



KINETICS OF WATER OXYGENATION IN PIPE AERATOR

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Abstract

The paper presents the results of investigations of the oxygen content in oxygenated water in a co-current pipe aerator with the diameter of 200 mm, with stainless steel Białecki rings with the diameter of 12 mm, for two cases: when the air is supplied by a compressor and when it is supplied by a jet pump. The oxygen content in the oxygenated water was assayed using an LDO oxygen sensor. The investigations of water oxygenation in the aerator were carried out during technical exploitation of the Scientific Research Water Station of Warsaw University of Life Sciences. The oxygen content O_2 in the oxygenated water was measured for the set air flow rate Q_p equal to 50, 100 and 150 $\text{dm}^3 \times \text{h}^{-1}$ and water flow rate Q_w equal to 10, 15 and 20 $\text{m}^3 \times \text{h}^{-1}$. During the tests, the temperature T of the air supplied to the aerator was also measured. The water temperature was constant during the tests and it was equal to 12°C. The oxygen content O_2 in the oxygenated water and the temperature T of the air supplied to the aerator were measured every 10 seconds. For each air flow rate Q_p and water flow rate Q_w being set, three measurement series were carried out and the obtained results were averaged.

The researches were aimed on the determination of the influence of air and water flow rate on the oxygen content in the water oxygenated in a pipe aerator with use of a compressor and a jet pump.

In the measurement range being tested, the effectiveness of water oxygenation increased with rise in the flow rate of the supplied air and decreased

with rise in the flow rate of the supplied water. The effectiveness of water oxygenation was higher if obtained by means of a jet pump than of a compressor.

Key words: water purification plant, water oxygenation, co-current pipe aerator, compressor, jet pump

INTRODUCTION

Due to water shortages, occurring in some areas, as well as to anthropogenic activity, water consumption is constantly growing, which results in increased need of water treatment. Therefore, it is crucial to improve devices and methods of purification of water for consumption and for various industrial purposes (Ojo *et al.* 2012) as well as construction of water purification plants characterized by the lowest possible energy consumption and the highest possible productivity.

Water oxygenation is a very complex process. Its run is affected by many factors acting directly or indirectly. The oxygen solubility in water depends mainly on water temperature and turbulence, and, to a less considerable degree, on water pressure and salinity as well as on physical and chemical properties of oxygen. An increase in water temperature causes a decrease in oxygen solubility in water. The motive force of dissolving oxygen in water is a difference between the oxygen concentration currently prevailing in water and the equilibrium concentration. On the other hand, with an increase in temperature, the coefficient of oxygen transfer to water increases, which causes that the process of dissolving oxygen is considerably faster in higher temperatures. With an increase in water turbulence, oxygen solubility in water increases.

In the accessible scientific and technical literature, there is few information concerning studies on effectiveness of water oxygenation, hydraulic operating conditions, rules of design and exploitation of pipe aerators with Białecki rings (Heidrich *et al.* 1980; Kalenik and Morawski 2013, 2009, 2007, 2004; Kowal and Świderka-Bróz 2005). The advantages of pipe aerators in comparison to classical ones are: small installation space, good effectiveness of water oxygenation and easy exploitation (Kalenik *et al.* 2006). Pipe aerators are installed vertically within a pipeline supplying water to filters.

The main aim of the investigations was to recognize the changes of the oxygen content in the water being oxygenated in a pipe aerator as the function of time, as well as to compare its oxygenation effectiveness when the air is supplied by means of a compressor and by means of a jet pump. The investigations of water oxygenation in the aerator were carried out during technical exploitation of the Scientific Research Water Station of Warsaw University of Life Sciences. The experimental installation consisted of a co-current pipe aerator with the

diameter of 200 mm, filled with stainless steel Białecki rings with the diameter of 12 mm.

WATER PURIFICATION PLANT

Scientific Research Water Station of Warsaw University of Life Sciences is automatized to a large extent and equipped in electronic controlling and measuring devices by Endress-Hauser Co. Ltd and Hach Lange Co. Ltd. The water purification plant produces water mainly for the WULS university campus in Ursynów (Warsaw). The water from quaternary beds is tapped from three drilled wells (Fig. 1).

The iron and manganese indexes are exceeded in raw water (Kalenik *and* Morawski 2007). Due to this, the indexes of the tapped water must be adapted to binding standards according to the Regulations of the Ministry of Health (2007, 2010).

