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FEM and Flow Simulation Module for selecting parameters in rotors flow systems

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ABSTRACT

Purpose: The aim of this research is to determine the construction parameters and the working parameters of the rotors modeled with the aid of the computer simulations. This research is conducted in the context of its application in different systems for sewage rectification.

Design/methodology/approach: Modeling and process analysis of the fluid flow under the working rotor conditions simulated with the SolidWorks 2010 - Flow Simulation Module.

Findings: The results presented here refer to the testing conducted for the systems of fluid flow under the real and virtual conditions.

Research limitations/implications: The studying of the fluid flow process under working rotor conditions permitted to obtain credible results for the applied FEM scheme.

Practical implications: FEM can be used as an effective tool for examination of the fluid flow phenomena for different working conditions of the flow systems. The latter holds provided pertinent tools for FEM analysis are invoked.

Originality/value: Application of FEM for studying fluid flow processes on the example with rotors.

Keywords: Numerical techniques; FEM analysis; Simulation of fluid flow processes; Modeling of the working devices - rotors

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METHODOLOGY OF RESEARCH, ANALYSIS AND MODELLING

1. Introduction

One of the basic problems occurring in Poland is the demand of the increasing number of population to use the sewerage system which needs to be constantly adjusted and extended. In addition, the rising need to equip the inhabitants from medium range population concentration (with 120 factor level) with sewerage system forms an extra demand. Due to the above mentioned challenges quite often many of the rural areas are not included in the future planed projects concerning installation of the new sewerage systems. In consequence the need for innovative technologies and devices for transportation and purification of the domestic sewages arises. These types of sewage systems require technical and technological solutions which involve among all the aeration of the transported water. Therefore a practical aim for such innovative approach is the elaboration of the concept to build devices enabling the air entrainment of the so-called rotors [1-3]. Thanks to the existing computer simulation tools, the Finite Element Method (in short FEM) combined with Fluid Flow Simulation Module are applied to adjust the rotor's parameters essential for fluid flow systems. Such parameters ought to take into account an impact of the flow conditions on the level of aeration for the flowing water. The FEM is a currently commonly used computer simulation tool for many engineering computations [4-5]. The development of FEM evolves simultaneously with the progress of the computer techniques. The abrupt development of the computer technologies in the end of 20^{th} century associated with the increase of computer computational and speed capacities as well as an increase of the computer memory make possible FEM to be applicable to many non-linear problems set for arbitrary geometry, in particular for 3D cases.

The applied herein computer aided design technology resorts to FEM and Flow Simulation Module used for fluid flow modeling in the systems of biological purification of sewage.

SolidWorks Flow Simulation is a perfect tool for an engineer who wishes to conduct a fluid flow analysis, but is not an expert within fluid simulation. SolidWorks Flow Simulation can be used in a diverse range of applications and is designed to be an extremely flexible software tool. If one strives to develop the machines, by using SolidWorks Flow Simulation during the product development cycle, it can help to build a better product within less time. Flow Simulation is a goal based flow analysis software. One simply instructs the program about the main designer's objectives e.g. maximal velocity in flow, specific pressure drops across examined model etc. and this software package will calculate these required goals and present all computed results to the user after the completion of the analysis. This functionality helps the potential user to obtain a much deeper engineering insight into designs.

SolidWorks Flow Simulation eliminates the necessity of changing the project in case of computing the flow of different fluids (Computational Fluid Dynamic) which effectively reduces the time and the costs involved. Having got the capacity of performing CFD analyses one can simulate the fluid and gas flows in the real circumstances. With this simulation design approach one opens the scenario of the so-called "what if". Under such scheme one can analyze the impact of the fluid flow on heat exchange and related forces acting on the immersed bodies or on its the surrounding other elements. We should point out here that the Flow Simulation encapsulates the analysis of the fluid flow. On the other hand the SolidWorks Simulation permits product verification with respect to their potential technical flaws before they even reach a production line. This ultimately allows to eliminate the errors at the preliminary prototype phase.

