Determination of Dissolved Oxygen Concentration in Stationary Water

IONELA MIHAELA CALUSARU1, NICOLAE BARAN1*, ALEXANDRU PATULEA1
1Politehnica University of Bucharest, Department of Thermotechnics, Engines, Thermic and Refrigeration Plants, 313 Splaiul Independentei, 060042, Bucharest, Romania

In the paper the differential equation of the transfer speed of the oxygen towards water is numerically integrated, software is written and theoretical results are presented. A setup for experimental tests regarding the functioning of fine bubble generators was designed and built in the frame of the Department of Thermotechnics, Engines, Thermic and Refrigeration Plants laboratory. Measurements regarding the increase of the concentration of oxygen dissolved in water were performed. Theoretical and experimental results were compared.

Keywords: dissolved oxygen in water, oxygen meter, fine bubble generator

Oxygenation, also named aeration in speciality literature [1, 2], constitutes the main operation that assures a proper quality of water in water treatment and purification processes.

Water oxygenation is a process of mass transfer (O₂ → H₂O) largely applied in the following areas: water treatment processes, biological purification of wastewater, separation and catchment of greases from wastewater.

In hydrodynamics of gas-liquid biphasic systems, the dispersed phase is represented by air bubbles generated by aeration systems and the continuous phase is represented by the liquid (clean water or wastewater).

The diffusion of oxygen in water is the most important factor to be considered in the conception and design stage of water oxygenation machines. These machines must assure the transfer of oxygen towards water with a minimum energy consumption.

Thus porous diffusers made form ceramic materials, plastic etc. are actually used. The modern machines that assure the dispersion of air in tanks or basins are called fine bubble generators.

Fine bubble generators (FBG) have to assure a uniform spreading of air in the whole mass of water. The finer and more uniform spread air bubbles, the more efficient the mass transfer from gas to liquid [2, 3]. According to the dimension of air bubbles that intrude in the water mass, the bubble generators are divided in [3]: fine bubble generators with the bubble diameter less than 1 mm; fine bubble generators with the bubble diameter in the range of 1 ÷ 3 mm; fine bubble generators with the bubble diameter superior to 3 ÷ 120 mm.

Compared to the porous diffusers manufactured from synthesised glass or other materials, the new type of fine bubble generator presented in this paper assures a uniform and accurate spreading of air bubbles, because it is made by electroerosion with a machine working in xoy coordinates.

The equation of transfer speed of oxygen in water

For pneumatic aeration equipment, the equation that describes the transfer speed of oxygen in water has the following shape [1, 4, 5]:

\[
\frac{dC}{d\tau} = aKL \left( C_s - C \right) \left( \frac{kg}{m^3 \cdot s} \right)
\] (1)

where:
\[
dC / d\tau \quad \text{– transfer speed of dissolved oxygen, that is the ratio between the mass of oxygen dissolved in a volume of water and the time;}
\]
\[
aKL \quad \text{– volumetric mass transfer coefficient [s⁻¹]};
\]
\[
C_s \quad \text{– mass concentration of oxygen in water at saturation [kg/m³]};
\]
\[
C \quad \text{– current mass concentration of oxygen in water [kg/m³]}. 
\]

Equation (1) is an ordinary differential equation that can be solved using one of the following methods: Runge-Kutta method; Adams-Bashford method; Euler method; Milne method.

In order to theoretically establish the variation of the concentration of oxygen dissolved in water function of the water oxygenation process duration for the FBG the following magnitudes have to be known:

- initial concentration of the oxygen dissolved in water for the temperature \( t = 20.5 \) °C; \( C_1 = 7.72 \) mg/L;
- saturation concentration for the same temperature and \( p = 750 \) mmHg is equal to \( C_s = 8.9 \) mg/L;
- duration of the oxygenation process \( \tau = 120 \) min;
- integration step \( h = 1 \) min, \( n = 120 \). 120 values are needed in order to build the chart \( C = f(\tau) \);
- the value \( aKL \) is established using the integral method [5] for the first two time intervals: \( 0 \rightarrow 15' \); \( 15' \rightarrow 30' \):

\[
aKL = \frac{\ln \left( \frac{C_2 - C_1}{C_3 - C_2} \right)}{\tau_2 - \tau_1} \left[ \text{min}^{-1} \right] 
\] (2)

where \( C_1 \) and \( C_2 \) denote the concentration of O₂ in water at the time moments \( \tau_1 \) and \( \tau_2 \).

If (2) is applied, it results that:

I) \( \tau_1 = 0' \rightarrow \tau_2 = 15' \rightarrow aKL_{1d} = \frac{1}{15 - 0} \ln \left( \frac{8.9 - 7.72}{8.9 - 8.3} \right) = 0.0363 \left[ \text{min}^{-1} \right] 
\] (3)

II) \( \tau_2 = 15' \rightarrow \tau_3 = 30' \rightarrow aKL_{1d} = \frac{1}{30 - 15} \ln \left( \frac{8.9 - 8.3}{8.9 - 8.53} \right) = 0.0490 \left[ \text{min}^{-1} \right] 
\] (4)

* email: n_baran_fimn@yahoo.com, 0746093500

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Thus computations lead to a mean value of $0.0427 \text{ [min}^{-1}]$ for the coefficient $a_{KL}$. This value is needed as input for the computation software written in order to build the chart $C=f(\tau)$.