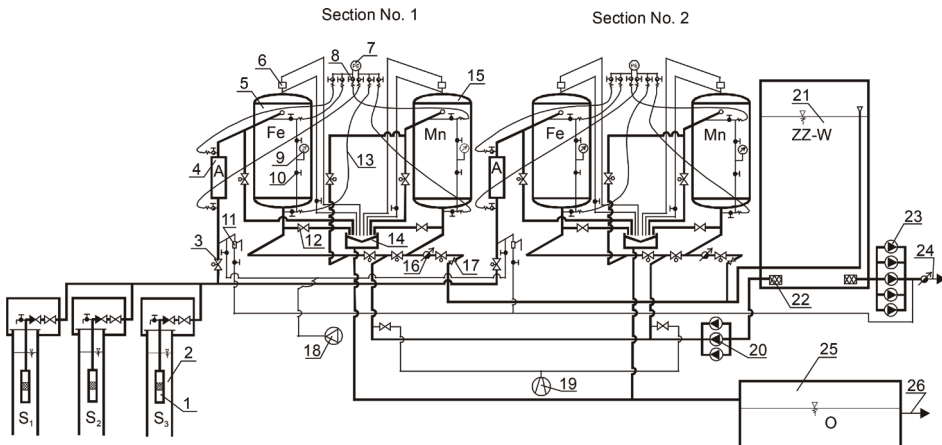


Figure 1. Water purification plant: 1 – deep-well pump, 2 – drilled well, 3 – automatic valve of flow regulation, 4 – aerator, 5 – deironing filter, 6 – deaerating ball valve, 7 – electronic meter of pressure difference, 8 – cut-off valve with impulse tip, 9 – manometer, 10 – cut-off valve, 11 – jet pump for water aeration, 12 – hand valve for flow regulation, 13 – impulse hoses, 14 – sewerage drain, 15 – demanganizing filter, 16 – electronic flow meter, 17 – poppet hand valve, 18 – compressor, 19 – air blower, 20 – filter cleaning pumps, 21 – spare and equalizing tank, 22 – suction rose, 23 – hydrophore-pump set, 24 – water-pipe network, 25 – decanter for washings treatment, 26 – sewerage network

The technology of water purification consists of water oxygenation in an aerator, filtration through a quartz sand bed in a deironing filter and filtration

through an active quartz sand bed in a demanganizing filter. The water purification is divided into two sections (1 and 2 in Fig. 1), built of an aerator (A), deironing filter (Fe) and demanganizing filter (Mn), finished in a spare and equalizing tank (ZZ-W). In the technological chain for purification of quaternary water, the diameter of the installed aerators is equal to 0.2 m, their length 1.5 m, the rings' diameter 12 mm and aerator filling height 0.75 m. The construction of deironing and demanganizing filters is identical. Their diameter is equal to 2.4 m. The filter bed thickness is equal to 1.0 m and the grain diameter $0.8 \div 1.2$ mm. The thickness of a retaining layer is equal to 0.3 m and the grain diameter $5 \div 15$ mm.

The process of water purification is as follows (Fig. 1): water from 30 m deep drilled wells (2) (Kalenik *and* Morawski 2007) is forced by deep-well pumps (1) to co-current pipe aerators (4) filled with Białecki rings (Fig. 2) where water mixes with air. The air can be forced to the aerators (Fig. 1) by a compressor (18) or sucked by a jet pump (11) along with water from the secondary pumping system. The air-water mix from the aerators flows to the deironing filters (5) where, on the sand bed, iron is removed from the water. The air surplus comes out through deaerating ball valves (6) mounted in the upper bottom of the filters. Then, the water from the deironing filters flows to the demanganizing filters (15) where, on the activated sand bed, manganese is removed from the water. The purified water flows from the filters to the spare and equalizing tank (21) and then it is forced to water-pipe network (24) by a hydrophore-pump set (23).

The filters (Fig. 1) are cleaned at first by the air forced to the system by an air blower (19) and then by the purified water forced by cleaning pumps (20) from the spare and equalizing tank (21). Washings from individual filters are discharged to sewerage drains (14) and then to a decanter (25) where iron and manganese deposits, washed out from the filters, accumulate (Kalenik *and* Morawski 2011). The water from over the deposits in the decanter is discharged to a sewerage network (26). The individual filters are cleaned one by one, with the frequency depending on their clogging. The deironing filters are cleaned more frequently because the iron content in raw water is eight times higher than the manganese content (Kalenik *and* Morawski 2007).