This type of modeling-based research enables the adjustment of the efficiency in the designed devices and systems tuned up to the real recipient's demands. Equally, it also allows to decrease the energy consumption for the new innovative technological solutions which in particular meets the current high standard EU requirements [8].

2. Results and discussion

The problem discussed herein, concerns the design of the innovative solutions for the systems concurrently draining and purifying the fluid in the residual units which diminishes to the much lower level incurred financial expenses. The use of such rotor-based technologies implies that they play de facto the role of the bioreactors for mineralization of organic compounds. Consequently, well designed, constructed and working rotor permits the existence of the conditions for the microorganisms to settle on the rotor surface. Thanks to its rotation the beneficial aeration and thus oxygenation occur which are needed for the biochemical decomposition of the impurities.

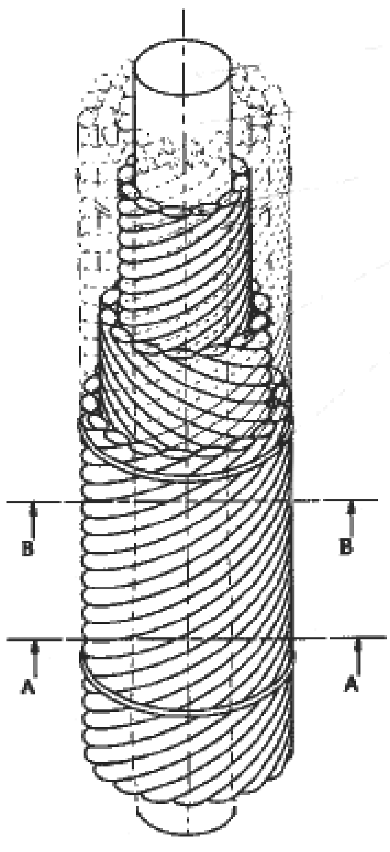

Fig. 1. The rotor's view with the laid out cylindrical channels

The adjustment of the rotor construction and its working parameters in modeling processes matters for the determination of the properties and parameters of such devise, which is meant to operate non-stop within the entire interval of the real time and to ascertain to them the most favorable conditions for aeration and turbulence of the flowing fluid. The construction and the operating principle of such rotor were patented (Call number W.119065 lodged 31.05.2010, number RWU.066284) [7].

The device of the rotor type (see Fig. 1) is built from many layers of the ducts - crimped pipes made of plastics and laid our cylindrically around rotor axis, where the shaft is positioned containing the float. On the shaft made from plastics, there are spooled coils around the cylinder envelope (see also [6] or [9]) from crimped pipes with ducts laid in cylindrical layers, twisted in alternating fashion, dextrorotatory and laevo-rotary. The crimped pipes contain not full recess and each second pipe in the layer is removed, and additionally protected with the bands. Application of such construction for the rotor makes effective and economic sewage aeration. It also permits to circulate sewage oblong the rotor's axis together with the active residue chamber. Depending on the construction, the examined devices can be either static or perform the rotational movement with respect to the rotary axis. The ducts made in the form of crimped pipes are positioned nears themselves interlaced. There are empty spaces between crimped ducts inside, where the mixture of air and water is collected. The movement of the rotor causes in the mixture of fluid and active residue, cyclic emerging and immersion of the caps. The rotor plays the aeration function.

Thanks to the revolving rotors the atmospheric air is encapsulated in the specially prepared furrows on their external perimeter and subsequently is input to the mixture of the active residue and sewage. During the operational mode of the rotor, inside it there are created different aeration zones with different oxygen condensation. Additionally, during this phase of operation mode various nitrifiers can possibly be supplemented. These processes can run simultaneously. The air contained in the furrows together with the forced fluid is ducted to the lower part of the device in question. As a result of the above process, the mixture of the air and fluid arises, which permits in turn the oxygenation. In sequel the air is gradually released to the internal zone ducts of the rotor. An appropriate adjustment of the angle of the bolt's lines for the crimped ducts, their quantity and the interlace applied have a decisive impact on the hydrodynamics of the process of mixing the air with sewage.

