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MODELLING OF PULVERISING AERATOR OPERATION PARAMETERS

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Summary. The paper describes the structure and operation of a new type of a pulverising aerator and stresses the necessity of developing and implementing aeration techniques to improve water quality of inland reservoirs. Mathematical modelling of hypolimnetic water inflow to the aerator intake chamber is presented, as well as the model being used to select the aerator's operation parameters and to determine the aerator conical turbine energy demand for pulverising aeration of hypoxic and anoxic water masses present in the near-bottom zone of numerous temperate water reservoirs.

Key words: aerator, modelling, pulverising aeration, water reservoirs

INTRODUCTION

Oxidation and decomposition of organic and mineral components are necessary for life processes and control the nature and dynamics of chemical transformations of biomass and mineral substances [Siuta 2006]. Oxygen deficiency is the cause and the effect of degradation of aquatic ecosystems. Treatments involving aeration of degraded waters [Rzewuska and Jankowski 1988, Lossow *et al.* 1998] are therefore necessary, because water resources, including those used in agriculture, are of enormous ecological and economic importance. There is thus the need to develop and implement appropriate aeration techniques [McGinnis and Little 1998, Siuta 2006] and to predict effects of the applied treatments [Lossow 1994]. A substantial progress has already been achieved, as confirmed by aeration devices and developed system [Beym 1989, Królikowski 1992, Zimny 1993] as well as by the work in progress and projects planned, which aim at improving the quality of lakes [Sanierung 1999, Matkowski and Podsiadłowski 2004, Zimny 2004]. The novel devices designed to aid revitalisation of anoxic areas include a new type of a pulverising aerator [Konieczny 2006] developed at the Institute for Land Reclamation and Grassland Farming (ILRGF) Western Pomeranian Research Centre in Szczecin. The device (Fig. 1) consists of two chambers (water intake chamber and aeration chamber), permanently mounted on a support stand and equipped with floats and inner drain pipes.

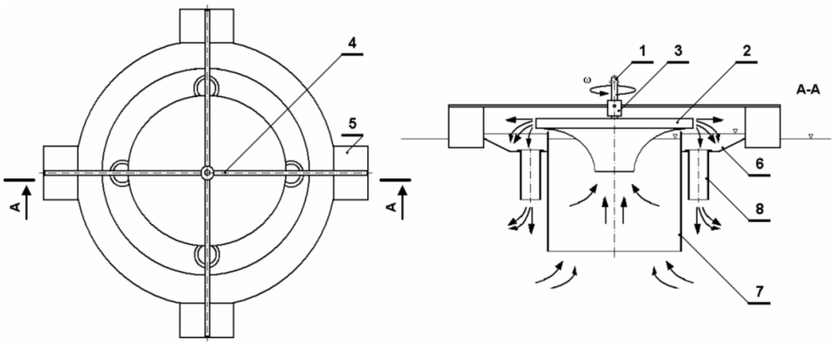

Fig. 1. Pulverising aerator developed at Institute for Land Reclamation and Grassland Farming (ILRGF) Western Pomeranian Research Centre in Szczecin: 1 – propeller shaft; 2 – conical turbine; 3 – hub, 4 – support; 5 – float; 6 – aeration chamber; 7 – water intake chamber; 8 – drain pipe

A hub with a revolving propeller shaft connected, in its lower part, to a conical turbine, is mounted in the axis of symmetry of the support stand. The power is transmitted onto the propeller shaft enclosed in the hub from a wind-driven, electric, or diesel engine. While revolving, the conical turbine takes up the influent hypolimnetic water via the water intake chamber; the water is then transported into the aeration chamber. The force with which the water is thrust by the conical turbine into the aeration chamber induces intensive aeration in the chamber; the aerated water is transported, via the drain pipes operating on the principle of connected vessels, to a depth dependent on the pipe length.