RESEARCH METHODOLOGY

The investigations of oxygen content O_2 in the water being oxygenated in the aerator with the Białecki rings were carried out for the clean rings after the aerator had been mechanically washed out. The mechanical washing was carried out according to the guidelines given in the publications (Kalenik *and* Morawski 2007; Kalenik *et al.* 2006). The oxygen content O_2 in the oxygenated water was assayed by means of an LDO oxygen sensor (11, Fig. 2) – the industrial instruments manufactured by Hach Lange Co. Ltd. were used. The measurement

accuracy for the LDO oxygen sensor is equal to $\pm 0.01 \text{ mgO}_2 \times \text{dm}^{-3}$ for the measurement range $0 \div 8 \text{ mgO}_2 \times \text{dm}^{-3}$ (LDO oxygen sensor catalogue card, 2015). The results of the investigations of oxygen content were registered by an SC 1000 transducer (9). The oxygen content in the oxygenated water in the aerator (5) was measured for the air supplied by a compressor or a jet pump – in both cases for the set air flow rate Q_p 50, 100, 150 $\text{dm}^3 \times \text{h}^{-1}$, and the set water flow rate Q_w 10, 15, 20 $\text{dm}^3 \times \text{h}^{-1}$. The temperature T of the air supplied to the aerator was also measured. The water temperature was constant during the investigations and equal to 12°C . The oxygen content and the air temperature T were measured every 10 seconds. Three measuring series were carried out for each set air flow rate Q_p and water flow rate Q_w , and then the obtained results were averaged. The measurements were carried out in the Section 1 (Fig. 1) during technical exploitation of the water purification plant.

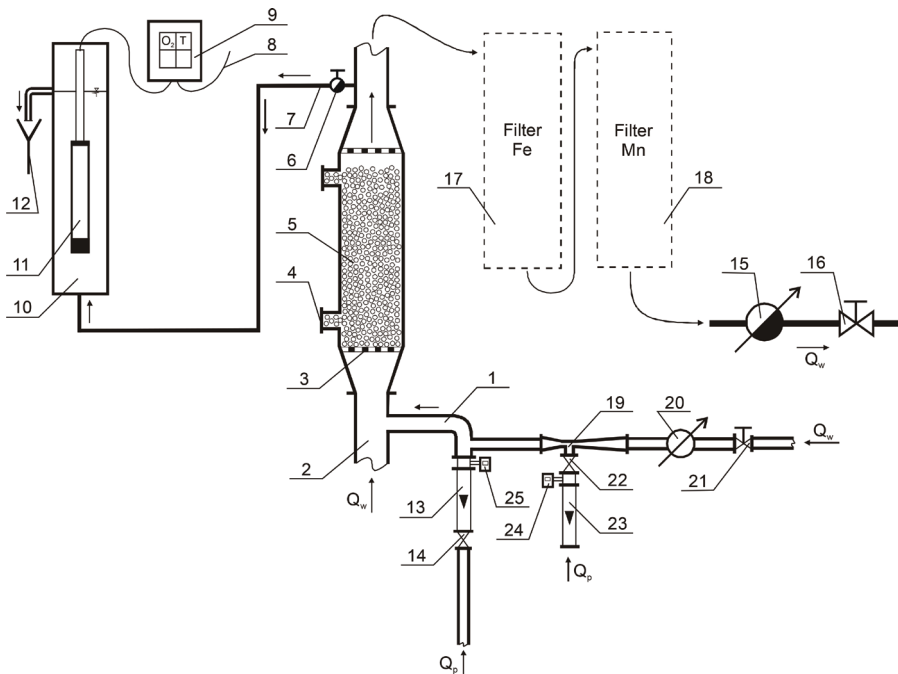


Figure 2. Scheme of the pipe aerator in Section 1 according to Fig. 1 along with measuring equipment: 1 – air supply pipe, 2 – water supply pipe, 3 – rings support grate, 4 – closing hatch, 5 – filling made of Bialecki rings, 6 – cut-off ball valve, 7 – hose supplying water to the oxygen sensor, 8 – power cable, 9 – SC 1000 transducer (recorder), 10 – transparent tank, 11 – LDO oxygen sensor, 12 – sewerage drain, 13, 23 – air flow rate rotameter, 14, 22 – air flow rate control valve, 15 – electronic flow meter, 16, 21 – poppet valve, 17 – deironing filter, 18 – demanganizing filter, 19 – jet pump, 20 – water flow meter, 24, 25 – electronic thermometer