The rotors discussed herein are applicable in the draining and purification systems of sewage in small domestic units which results in decrease in financial expenditures and investments within this sector of economy.

The research conducted herein and based on FEM concerning the determination of the rotor's parameters is divided into the following stages:

- The analyzed domain is divided first at the abstract level into finite number of geometrically simple elements, i.e. the so-called finite elements.
- Next we assume that these finite elements are linked together in the finite number of the points situated at the perimeter of the rotor. Most frequently they form the corner points. Those selected points are commonly coined as knot points. The unknown searched quantities representing the specific physical data constitute the fundamental set of unknowns.
- In sequel special functions are selected which unambiguously define the distribution of the analyzed physical quantities inside the finite elements, depending on the values of such physical quantities at the knot points. Those functions are frequently termed as knot functions or alternatively as shape functions.
- Partial or Ordinary Differential Equations (either PDEs or ODEs) modeling the given examined phenomenon are transformed via the so-called weighing functions into the corresponding equations within Finite Element Method. The original differential equations are replaced with the system of algebraic equations.
- Next, upon resorting to the equations of Finite Element Method one performs the so-called assembling of the system of equations generated in the previous step. More precisely, one computes both the coefficients associated with the particular unknowns and the respective right-hand sides of the corresponding algebraic equations. If the posed problem is not stationary, then during the process of determination of the above mentioned right-hand sides, the initial conditions are also exploited. The number of equations appearing in this algebraic system is equal to the number of knots multiplied by the number of degree freedoms for all knots i.e. the number of unknowns occurring in single knot.
- Such generated algebraic system is augmented next with the associated boundary conditions. Inclusion of complementary boundary conditions is achieved upon pertinent modifications entered to the matrix coefficients and the corresponding vector of the right-hand sides of the initial algebraic equations.
- Finally, the above mentioned algebraic system is solved, hence yielding the numerical values representing the searched physical quantities computed and approximated at the knot points.
- Depending on the type of the posed problem and the research objectives one computes additional quantities.

The computer aided research exploiting the FEM allows to determine the process parameters so that the real efficiency of the device is attained. The specific research conducted here concerns the different levels of the forced fluid pressures applied to the rotor's ducts. This problem is vital as the fluid pressure impacts on the oxygen condensation. The verification of such question with the aid of Flow Simulation package gives the opportunity of selecting better parameters improving the efficiency of the rotors.

Flow Simulation is the convenient computer software which enables to simulate the fluid flows and facilitates the theoretical analysis of their behavior. This software eliminates the necessity of any real project modification for other real-time external system, including the pending analysis. Ultimately it reduces the preparation time and decreases the financial costs involved. Such approach aimed to the final real task guarantees an easy insight and control into the execution and functioning of the project under real conditions.

The technology linked to the application of the FEM and the use of specialized software package Flow Simulation has many advantages in researching the fluid flow processes with the use of the so-called reverse algorithm. It contains many innovative advantages within the product and processing field.

The system for data analysis for a given explored phenomenon involves varying boundary conditions i.e.:

- quantity of the crimped ducts,
- diameter of the ducts,

- positioning of the angle of the bolt's line with respect to the device rotation axis (for mobile rotor),
- fluid pressure forced into ducts (for static rotor).

Our algorithm is based on the inverse research method. It contains the possibility of results' verification of the conducted experiments. Hence it permits to obtain the outcomes with the high credibility level for different boundary conditions [10-13]. Figures 2a and 2b illustrate the efficiency of the rotor's work as a function of fixed boundary conditions in FEM. Figure 3 illustrates rotor's system in horizontal operation. Figures 4 shows the most efficient system of the stroke and angle of the bolt's line.
Aeration of the liquid is supported by the notch system positioned on the aeration duct - see Figure 5.

