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DETERMINING THE ENERGY OF A WIND ROTOR IN A PULVERIZING AERATOR SYSTEM

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Summary. The paper discusses problems of lake water quality improvement aided by slow-moving wind turbines, the structure and function of a wind-driven pulverising aerator, and mathematical calculation of rotor energy. Knowledge on the theoretical Savonius rotor energy in the pulverising aerator system will assist in the selection of aerator operation parameters and improve the efficiency of pulverising aeration of Lake Starzyc.

Key words: wind energy, Savonius rotor, pulverising aerator, lakes

INTRODUCTION

Advanced eutrophication has become a world-wide problem [Mientki 2000] which calls for actions involving reduction of wastewater discharge to lakes and some complementary technological measures [Podsiadłowski 2007]. In view of threats for the natural environment posed by the use of fossil fuels [Turowski 2000] it is particularly worthwhile to consider slow-moving rotor-based wind-driven devices to be applied in efforts aimed at improving the present water quality of lakes [Piesik J., Piesik Z. 2003]. Technical parameters of slow-moving rotors [Jagodziński 1959] make it possible to utilise wind energy resources from the minimum speed of 2 $m \cdot s^{-1}$ [Mikielewicz 2004]. A slow-moving wind-driven rotor was first used in lake rehabilitation-oriented aeration of Polish lakes [Jankowski 2007; Solarczyk, Burak 2000] in the late 1980's when it was positioned on the shore of Lake Starodworskie in Olsztyn. Favourable results of the relevant research [Jaszczułt 1990] led to the development, by the Agricultural University in Poznań, and application, in 1996 on Lake Jaroszewskie at Sieraków, of a new type of wind-driven aerator (Fig. 1.) functioning in the so-called pulverising aeration technology [Zimny 2004]. The aerator, described in the literature [Konieczny 2006; Podsiadłowski et al. 2000], is capable of moving freely on the lake surface (within an area delimited by the length of the anchor line) and transporting the aerated water down to the near-bottom zone. Water aeration occurs on the surface in the pulverising segment via a Savonius rotor-driven paddle wheel through a transmission system. The near-bottom water flows through the aerator via hoses (risers) according to the principle of connected vessels.

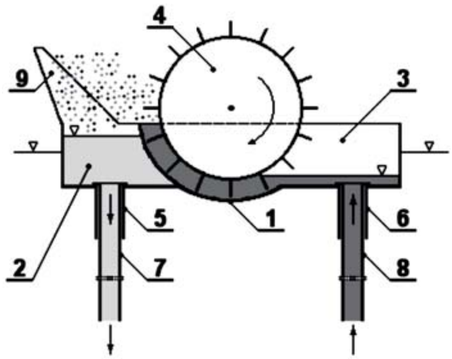

Fig. 1. A model of pulverising aeration technology system (after Podsiadłowski): 1, pulverising segment; 2, aeration chamber; 3, water intake chamber; 4, paddle wheel; 5, aeration chamber nozzle; 6, suction chamber nozzle; 7, pumping hose; 8, suction hose; 9, splash plate

The present work was aimed at presenting a mathematical method for calculation and determination of wind rotor energy under climatic conditions of Lake Starzyc which, together with an adjacent area, is a component of the Iński Landscape Park's buffer zone [Wesołowski et al. 2006]. It is assumed that an ability and possibility of mathematical calculation of the Savonius rotor energy will aid in an appropriate selection of aerator operation parameters and in undertaking effective measures for improving the quality of near-bottom water in Lake Starzyc, using the pulverising aeration technology for lake rehabilitation via water aeration.

METHODS OF STUDY

Calculation and determination of the Savonius wind rotor energy in the pulverising aerator system, placed 2 m from the Lake Starzyc surface, includes: height h_s=5 m of a rotor (cross-section surface A=20 m^2 in the vertical rotation axis); decadal wind velocity data (Resko IMWM station) [Biuletyny Agrometeorologiczne 1980-1991] over the growing seasons (April-September) of 1980-1991; wind energy utilisation index C_1=0.2; land-water roughness index K_{sz}=1.4 [Massel 1995]; and a constant air stream density ρ=1.168kg·m^{-3}. The decadal wind velocities were re-calculated with respect to the Lake Starzyc surface and to 11 levels of profile h_s subdivided into 10 sections 0.5-m long each. Wind velocities in the vertical profile were calculated with a nomogram (Fig. 2) and a correction factor calculated with a power function, using the Microsoft Excel software:

$$K_z=0.7271 \cdot z^{0.1383} \qquad (1)$$

Taking into account the relationships given by Sobolewski and Żurański [1981] for determining wind energy resources, the calculations made use of a formula for kinetic energy of air moving at a speed v (m·s^{-1}):

$$E=0.5 \cdot m \cdot v^2 \qquad J \cdot s^{-1}, \qquad (2)$$

where:

$$m=\rho \cdot A \cdot v \qquad kg \cdot s^{-1} \qquad (3)$$

is the air stream density (ρ) vector perpendicular to surface A.