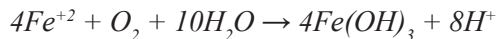
The measurements of O_2 content in oxygenated water in the co-current pipe aerator fed with air by a compressor were performed in the following way (Fig. 2): before start of each measurement series it was checked if the valves (21, 22) were closed and the valve (6) open. Then, on the electronic flow meter (15), an appropriate water flow rate Q_w was set with the poppet valve (16). After that, an appropriate air flow rate Q_p was set with the rotameter (13) as well as with the air flow rate control valve (14). Every 10 seconds the oxygen (O_2) content in the oxygenated water was read on the recorder (9) display and the temperature T of the air supplied to the aerator – on the electronic thermometer (25) display.

The measurements of O_2 content in oxygenated water in the co-current pipe aerator fed with air by a jet pump were performed in the following way (Fig. 2): before start of each measurement series it was checked if the valve (14) was closed and the valves (6, 21) open. Then, on the electronic flow meter (15), an appropriate water flow rate Q_w was set with the poppet valve (16). After that, an appropriate air flow rate Q_p was set with the rotameter (23) as well as with the air flow rate control valve (22). Every 10 seconds the oxygen (O_2) content in the oxygenated water was read on the recorder (9) display and the temperature T of the air supplied to the aerator – on the electronic thermometer (24) display.

RESULTS AND THEIR DISCUSSION

Water oxygenation is a standard process applied in underground water purification plants to oxygenate iron and manganese as well as to remove gases dissolved in water, usually aggressive CO_2 and possible hydrogen sulfide H_2S as well as dissolved ammonium ions NH_4^+ . In the case of the water purification process applied at the Scientific Research Water Station (Fig. 1), oxygen is used mainly to oxygenate iron and manganese.

The removing of iron from water consists in oxygenation of dissolved iron compounds on the oxidation state +2 to insoluble iron compounds on the oxidation state +3 and then on removing of these insoluble iron compounds from water in the process of filtration (Siabi 2008). The iron oxidation process with oxygen from air takes place according to the reaction (Nawrocki and Biłozor 2000):



The occurring insoluble colloid of iron hydroxide $Fe(OH)_3$, (i.e. rust) makes water cloudy and negatively affects its taste.

The results' analysis (Figs. 3 and 4) allows for stating that the effectiveness of the water oxygenation increases with rise in the flow rate Q_p of the air supplied to the co-current pipe aerator with Bialecki rings and decreases with rise in

the flow rate Q_w of the supplied water. This phenomenon occurs also in Venturi aerators (Waligórski and Podgórnikaowa 1972). The performed investigations show that, in the measurement range being tested, the volume of the supplied air is crucial if water is oxygenated in co-current pipe aerators with Białecki rings. Significantly higher effectiveness of the water oxygenation in the pipe aerator was obtained when a jet pump was used. The reason for this is as follows: if the air flow is the result of the pressure reduction in comparison to the atmospheric pressure (the air is sucked), then the adiabatic process takes place (the air stream is decompressed) and the temperature of the air stream abruptly falls which causes that more oxygen dissolves in the water oxygenated in the pipe aerator. This phenomenon is confirmed by the measurements of the temperature of the air stream supplied to the pipe aerator by a jet pump (Fig. 6) – the analysis of the results allows for stating that till the 120th second of the process the temperature increased and then started to decrease. On the contrary, the temperature of the air stream supplied to the aerator by a compressor (Fig. 5) initially increased and then remained on a constant level. The temperature of the air stream supplied to the aerator by a compressor was 2°C higher on average than the temperature of the air stream supplied to the aerator by a jet pump.