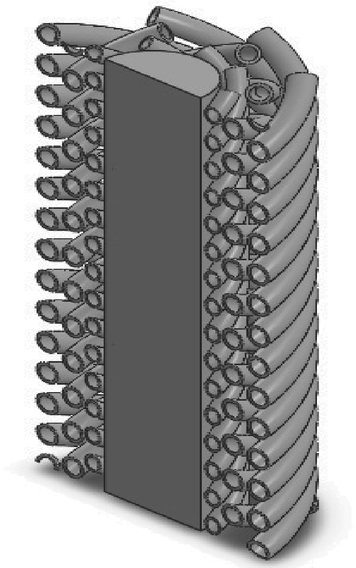

Fig. 2a. Rotor's longitudinal section

Fig. 2b. Rotor's cross-section

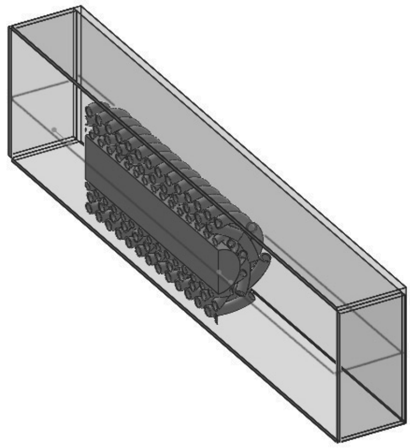

Fig. 3. Rotor's system in horizontal operation

a) b)

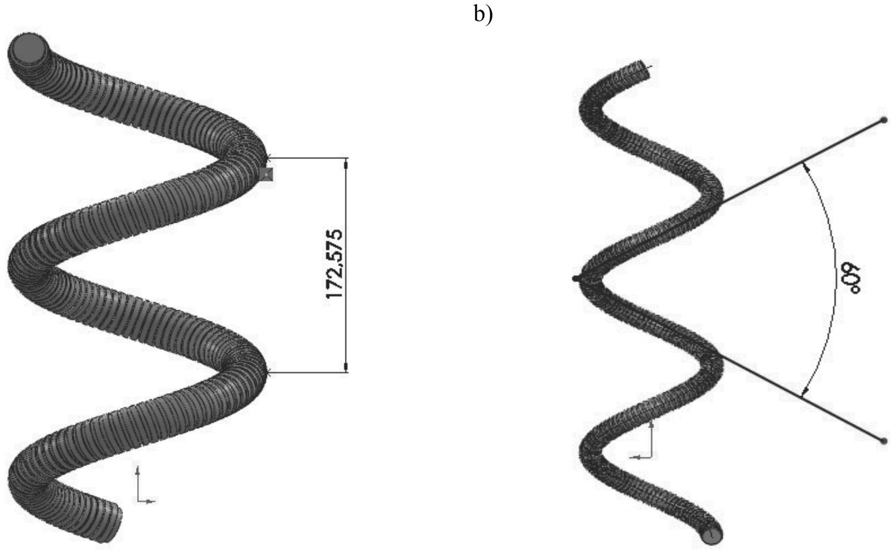

Fig. 4. The most efficient system of the a) stroke b) angle of the bolt's line

The obtained effects and their examples are presented in Figs. 6 (a-c). They both illustrate variation of the flow from the construction and building of the ducts which were introduced above. The comparisons made on Figs. 6a,b, 7a,b show that even minor construction changes and minor variations in flow conditions substantially influence the fluid flow and fluid aeration properties [14-15].

3. Conclusions

Application of simulation research with the aid of FEM together with highly specialized software Flow Simulation enables the assessment of the impact of some specific construction elements as well as fluid flow parameters in systems equipped with such designed rotors. Finally, one concludes that the application of herein discussed technology furnished in rotors should bring many advantages, among all such as:

- reduction of the operating rotor's costs,
- an increase of the competitive edge for all companies applying the above discussed technology,
- operating cost reduction for the biological waste disposal units by adjusting the parameters to the real needs,
- elimination of prototype creation for any new devices. No need to perform pre-measurements for fluid flows in different configurations,
- possibility of optimizing the technological solutions tailored to specific customer's requests,
- the possibility of verification of the conducted examination,
- result acquisition with high credibility level for various FEM programming type.