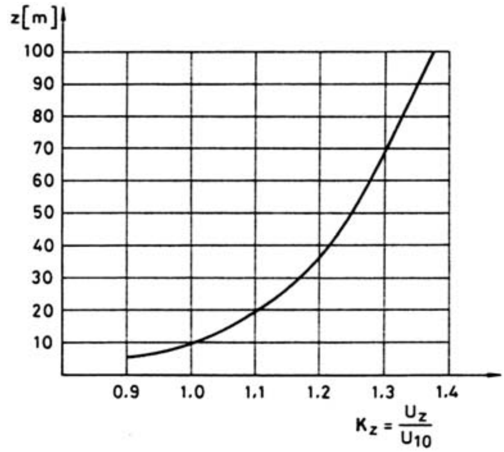

Fig. 2. Nomogram of wind speed changes in a vertical profile [Massel 1995; Wiśniewski, Wolski 2005]: K_z, correction factor; U_z, wind speed at height z; U_{10}, wind speed at height 10 m

RESULTS

Wind speed variability results in changes in the air stream energy. The air stream effects on Lake Starzyc area subjected to wind action [PN-77/B-02011] and on the IMWM Resko station is a net result of a number of factors resulting primarily from land and water roughness effect and local differences in the vertical profile. To simplify the calculations for the Savonius rotor energy in the pulverising aerator system, mean decadal wind speeds were used. Wind resources under the climatic conditions of Lake Starzyc were calculated with:

$$v = v_{10} \cdot K_{sz} \qquad m \cdot s^{-1}, \tag{4}$$

where:

v_{10} wind speed ($m \cdot s^{-1}$) at height 10 m in the meteorological station profile;
K_{sz} land-water roughness coefficient.

Power function (1) and the nomogram were used to recalculate the wind speeds (4) at every 0.5 m at the rotor height h_s. The obtained horizontal air stream speeds (v, $m \cdot s^{-1}$) were averaged across 10 0.5-m wide sections of the vertical profile A, using the formula:

$$v_{śr} = \frac{v_h + v_{0,5}}{2} \qquad m \cdot s^{-1}, \tag{5}$$

where:

$v_{śr}$ mean horizontal wind speed, $m \cdot s^{-1}$;
v_h wind speed ($m \cdot s^{-1}$) at the considered vertical profile height level;
$v_{0,5}$ wind speed ($m \cdot s^{-1}$) at a distance of 0.5 m from the point of reference.

Equations (2) and (3) describing unit kinetic energy of air moving across rotor surface A were used to calculate decadal wind stream power in the following way:

$$P=0.5\cdot\rho\cdot A\cdot v^3 \qquad W, \tag{6}$$

where index v was determined, at constant air mass stream density ρ adopted for standard conditions (25°C; 100kPa) as used in aerodynamics, by:

$$v=\sum_{i=1}^{n} v_{\acute{s}r_i} \qquad m\cdot s^{-1}, \tag{7}$$

where:

- n the number of partial surfaces A in the rotor cross-section;
- decadal mean wind speed ($m\cdot s^{-1}$) in the *i*-th section of rotor h_s.

As a wind rotor transforms the air mass stream into rotation mechanical energy (which involves energy losses), the rotor energy calculations included an aerodynamic index of wind energy utilisation [Marecki 1995; Bleckwell et al. 1977]:

$$C_l= \eta_{sm}\cdot\xi_t. \tag{8}$$

where the term η_{sm} is the rotor aerodynamic efficiency and ξ_t is the theoretical coefficient of wind energy utilisation:

$$\xi_t=4\cdot e\cdot(1-e)\ \cdot(1+e)^{-1}, \tag{9}$$

in which the term e, denoting coefficient of air stream inhibition is determined by:

$$e=v_2\cdot v_1^{-1}, \tag{10}$$

where:

- v_1 air speed ($m\cdot s^{-1}$) in front of wind-driven rotor;
- v_2 air speed ($m\cdot s^{-1}$) behind the wind-driven rotor.

Considering equations (6), (8), and literature information [Pudlik 2005; Zeńczak 2004; Marecki 1995], the theoretical power of the Savonius rotor was determined as:

$$P_{\acute{s}r}=0.5\cdot\rho\cdot A\cdot v^3\cdot C_l\cdot 10^{-3} \qquad kW, \tag{11}$$

for mean net wind speeds in the profile h_s. Calculations carried out with equation (11) involved time t (s) of wind duration in a decade. The formula:

$$E_c=\sum_{i=1}^{n} P_{\acute{s}r_i}\cdot t_i \qquad kWh, \tag{12}$$

which is a sum of products of power P and time t of wind duration in a decade, the total theoretical energy of a wind rotor in the pulverising aerator system was determined for individual months of growing seasons of 1980-1991. Because the magnitude of the monthly rotor energy is important in view of assessing a remediating potential of water aeration with the system used, equation (12) was entered into equation:

$$E_m = \frac{E_c}{i} \qquad kWh, \tag{13}$$

where:

i the number of months in the decades considered,

and theoretical values of mean monthly rotor energy were calculated. The data obtained (Table 1) served as a basis on which to determine operational parameters of a pulverising aerator and water pulverising energy necessary for the remediating aeration of near-bottom water in Lake Starzyc.

Table 1. Mean monthly theoretical energy (kWh) of Savonius rotor in a pulverising aerator system under climatic conditions of Lake Starzyc

Lake	April	May	June	July	August	September
Starzyc	39.77	29.92	36.31	20.76	19.31	36.13

CONCLUSIONS

1. The Savonius rotor energy depends on wind speed distribution along a vertical profile and on energy losses associated with air stream mass flow through the rotor.
2. For the growing season and climatic conditions of Lake Starzyc, the mean monthly theoretical energy of a Savonius rotor is estimated at 19-40 kWh.
3. Mathematical calculations and determination of the Savonius rotor energy make it possible to select appropriate parameters of aerator operation in the system of pulverising aeration of Lake Starzyc.

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