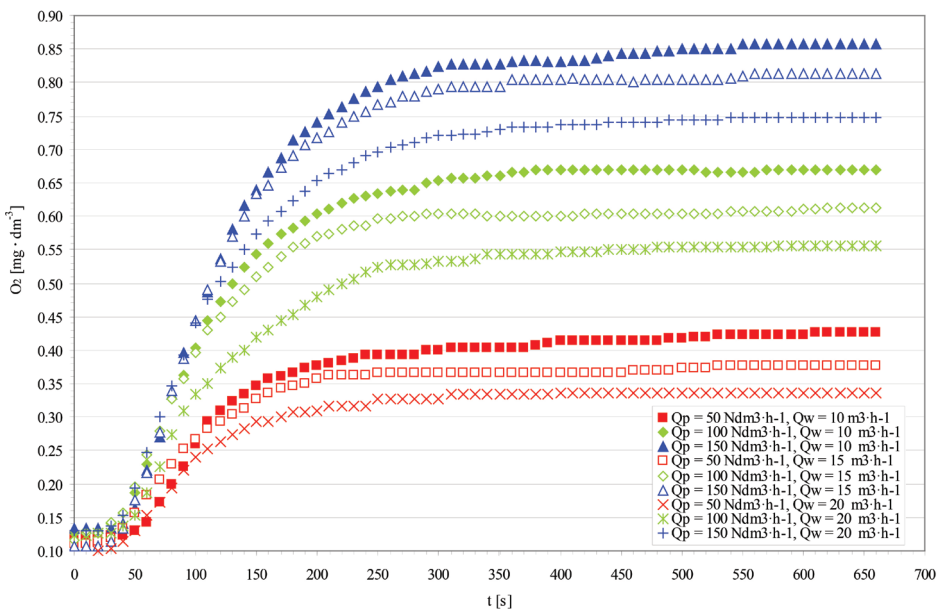


Figure 3. Influence of the air flow rate Q_p and water flow rate Q_w on oxygen content in the water oxygenated in the co-current pipe aerator fed with air by a compressor

Before oxygenation in the pipe aerator, the initial oxygen content in the water fluctuated between 0.10 and 0.13 mgO₂×dm⁻³ for the set values of Q_w. During the oxygenation process in the pipe aerator, for all set values of Q_w and Q_p, the oxygen content in the water abruptly increased till 250th second and then stabilized on a constant level (Figs. 3 and 4). Full saturation of the water with oxygen took place after 500 seconds. Table 1 presents the values of the full saturation of the water with oxygen for individual set values of Q_p and Q_w as well as percentage comparison of the effectiveness of water oxygenation in the pipe aerator fed with air by a jet pump and by a compressor. For Q_p = 50 Ndm³×h⁻¹ and Q_w = 10 m³×h⁻¹, 222% more oxygen dissolved in the water being oxygenated when the aerator was fed with air by a jet pump than when it was fed by a compressor, whereas for Q_p = 150 Ndm³×h⁻¹ and Q_w = 20 m³×h⁻¹ only 61% more. Along with rise in the air flow rate Q_p and water flow rate Q_w, the difference between the oxygen content in the water oxygenated with application of a jet pump and with a compressor decreases.