A mathematical model of the hypolimnetic water inflow into the intake chamber is presented below. The knowledge on the hypolimnetic water advection into the intake chamber is necessary to select operation parameters and to determine the conical turbine energy consumption in relation to the planned treatments involving pulverised aeration of lacustrine near-bottom waters. It is assumed that the appropriate selection of operation parameters and the knowledge of energy demand will benefit successful future application of pulverising aeration to treatment of deoxygenated hypolimnetic water masses in numerous temperate water bodies.

METHODS OF STUDY

The mathematical model of the hypolimnetic water inflow into the pulverising aerator intake chamber operating on the principle of connected vessels was developed at constant operation parameters of the conical turbine (energy demand for intake and transport of hypolimnetic water N =1.5 kW and overall efficiency η = 0.6) and pulverising aeration process [Podsiadłowski and Pieczyński 2001], based on the following assumed input parameters of the model: atmospheric pressure P_{atm} = 101325 Pa; gravitational constant g = 9.81 m·s^{-1}; fluid density in open tank ρ = 1 kg·m^{-3}; water level difference between the open tank and the water intake chamber h = 0.25 m; open tank water column height h_1 = 5 m; height of the hypolimnetic water column influent into the intake chamber h_2 = 4.75 m; diameter of the water stream cross-section in the intake chamber d = 0.8 m; stream velocity coefficient φ = 0.97; volume of hypolimnetic water to be treated by pulverised aeration V = 25000 m^3; the output parameter is the energy A (kWh) of the aerator's conical turbine, used for pulverising aeration of the hypolimnetic water.

The simplified physical model of the object of study is shown in Fig. 2 in the form of a set of connected vessels.

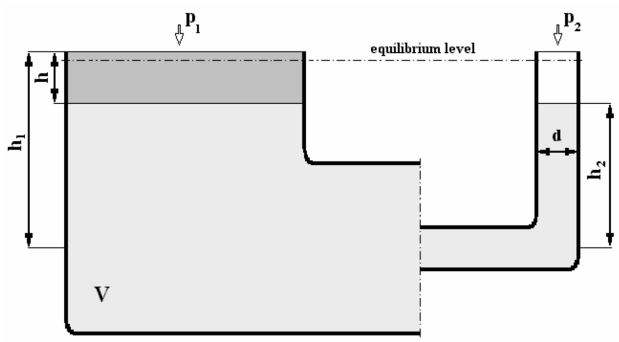

Fig. 2. Physical model of the object of study: h_1 – open tank water column height considered; h_2 – assumed height of water column entering the intake chamber at constant conical turbine operation parameters; p_1 – water surface pressure in the open tank; p_2 – water surface pressure in the intake chamber; d – water stream diameter in the intake chamber; V – volume of hypolimnetic water to be treated by pulverising aeration

The aerator system water intake chamber of internal diameter d (Fig. 2) was assumed to support stationary movement of true non-compressible fluid of known viscosity. The stream continuity equation given by the formula:

$$v_1 \cdot S_1 = v_2 \cdot S_2 \tag{1}$$

where:

- v_1 – initial stream velocity;
- v_2 – final stream velocity;
- S_1 – surface area of lake basin'
- S_2 – water surface area in intake chamber;

allowed to obtain the final velocity v_2 in the form given by equation (3) for the surface of a water column of cross-section d and height h_2:

$$v_2 = v_1 \cdot S_1 \cdot S_2^{-1} .. \mathrm{m \cdot s^{-1}} \tag{2}$$

Bernoulli's equation in the form given by equation (3) was used when formulating the mathematical model of hypolimnetic water inflow to the water column reference level h_2 at constant operation parameters of the aerator's conical turbine during pulverising aeration:

$$\frac{p_1}{\gamma}+\frac{v_1^2}{2g}+h_1=\frac{p_2}{\gamma}+\frac{v_2^2}{2g}+h_2 \tag{3}$$

where:

p_1 – pressure on the water surface of the open tank;
p_2 – pressure on the water surface in the intake chamber;
v_1 – water mass velocity on the surface of the open tank;
v_2 – water mass velocity on the surface in the intake chamber;
h_1 – open tank water column height;
h_2 – intake chamber water column height;

