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Factors Affecting Coverage Ratio of Fine Disc Air Diffusers in Aeration Tanks

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Abstract— *In this paper we studied the effect of different fine bubble disc diffusers coverage ratios (diffusers density) on the aeration efficiency compared with the associated increase in both implementation and maintenance costs. Studies were done on a wastewater treatment plant (WWTP) with a capacity of 20000 m3/day using SSI™ fine bubble diffusers - AFD270 9" disc - for four densities 2.5 %, 5 %, 10 % and 15 %. Each step in the increase in diffuser density was found to double the number of diffusers thus increasing the costs with only (2-3) % increase in the standard oxygen tranfer efficiency (SOTE). Data from eleven WWTPs in stable operation using two treatment methods and low diffuser densities of 2.5 % and 5 % showed that the average dissolved oxygen (DO) concentration in the aeration basins was above 5.50 mg/L. According to the theoretical design and monitoring of the operating WWTPs, four factors were documented and seen to affect the coverage ratio rather than the direct selection as recommended by fine discs manufacturers and suppliers. Findings in this paper helped to reduce the escalating controversy between designers and manufacturers and suppliers that was locally debated.*

Keywords— *Fine bubble diffusers, oxygen transfer rate, coverage ratio, aeration efficiency*.

I. Introduction

Aeration plays a vital role in biological aerobic wastewater treatment since its invention for the basic conventional systems and for all other modifications that emerged afterwards and for those that are still emerging. Aeration must be sufficient for the requirements of the biological reactions while at the same time ensuring good and homogenous mixing of the aeration tanks with no any dead points (Drewnowski et al. 2018; Al-Ahmady 2006). Numerous aeration devices have since been developed and many others are still underway but, however, these aeration devices can be grouped into two main categories; diffused aeration and mechanical aeration. Optimizing the design of aeration systems for both implementation and operation costs is a necessity as aeration alone consumes about (60-70) % of the total energy consumed in wastewater treatment plants (Amano *et al.* 2012; Drewnowski *et al.* 2019; Qasim & Zhu 2018; Lozano Avilés *et al.* 2020a). All current research work work is focused on the increase of the standard oxygen transfer efficiency (SOTE), standard oxygen tranfer rate (SOTR) and reducing the required power to tranfer one mass unit of oxygen.

An inverse relationship between the size of the air bubble and the rate of air dissolving in water, as the smaller the air bubble is, the greater the surface area of the total air bubbles, and consequently the rate of air dissolution within the water molecules increases, which increases the efficiency of aeration (Cheng *et al.* 2016; Herrmann-Heber *et al.* 2021). Fine air bubbles diffusers when used in suspended culture aeration tanks such as conventional activated sludge, extended aeration, etc. give better oxygen transfer efficiency taking into consideration the other factors involved (Schwarz *et al.* 2021). Diffusers density (coverage ratio) is the ratio of the area of the diffusers to the aeration tank surface area and it is one of the main factors that affect the volumetric oxygen transfer rate; it is also inversely proportional with the diffusers flux for a fixed oxygen transfer rate. Research studies and manufacturers technical data report an optimum diffuser density range of (5-20) % of the reactor surface area (Capela *et al.* 2001; Grundfos 2018). Studies on a plug flow activated sludge wastewater treatment plant using three diffuser densities of 49.57 %, 29.06 % and 21.37 % showed that oxygen transfer efficiency dropped by about 30 % when using diffuser density of 21.37 % compared with the higher density of 49.57 % (Lozano Avilés *et al.* 2020b). This high diffuser density decreases the energy consumption but increases the initial capital costs of implementation and maintenance together with the increased surface coverage of the reactor floor making it difficult to maintain. It is also important to note that there is a maximum value for the diffusers density after which the recorded SOTE increase is negligible (diminishing returns), which is calculated by airflow rate, diffuser size and the spacing between diffusers (Baquero-Rodríguez *et al.* 2018; U.S. EPA, 1989).