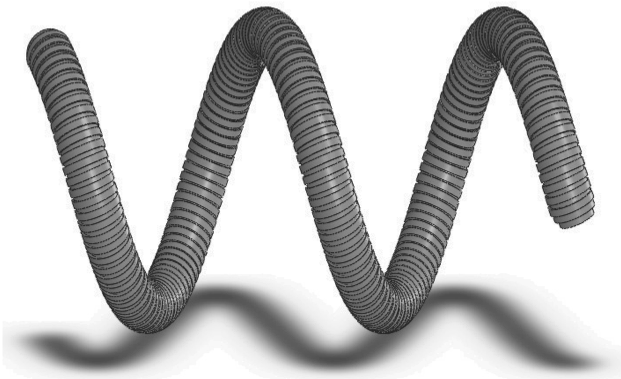

Fig. 5. Notch system positioned on the aeration duct

In this paper we described a new technology which is based on FEM and resorts to specialized software packaged namely Flow Simulation. It is designed to conduct a research on fluid flows processes taking place inside such devices and on any systems aimed for biological rectification of the sewage. Our approach relies on the algorithm using an inverse research method which contains all features for innovative process and product technology known and widely applied in the last 5 years.

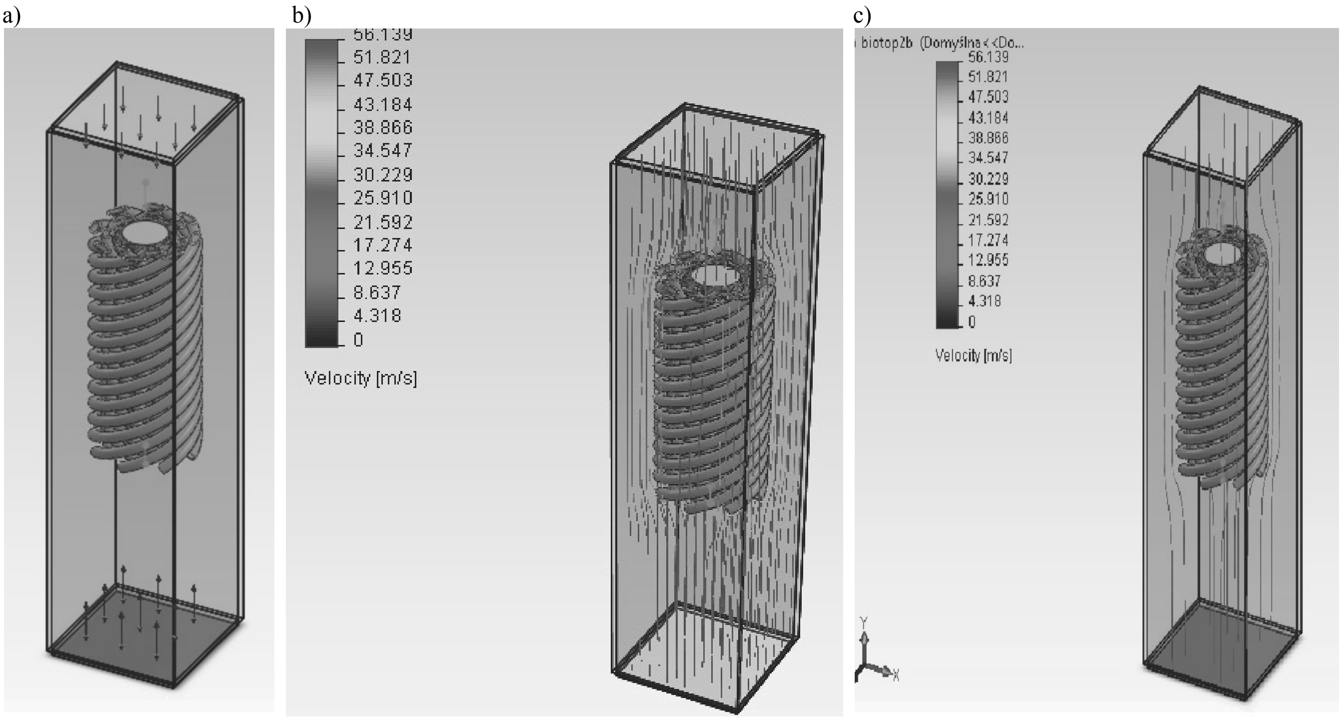

Fig. 6 (a-c). Fluid flow with fixed boundary conditions during the aeration process

