.

4. Conclusion
The modified submersible rotating biofilter MSRB was developed and patented for the treatment of wastewater from small settlements in Syria. To study the process of biological treatment and its optimal parameters, an experimental pilot plant should be created for carrying out the necessary experiments. In this article, a new approach to the design and calculation of the structural dimensions of the MSRB pilot plant is developed on the basis of a theoretical analysis of design methods and calculation of rotating biological contactors.

Acknowledgments
We thank GOODFEED company, Rostov on Don, Russia for supporting this study by providing biofilterms biomass carriers without any financial charge.

References
[1] Cortez S, Teixeira P; Oliveira R and Mota M 2011 Biodegradation 22 661–71
[2] Saied M A and Serpokrilov N S 2020 IOP Conf. Ser.: Mater. Sci. Eng. 778 775 012096
[3] Saied M 2020 IPC CO2F 150 2019137412
[4] Spengel D B and Dzombak D A 1992 Water Environ Res 64 223–34
[5] Hewawasam C, Matsuura N, Maharjan N, Hatamoto M and Yamaguchi T 2017 Biochemical Engineering Journal 128 162–7
[6] Sirianuntapiboon S and Tondee T 2000 Journal of Scientific Technology 5 28-39
[7] Davod K 2003 Improvement of wastewater treatment technology on rotating biocontactors (St. Petersburg) 165
[8] Hassard F, Biddle J, Cartmell E and Stephenson T 2016 Process Safety and Environmental Protection 103 69–75
[9] Voronov Yu V and Yakovlev S V 2006 Water disposal and wastewater treatment (Moscow Publishing house of construction universities) 704
[10] German Rules and Standards: Dimensioning of Trickling filters and rotating biological contactors 2001 (German Association for Water, Wastewater and Waste) 25
[11] Saied M 2014 Evaluating the efficiency of some sewage systems in Lattakia Governorate (MA thesis, Tishreen University, Syria) 126