In all aeration systems, apart from aeration required for oxidation of matter, it is always required to maintain a minimum level of aeration within the reactors at all times, regardless of the quantity of flow nor concentration, to maintain minimum mixing requirements to assure that organisms come into contact with the food source within the incoming wastewater. The recommended homogenous mixing aeration values represent calculated values of velocity gradient (G) for different tank depths and range (0.01-0.015) m^3 air/m^3 of tank volume/minute for grid systems (Tchobanoglous *et al.* 2003; U.S. EPA, 1989). Energy requirements for aeration, that are expressed interms of the standard aeration efficiency (SAE), are highly dependant on the diffuser density together with many other factors and values recorded in literature for fine bubble diffuers discs are in the range (2-7) kgO_2/kWh (Longo *et al.* 2016; Lozano Avilés *et al.* 2019; Tchobanoglous *et al.* 2003)

This research paper addresses the effect of fine disc air diffusers density (coverage ratio) in aeration tanks with regards oxygen transfer efficiency and implementation and energy costs savings. It also clarifies the debate that has been and is always raised up by manufacturers that increasing diffuser density increases SOTE regardless of the high installations cost. This will be done by demonstrating theoretical calculations and practical applications in existing operating wastewater treatment plants (WWTPs). Factors affecting the coverage ratio of fine discs in the aeration tanks are also thoroughly defined.

II. MATERIALS AND METHODS

2.1 SOTE theoretical calculations for different diffuser densities

Theoretical calculations were done on a wastewater treatment plant with a capacity of 20000 m^3/day and diffusers were calculated for three different diffuser densities 5 %, 10 % and 15 % apart from the basic design of 2.5 %. The following factors were taken into consideration during the design of the aeration basins: -

1) Aeration rate required for aeration basins

Biological oxidation requirements

The amount of oxygen needed to oxidize organic matter is initially calculated by assuming the value of the rate of oxygen consumption needed to oxidize a kilogram of organic matter (BOD), which is in the range of (1-kilogram oxygen/1-kilogram organic matter), consequently the daily standard oxygen quantity is determined. The actual required amount of oxygen is calculated according to the characteristics of the wastewater and the nature, climate and topography of the WWTP area.

The required air volume is determined through a set of values such as the percentage of oxygen in the air, oxygen density and the efficiency of oxygen-to-water transfer. The efficiency of oxygen-to-water transfer is imposed according to the recommendations of air diffuser suppliers that the aeration rate of the diffuser is in the middle of the diffuser operating range, and according to (Figure 1) (SSI aeration systems 2022). The oxygen transfer efficiency of water is almost imposed at 6.5% per meter of the side water depth; the total air discharge required for the oxidation determined, air blowers are sized to provide the calculated air discharge and then the required number of diffusers is determined based on a SSI™ fine bubble diffuser - AFD270 9" disc.

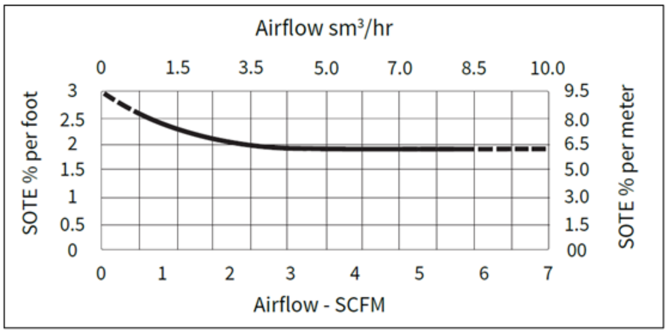

Figure 1 Relationship between the aeration rate of air diffusers and the efficiency of oxygen transfer to water (SSI aeration systems 2022)

Mixing requirements

Aeration for the homogenous mixing requirements are calculated as given by Tchobanoglous *et al.* 2003.

2) Required number of air diffusers

Of the several factors available for determining the number of fine disc diffusers, the following most two important factors were obeyed.

Diffusers flux

Diffuser flux is taken as per specifications of the SSI™ fine bubble diffuser - AFD270 9" disc given by the manufacturer which include: -

- Design flow rate: (2.5-5.0) Sm^3/hr
- Full flow range: (0-7) Sm^3/hr
- Active surface area: 0.0375 m^2
- Membrane pore size = 1 mm
- Membrane material = EDPM

Diffusers spacing

Diffusers should be equally spaced and symmetrically placed at the floor of aeration tanks. This arrangement should allow for easy access for walking during installation and periodic maintenance. Minimum clear walkway distance of 51 cm (20 inches) is usually sufficient and a maximum clear distance of 100 cm (3.28 ft) is highly recommended to prevent the formation of both dead zones and spiral bubble flow within the air basins (U.S. EPA, 1989). Recently, suppliers and manufacturers recommended the choice of the number of disc diffusers and consequently the spacing between diffusers depending on the coverage ratio (diffuser density) which they see is better ranged between 5 % to 20 % of tank surface area (Grundfos 2018).