The numerical integration of the differential equation of the oxygen transfer speed was performed with the Euler method [6-8].

120 points of the function $C=f(\tau)$ were obtained following the computation scheme. Their graphical representation leads to the chart presented in figure 1.

After two hours of function $C$ (current mass concentration) $\approx C_s$ (mass concentration of oxygen in water at saturation).

**Experimental researches**

*Purpose of the experimental researches*

The interest is to find that this method (Euler) is accurate, which is the deviation from the real phenomenon. For this purpose, the concentration of oxygen ($C$) in the water mass function of the time will be measured; because the oxygen dissolved in water is not consumed by fish or other microorganisms, oxygen concentration will increase in time; the conditions are non-stationary.

*The description of the experimental setup*

The setup was designed and built in the frame of the laboratory of the Department of Thermotechnics, Engines, Thermic and Refrigeration Plants in order to research water oxygenation processes [9, 10]. The water from the public network is introduced in a tank (10) and the compressed air spread in water using the fine bubble generator (FBG) (13) will lead to the increase of the concentration of oxygen dissolved in water, increase conditioned by the working time of the FBG.

Concentration of the oxygen dissolved in water is measured with a digital display oxygen meter that uses the principle of the electric method [4] (fig.3).

The instruction manual of the oxygen meter requires that, in order to obtain accurate measurements, water must flow with a minimum speed of 0.3 m/s. This would lead to an important water consumption in the laboratory, thus it was established that the probe (12) must be moved with a speed of:

$$v = \frac{S \cdot \pi d}{\tau}$$

where:
- $d$ – diameter of the circle on which the probe moves; the circle is situated at the midway between the tank side and the tank axis, $d=0.25 \text{ m}$;
- $\tau$ – duration of a complete rotation of the probe; $\tau = 2 \text{ s}$.
The speed of the probe will be:

\[ v = \frac{\pi \cdot 0.25}{2} = 0.3925 \text{[m/s]} \] (6)

Pressure of the compressed air and air flow rate were measured; these values were kept constant during measurements.

The experimental stand contains a fine bubble generator (F.B.G.) where the nozzles in number of 37 with \( \Phi = 0.5 \text{ mm} \) were disposed on a single row, so that the bubble columns create a bubble curtain similar to the one formed by a planar jet with a rectangular shape transversal section. The repartition of the \( \Phi = 0.5 \text{ mm} \) nozzles (fig. 4) was manufactured with a machine by electro erosion.

A rotated view of the section A-A from figure 4 is presented in figure 5.

In figure 6 is observed the fine bubble generator in operation, in dynamic conditions.

The probe is lifted from the water during the operation of the fine bubble generator.

Methodology of measurements, obtained experimental results

For a constructive version of FBG of rectangular shape with \( \Phi = 0.5 \text{ mm} \) nozzles, the measurements are performed in eight stages. At the beginning of the first stage, figure 2, the height of the water layer over the FBG is \( h = 500 \text{ mm} \), the initial O\(_2\) concentration being \( C_0 = 7.72 \text{ mg/L} \), the indication of the electric meter being \( E_0 = 0.0325 \text{ kWh} \) and water temperature \( t = 20.5\text{°C} \).

Pressure and flow rate of air that enter the FBG are measured: \( p_1 = 583.44 \text{ mmH}_2\text{O}; V = 600 \text{ dm}^3/\text{h} \), values that are kept constant during measurements.

After a functioning of the FBG for \( \Delta \tau_1 = 15', \) it is stopped and \( O_2\) concentration is measured by rotating the probe in water. The FBG is put in functioning again and air is blasted in water during 15', the total time being \( \Delta \tau_2 = 30' ; \) \( O_2\) concentration is measured.

Similarly, the time values of \( \Delta \tau_3 = 45', \Delta \tau_4 = 60', \Delta \tau_5 = 75', \Delta \tau_6 = 90', \Delta \tau_7 = 105', \Delta \tau_8 = 120' \) are reached.

Finally, the concentration of \( O_2\) dissolved in water after two hours of FBG functioning is measured. The chart \( C_{O_2}=f(\tau) \), curve no.2 from figure 7, is traced based on experimental data.

Figure 7 proves good coincidence between theoretical results and obtained experimental results.

Conclusions

It can be noticed that theoretical results regarding the variation of the concentration of oxygen dissolved in water obtained by Euler method are more accurate compared with experimental results. The deviation between theoretical and experimental values is of 0.3% for Euler method.

Unconventional technology was used in order to manufacture the nozzle plate, namely the nozzles were manufactured by electro erosion, fact that brings certain advantages. Placing 2-3 consecutive rows of rectangular shape FBGs creates a bubble curtain that can oxygenate a flowing layer of used water, phenomenon that appears in water treatment plants.

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