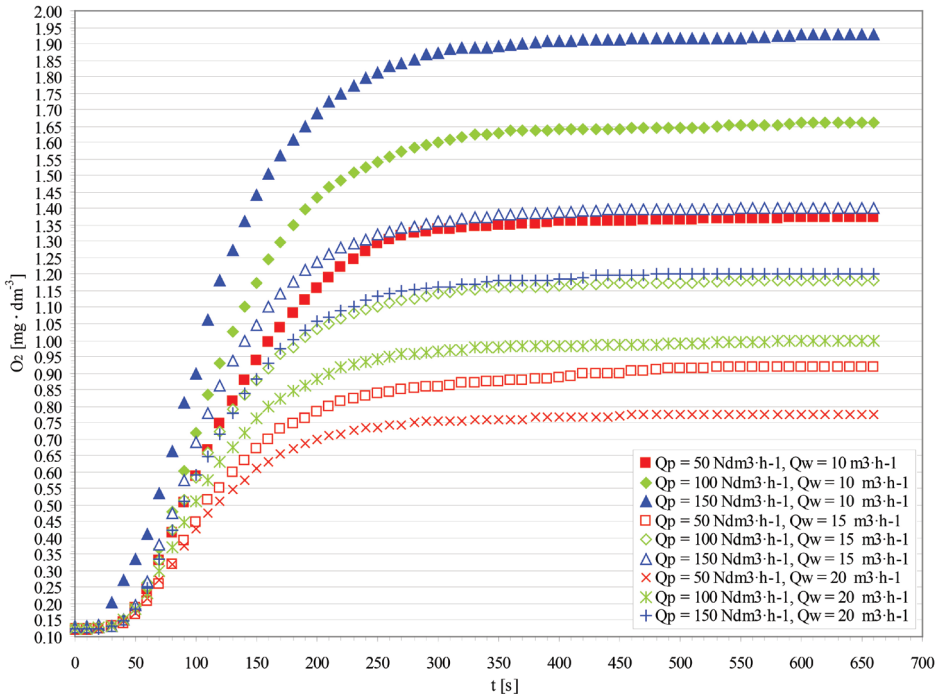


Figure 4. Influence of the air flow rate Q_p and water flow rate Q_w on oxygen content in the water oxygenated in the co-current pipe aerator fed with air by a jet pump

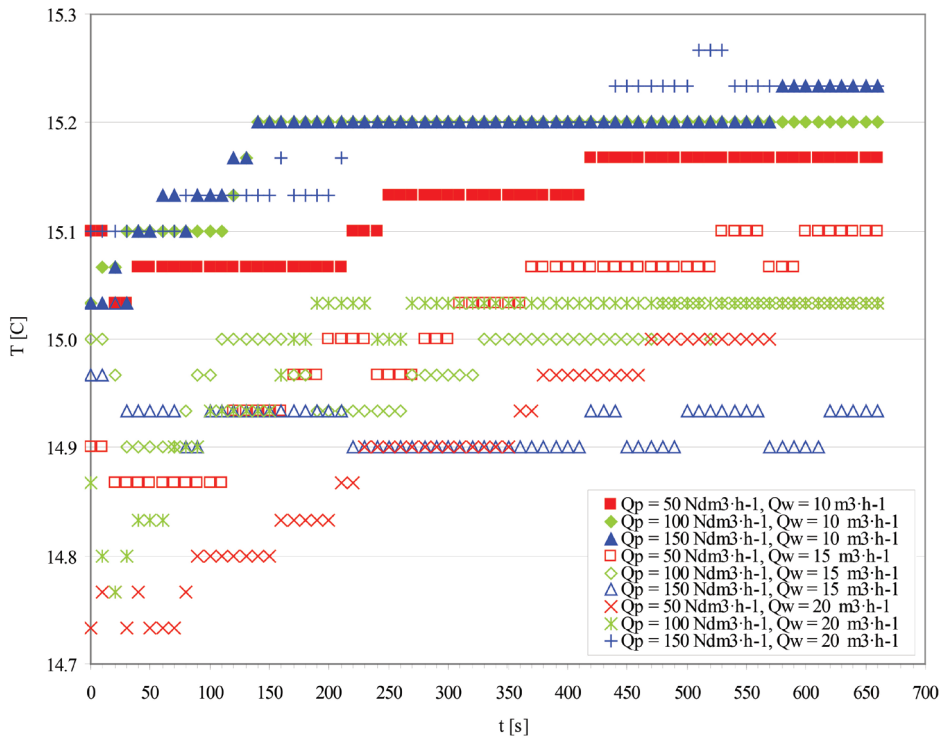


Figure 5. Changes of the temperature of the air forced to the co-current pipe aerator by a compressor

The method of water oxygenation is very important in the context of energy consumption of water purification plants. It is evaluated that 7% of the global energy production is consumed in the processes of water purification and distribution as well as sewage treatment (Young 2010). Since in a jet pump the energy of water stream is used to suck air, applying jet pumps for water oxygenation saves the energy which would be needed by a compressor. On the other hand, if a jet pump is being used, then the water stream comes into a throat which results in pressure losses and in the increase of the energy consumed by a jet pump. In the performed investigations, the air suction in a jet pump was evoked by flow of the purified water drawn from the pressure conduit of the secondary pumping station. Such way is called by authors a separate water supply because water does not come from the pressure pipeline on which the aerating system is installed. The application of a jet pump does not significantly affect hydraulic conditions at the secondary pumping station. However, the water powering the jet pump circulates in a closed cycle. The decision concerning the way of deliv-

ering oxygen to water should be preceded by a thorough technological analysis for each water purification plant.