3) WWTP design output

- Design flow rate of the plant=20000m^3/day
- Type of treatment technology = Extended aeration
- No. of aeration tanks = 2tanks
- Length of aeration tank = 84m
- Width of aeration tank = 36m
- Water depth of aeration tank= 5.50m
- Surface area per aeration tank= 3024m^2/tank
- Total surface area of aeration tanks= 6048m^2
- Water volume per aeration tank= 16632m^3/tank
- Total volume of aeration tanks= 33264m^3
- No. of duty air blowers = 4blowers
- Air flow rate per air blower= 5100m^3/hrs/blower
- Total air flow rate of air blowers= 20400m^3/hrs
- Type of air blowers= Positive displacement

Checking the homogenous mixing requirements

- Aeration rate per meter cubic of aeration tank

= 20400/33264

= 0.613 m^3/m^3/hrs

= 0.0105 m^3/m^3/min

(In design range 0.01 – 0.015 m^3/m^3/min)

Design of fine disc air diffusers (flux, density, number)

- Assume the diffuser type is (9")
- Diffuser full working range

= 0-7.0 m^3/hrs/diffuser

- Assume diffuser design aeration rate

= 5.0 m^3/hrs/diffuser

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- Required no. of air diffusers
  = 20400/5
  = 4080 diffusers
- Air diffusers per aeration tank
  = 4080/2
  = 2040 diffusers/tank
- Effective area per air diffuser
  = 0.0375 m^2/diffuser
- Total effective area of air diffusers per aeration tank
  = 0.0375*2040
  = 76.50 m^2/tank
- % Effective coverage area
  = 76.50/3024
  = 2.53 %
- Diameter of disc air diffuser
  = 0.277 m
- Actual coverage area per air diffuser
  = 3024/2040
  = 1.482 m^2
- Spacing between 2 sequence diffusers
  = $(1.482)^{0.5}$-0.277
  = 0.94 m
  (Accepted, less than 1.0 m)

4) Required fine disc diffusers for 5 % density

- The number of air diffusers required to cover 5 % of the basins according to the effective area of the diffusers
  = 6048*0.05/0.0375
  = 8064 diffusers
- Actual aeration rate per diffuser
  = 20400/8064
  = 2.53 m^3/hrs/diffuser
- SOTE at 5 % density
  = 6.5*5.5 = 35.75 %

5) Required fine disc diffusers for 10 % density

- The number of air diffusers required to cover 10 % of the basins according to the effective area of the diffusers
  = 6048*0.10/0.0375
  = 16128 diffusers
- Actual aeration rate per diffuser
  = 20400/16128
  = 1.26 m^3/hrs/diffuser
- SOTE at 10 % density
  = 7.0*5.5 = 38.50 %

6) Required fine disc diffusers for 15 % density

- The number of air diffusers required to cover 15 % of the basins according to the effective area of the diffusers
  = 6048*0.15/0.0375
  = 24192 diffusers
- Actual aeration rate per diffuser
  = 20400/24192
  = 0.84 m^3/hrs/diffuser
- SOTE at 15 % density
  = 8.0*5.5 = 44.00 %

B. Practical field data from existing wastewater treatment plants

Samples of existing WWTPs operating in Egypt and using the same fine bubble disc diffusers are shown in Table 1. A total of eleven WWTPs with different flow rates, six operating with step feeding technology and the remaining five operating with extended aeration technology. All the eleven WWTPs are in operation and are giving stable effluent results.

TABLE 1 Fine discs diffusers data for existing WWTPs operating in Egypt

WWTP	Design capacity (m^3/day)	Technology	No. of aeration tanks	Dimensions of (A.T.) (m)			Total No. of air diffusers	Effective area per air diffuser (m^2)	% Coverage area of air diffusers
				Length	Width	Water depth			
Hazek	14000	**Step feeding**	2	55	12	5.5	1800	0.0375	**5.18**
Ain Ghosien	7000		2	40	9	5	1000	0.0375	**5.28**
Denohia	14000		3	50	14	5.5	2850	0.0375	**5.16**
Gabal El Tair	7500		2	49	12.5	5	1632	0.0375	**5.06**
Mahalet Diaay	7000		2	40	11.5	5	1360	0.0375	**5.62**
El Boghdady	9000		3	40	12.5	4.9	1800	0.0375	**4.56**
Eqleet	20000	**Extended aeration**	2	84	36	5.5	3840	0.0375	**2.41**
El Ramady	10000		2	60	25	5.5	1904	0.0375	**2.41**
Wady Abady	3000		3	30	10	5.5	648	0.0375	**2.74**
El Radesia	5000		2	50	15	5.5	960	0.0375	**2.43**
Fars	2000		2	35	12	4	528	0.0375	**2.39**