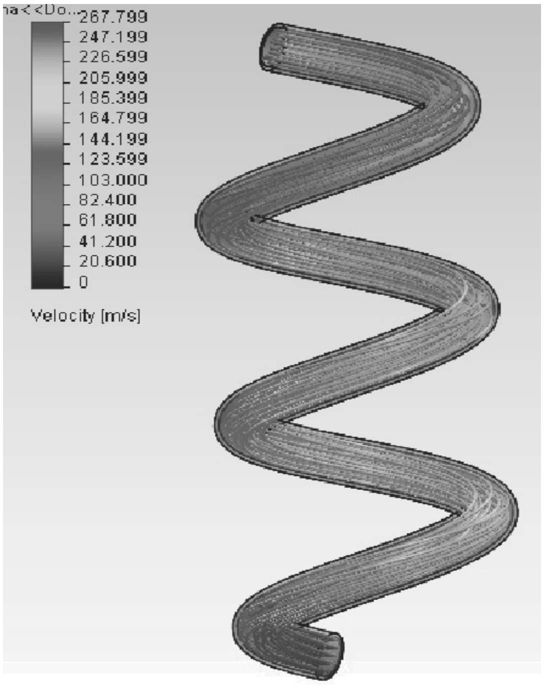

Fig. 7a. Fluid flow in single rotor's duct

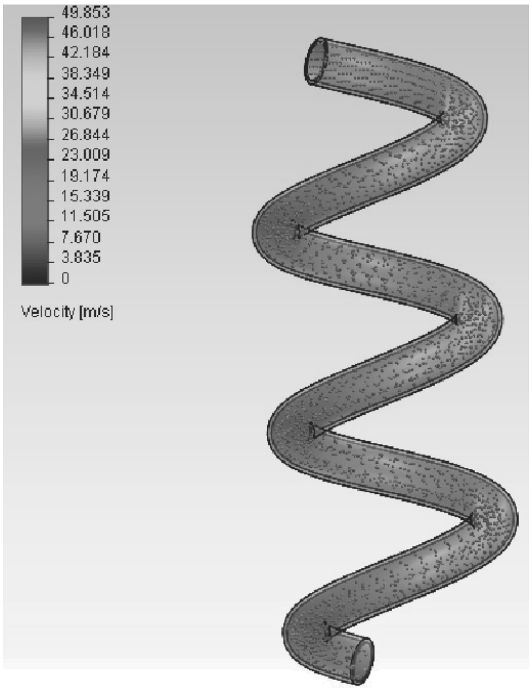

Fig. 7b. Waste flow in single rotor's duct

The elaborated herein rotor's model based on a given a priori boundary conditions sheds light on the examined phenomenon It explains the problem and permits to determine the angles of the line to position the ducts for the most efficient rotor's operation. Unfortunately the analysis of the fluid flow does not allow to conduct the more extensive interpretation within the three-dimensional system thanks to the inability of accounting for associated chemical phenomena. The analysis performed in this project permits in future to extend the flow simulation for different dimensions of the components of the discussed device without the necessity of building the testing prototypes.

Taking into account the above, any further research should incorporate the multiple aspects and parallelism of the applied computation e.g. by resorting to the systems of parallel multiple rotors. At this point, it should also be emphasized that the FEM analysis generically is based on certain geometrical simplifications which ultimately impacts on the credibility of the simulated research results. It is also worth mentioning that the researching process applied in Flow Simulation modeling uses the fluids with homogeneous densities. The latter does not occur in the real situation. Evidently, the rotors operating in sewage-treatment plants deal with heavily contaminated fluids.

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