$$\gamma=\rho\cdot g \text{ – specific weight of water} \tag{4}$$

RESULTS

A case was considered in which hypolimnetic water autonomously advected to the water column height h_2, the intake chamber boundary for water intake by the aerator's conical turbine. As the pressures p_1 and p_2 on the surface of the water column h_1 in the pulverising aeration-treated reservoir, and in the intake chamber water column of height h_2, respectively, are equal to the atmospheric pressure, and undergo only slight changes within the h_1 and h_2 change ranges, further calculations assumed $p_1 = p_2$. Transformation of Bernoulli's equation in the form (3) yielded:

$$\frac{v_1^2}{2g}+h_1=\frac{v_2^2}{2g}+h_2, \tag{5}$$

in which, based on formula (2) and having considered the surface ratio of S_1»S_2 for flat surfaces on the surface of the lake and on the surface of the intake chamber water column, the component $v_1^2\cdot 2g^{-1}$ was ignored. A theoretical equation in the form of Torricelli's formula was obtained:

$$v_2=\sqrt{2\cdot h\cdot g} \qquad \text{m}\cdot\text{s}^{-1} \tag{6}$$

where:

$h = h_1 – h_2$, m.

It describes, for the conical turbine, the free velocity of water mass inflow from the hypolimnion to the reference level h_2.

With consideration to the true path of hypolimnetic water inflow to the water column height h_2, the calculations involved the experimental velocity index φ [Mitosek 2001] which takes into account losses produced during water flow through the intake chamber submerged in the open tank (lake). For the stream diameter d in the intake chamber of the cross-section diameter of

$$S_2 = 0.25\cdot\pi\cdot d^2 \qquad \text{m}^2 \tag{7}$$

and velocity (6) of the fluid stream mass on the surface of water column h_2, the formula:

$$Q = \varphi \cdot v_2 \cdot S_2 \qquad \mathrm{m^3 \cdot s^{-1}} \tag{8}$$

was used to determine unit volumetric intensity of water mass inflow (Q = 1.1 $\mathrm{m^3 \cdot s^{-1}}$).

Assuming that the lake water volume to be treated by pulverising aeration equals V, the formula:

$$t = \frac{V \cdot Q^{-1}}{3600} \qquad \mathrm{h} \tag{9}$$

was used to estimate, for constant parameters of conical turbine operation, the time of advection of hypolimnetic water to the reference level h_2 in the intake chamber (t = 6.4 h).

As the aerator is required to ensure the volumetric intake, described by formula (8), and transport of water from the height h_2 in the intake chamber to the aeration chamber, the calculations performed for a new generation device assumed a theoretical power required by the conical turbine, N, based on the unit power in pulverising aeration [Konieczny 2002]. In addition, based on the generally available indices of pump performance efficiency [Jankowski 1975] in the form of volumetric (η_v), hydraulic (η_h), and mechanical (η_m) losses, the total turbine efficiency η was assumed. The effective energy was determined for time (9) as:

$$A = \int_0^t (\eta \cdot N)\,dt \qquad \mathrm{kWh}, \tag{10}$$

and its value A = 5.8 kWh is the total true energy demand of the aerator for pulverising aeration of de-oxygenated hypolimnetic water in the lake.

CONCLUSIONS

1. The volumetric output of the pulverising aerator during hypolimnetic water aeration is a result of the height difference between the water column in the lake (open tank) and in the intake chamber.
2. The total energy demand of the aerator system designed to treat 25,000 $\mathrm{m^3}$ of hypolimnetic lake water amounts to A = 5.8 kWh.
3. The necessity of mathematical modelling of hypolimnetic water inflow into the intake chamber of a new generation aerator results from a possibility to determine the energy demand and to select operation parameters of the aerator’s conical turbine during pulverising aeration of any hypolimnetic zone in any surface water reservoir.

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