III. Results and Discussion

3.1 Theoretical calculations for different diffuser densities

Values indicated in Table 2 show the summary of the calculated output for the different diffusers coverage area starting from the basic design (BD) with a density of 2.5 % and ending with 15 % density. From these values we can deduce that by increasing the coverage ratio from 2.5 % to 5 % we double the number of diffusers and achieve an increase of aeration efficiency of 2.75 % only and the diffusers flow rate drops to almost half. Also the spacing between the diffusers is reduced by about 0.35 m. Almost similar increment values can be noticed by further increasing the coverage ratio. In general, we can see that the double increase in the implementation costs of the aeration system is only rewarded by a 2.75 % increase in efficiency. Further increase of the coverage ratio drops the diffuser flow rate out of the optimum operating range and drastically reducing the the spacing between the diffusers that

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makes maintenance works very difficult. Furthermore, operating the diffusers at a very low flow rate increases the chance of clogging or scaling in the air diffusers, especially when the air blowers stop working for any reason, because the small aeration rates do not help to remove the plankton that is deposited on the air diffusers when they restart again.

TABLE 2. Comparison between the different diffusers densities

Diffusers density (%)	Design capacity (m^3/day)	Total No. of air diffusers	Diffuser flow rate (m^3/hrs)	SOTE (%)	Effective area per air diffuser (m^2)	Spacing between diffusers (m)
2.5 (BD)	20000	4080	5.00	33.00	0.0375	0.94
5	20000	8064	2.53	35.75	0.0375	0.59
10	20000	16128	1.26	38.50	0.0375	0.34
15	20000	24192	0.84	44.00	0.0375	0.22

TABLE 3. Operational values for the different WWTPs

WWTP	Step feeding method						Extended aeration method				
	Hazek	Ain Ghosien	Denohia	Gabal El Tair	Mahalet Diaay	El Boghdady	Eqleet	El Ramady	Wady Abady	El Radesia	Fars
Design capacity (m^3/day)	14000	7000	14000	7500	7000	9000	20000	10000	3000	5000	2000
Volume of aeration tanks (m^3)	7260	3600	11550	6125	4600	7350	33264	16500	4950	8250	3360
Water depth (m)	5.50	5.00	5.50	5.00	5.00	4.90	5.50	5.50	5.50	5.50	4.00
Required air flow rate (m^3/hrs)	14500	7200	14500	8000	7200	9400	20400	10200	3100	5200	2060
Total No. of air diffusers	1800	1000	2850	1632	1360	1800	3840	1904	648	960	528
Diffuser flow rate (m^3/hrs)	8.06	7.20	5.09	4.90	5.30	5.22	5.31	5.36	4.78	8.60	3.90
% Coverage area of air diffusers	5.18	5.28	5.16	5.06	5.62	4.59	2.41	2.41	2.74	2.43	2.39
SOTE (%)	35.20	32.00	35.20	32.00	32.00	31.36	35.75	35.75	35.75	35.75	26.00
DO (mg/L)	5.80	4.95	5.40	5.75	6.52	5.25	5.35	5.85	5.15	5.75	6.05

3.2 Existing WWTPs in operation

From the data shown in Table 2 we can deduce that large scale applications of fine bubble disc aerators diffusers density depends on the type of treatment technology adopted in the WWTPs. It is also clear from the table that the original design of these treatment plants depended on low diffuser density values which are in the average of 2.5 % for the extended aeration systems and 5.0 % for the step aeration systems. Being a very complex process, aeration of biological reactors and the oxygen transfer at the air/water interface depends on multiple factors for calculating the standard oxygen transfer rate (SOTR), standard aeration efficiency (SAE) and the volumetric transfer coefficient (K_La_{20}) as given by (ASCE 2006; Herrmann-Heber *et al.* 2021; Therrien *et al.* 2019). These factors include tank depth, tank mixing intensity (agitation), air flow rate, bubble size, temperature and pressure. K_La_{20} is time dependent and varies from the start of aeration of an oxygen stripped water till it reaches it saturation value.