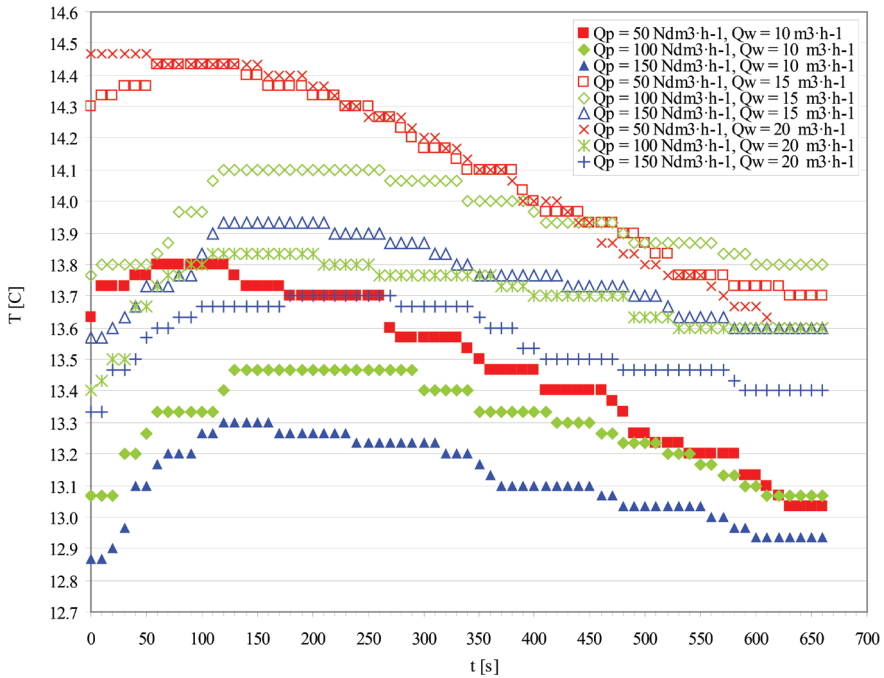


Figure 6. Changes of the temperature of the air sucked to the co-current pipe aerator by a jet pump

Table 1. Comparison of the effectiveness of water oxygenation for the cases when the pipe aerator was fed with air by a jet pump and when it was fed by a compressor

Data description	Compressor			Jet pump			Comparison		
	O ₂ [mg×dm ⁻³]	O ₂ [mg×dm ⁻³]	O ₂ [mg×dm ⁻³]	O ₂ [mg×dm ⁻³]	O ₂ [mg×dm ⁻³]	O ₂ [mg×dm ⁻³]	O ₂ [%] for	O ₂ [%] for	O ₂ [%] for
	for Q _p = 50 Ndm ³ ×h ⁻¹	for Q _p = 100 Ndm ³ ×h ⁻¹	for Q _p = 150 Ndm ³ ×h ⁻¹	for Q _p = 50 Ndm ³ ×h ⁻¹	for Q _p = 100 Ndm ³ ×h ⁻¹	for Q _p = 150 Ndm ³ ×h ⁻¹	Q _p = 50 Ndm ³ ×h ⁻¹	Q _p = 100 Ndm ³ ×h ⁻¹	Q _p = 150 Ndm ³ ×h ⁻¹
Q _w = 10 m ³ ×h ⁻¹	0.43	0.67	0.86	1.37	1.66	1.93	222	148	125
Q _w = 15 m ³ ×h ⁻¹	0.38	0.61	0.81	0.92	1.18	1.40	144	93	72
Q _w = 20 m ³ ×h ⁻¹	0.34	0.56	0.75	0.77	1.00	1.20	130	79	61

SUMMARY

The performed investigations showed that the effectiveness of water oxygenation increased with rise in flow rate of the air delivered to the co-current pipe aerator with Białecki rings, and decreased with rise in flow rate of the delivered water. The effectiveness of water oxygenation in the co-current pipe aerator was higher when the air was supplied by a jet pump, fed by so-called separate water, than when the air was supplied by a compressor.

Constructions with jet pumps are simpler and more fail-safe than these with compressors due to almost maintenance-free operation of a jet pump. The investigations were performed for one type of a jet pump installed in a working system. Due to this, further investigations are necessary for higher diameters of jet pumps and higher flow rates of the sucked air.

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