Table 3 shows the data obtained from the WWTPs that were monitored and the aeration efficiency was taken from the average dissolved oxygen (DO) values shown for each plant. All the WWTPs effluent values were below the requirements of the Egyptian law 48 for the year 1992 with regrads the parameters; total suspended solids (below 50 mg/L), biological oxygen demand (below 50 mg/L) and chemical oxygen demand (below 80 mg/L).

3.3 Factors affecting the coverage area of fine disc air diffusers

Depending on what was previously explained above, it will not be fair to consider the percentage of air diffusers coverage area as a specific determinant for selecting the number of diffusers required although SOTE increases by the increase in coverage ratio. The percentage SOTE increase is very low compared with the negative effects. Thus it is favored to consider results obtained from the basic design (BD) rather than depending on the coverage ratio. Instead of the direct selection of the percentage of coverage area of air diffusers, the following factors are important and affect the selection of the diffusers coverage ratio: -

3.3.1 The selected biological treatment technology

The type of biological treatment technology used in the treatment plant greatly affects the coverage of air diffusers in aeration basins (where the other design parameters are fixed). For example, the coverage area of air diffusers in the conventional aeration basins or step feeding aeration basins is high compared to extended aeration basins, as the retention time in conventional aeration basins and step feeding (3-8 hours) is much less than extended aeration basins (18-36 hours).

The high difference in the percentage of coverage area of air diffusers is noticeable in case of using biological treatment techniques that are characterized by very short retention times, such as the (MBBR) technology, which adopts the hybrid growth (suspended & attached) technology, compared with the biological treatment technology used in conventional, step feeding or extended aeration systems which adopt the suspended growth technology. Hybrid growth systems need aeration basin sizes much smaller than its counterparts that depend on the suspended growth of bacteria; due to the significant increase in the concentration of bacteria in the hybrid growth when compared with the suspended growth and this, consequently, leads to the increase in the coverage area of air diffusers.

3.3.2 Water depth in aeration basins

For the same biological treatment technology, the difference in the water depth in the aeration basins leads to a difference in the coverage area of the air diffusers in the basins (where the other design parameters are fixed). As the increase in the water depth of the aeration basin leads to an increase in the overall efficiency of the oxygen transfer, due to the increase in the contact time of air bubbles with water, which leads to a decrease in the total aeration rate required, resulting in the decrease in the coverage area of air diffusers in aeration basins.

3.3.3 Type and model of the fine disc air diffuser

For the same type of air diffusers, different manufacturers, suppliers and variants results in different design data, aeration rates and dimensions, which also leads to difference in the coverage area of air diffusers in the aeration basins.

3.3.4 Climate and topography of the plant site

Difference in the climate and the topography of the plant site leads to the difference in the parameters used to convert the standard amount of oxygen required to the actual amount of oxygen needed to be produced from the air blowers (AOR/SOR). The difference in the actual quantities of oxygen required leads to the need of different aeration rates and reflects on the design of the air blowers, consequently, leading to the selection of different numbers of air diffusers and the change in the coverage area of the diffusers in aeration basins.

IV. Conclusion

In this research work studies were done for the design of wastewater aeration tanks using fine disc diffusers with different coverage ratios in order to study their effect on the aeration efficiency compared with the increase in implementation and maintenance costs. Actual data obtained from WWTPs in operation were compared with the theoretical data in the first part of this research work. Comparison between the findings in this research work was also made with data available in literature and fine disc manufacturers recommendations. Consequently the following conclusions can be summerized from our work: -

- The increase in diffusers coverage ratio doubles and tripples the numbers of diffusers with only (2-3) % increase in SOTE.
- Increasing the diffusers coverage ratio to (10-15) % as recommended by manufacturers and suppliers (in Egypt) not only increases the costs but decreases the spacing between the diffusers to about (20-30) cms which makes it very difficult to maintain. It also reduces the diffusers flow rate making it more susceptible for clogging and scaling.
- WWTPs operating with a diffusers coverage ratios of 2.5 % and 5% using two different treatment methods showed stable operation with high suitable DO values in the aeration basin and all the effluent treated wastewater charateristics complied with the requirements of the Egyptian law. The reduced oxygen transfer rate due to spiral flows that are thought to reduce bubble detention time was not detected.
- The selection of the diffusers coverage ratio was seen to better depend on the four factors stated in this research work rather than by the direct choice of the coverage ratio as postulated by manufacturers and suppliers.

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