Attachment 2b

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SUMMARY OF PROFESSIONAL ACCOMPLISHMENTS

1. Full name

Jerzy Piotr Mikosz

2. Academic diplomas and degrees

1988 **M. Sc. in Environmental Engineering**
Cracow University of Technology, Faculty of Water and Sanitary Engineering
Master's thesis entitled: „Technological efficiency and operational recommendations for Jarosław wastewater treatment plant based on start-up tests" (in Polish). Supervisor: dr inż. Wiesława Styka.

1994 **Master of Public Affairs**
The University of Texas at Austin, Lyndon B. Johnson School of Public Affairs (USA).
Master's thesis entitled: „*Water management reform in Poland: A step toward eco-development*". Supervisors: prof. David Eaton, prof. Jurgen Schmandt.

1999 **Ph. D. in Environmental Engineering**
Cracow University of Technology, Faculty of Environmental Engineering
Ph.D. dissertation: „*Application of dynamic computer simulation for selection of strategy of biological nutrient removal from municipal wastewater*" (in Polish). Supervisor: prof. dr hab. inż. Jerzy Kurbiel; reviewers: prof. dr inż. Marek Roman, dr hab. inż. Krzysztof Bartoszewski, dr hab. inż. Wojciech Dąbrowski.

3. Information on employment in scientific institutions

2000–present **Adjunct** in the Chair of Environmental Technologies (formerly: Division of Water and Wastewater Treatment, Institute of Water Supply and Environmental Protection, Cracow University of Technology.

- 2009–2013 Deputy Director for Scientific Affairs at the Institute of Water Supply and Environmental Protection, Cracow University of Technology.
- 2002–2008 Vice Dean at the Faculty of Environmental Engineering, Cracow University of Technology.

1994–1995 **Research fellow** (intern) at The Lyndon B. Johnson School of Public Affairs, The University of Texas at Austin (USA).

1990–2000 **Assistant** at Division of Water and Wastewater Treatment, Institute of Water Supply and Environmental Protection, Cracow University of Technology (in years 1992-1995 academic leave due to studies abroad and internship).

1988–1990 **Assistant trainee** at Division of Water and Wastewater Treatment, Institute of Water Supply and Environmental Protection, Cracow University of Technology.

4. Scientific accomplishment according to article 16 section 2 of the Act of 14th March 2003 on Academic Degrees, Academic Title and Degrees and Title in Arts (Dz. U. nr 65, p. 595, as amended)

4.1. Title of scientific accomplishment

Cycle of related publications entitled:

„Theoretical and practical aspects of mathematical modeling of multi-stage activated sludge process including N_2O emission"

4.2. Author, title of publication, year, publisher, reviewers

1. **Mikosz Jerzy** (2017) *Theoretical and practical aspects of mathematical modeling of multi-stage activated sludge process including N_2O emission*. Cracow University of Technology Publishing Office, Monograph 543, Series: Environmental Engineering; scientific editor: prof dr hab. inż. Anna M. Anielak; reviewers: prof. dr hab. inż. Stanisław Biedugnis, prof. dr hab. inż. Jan Pawełek (Att. 5.1).
   MNiSW[1]: **25 pt**.
2. **Mikosz Jerzy** (2015) Determination of permissible industrial pollution load at a municipal wastewater treatment plant, *International Journal of Environmental Science and Technology*, Vol. 12, Iss. 3, pp. 827-836 (Att. 5.2).
   IF (2015): **2,344**; MNiSW (2015): **30 pt**.; citations in Web of Science: **6**
3. **Mikosz Jerzy** (2016) Analysis of greenhouse gas emissions and the energy balance in a model municipal wastewater treatment plant, *Desalination and Water Treatment*, Vol. 57, Iss. 59, pp. 28551-28559 (Att. 5.3).
   IF (2016): **1,272**; MNiSW (2016): **20 pt**.; citations in Web of Science: **0**

4.3. Presentation of the scientific objectives of the above publications and the obtained results with discussion of potential applications

4.3.1. Introduction

High complexity of the phenomena occurring in multiphase activated sludge results from interactions between the processes of organic compounds oxidation, biological nitrification and denitrification, and biological excess phosphorus removal. A multiphase reactor operates under highly dynamic conditions that are stimulated by variable flow and quality of the incoming wastewater and the changing operational parameters[2]. Mathematical description of the phenomena occurring in so complex system requires in-depth knowledge on theoretical basis of the physical, chemical and biological processes, a reliable mathematical model and a consistent set of input data. Such mathematical models are applied for many years in practice at municipal wastewater treatment plants.

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[1] Polish Ministry of Science and Higher Education (MNiSW)

[2] Ekama, G. A., Marais, G. v. R. (1979) Dynamic Behavior of the Activated Sludge Process. *J Water Pollut Control Fed*, 51, 3, 534-556.

In recent years more and more attention is paid to emission of greenhouse gases from wastewater treatment processes and the attempts are made to include the description of this phenomena in the activated sludge models[3]. This concerns the emission of such gases as carbon oxide(IV) (CO_2) and methane (CH_4), and primarily nitrous oxide(I) (N_2O), as a gas with the highest value of global warming potential (296). In many situations mathematical modelling is the only way to determine the size of greenhouse gas emission from large-volume objects at wastewater treatment plants. Incorporation of N_2O and CO_2 as additional components in activated sludge models leads to the need for a very detailed description of the changes taking place there, and thus the increased complexity of these models, which results in a greater demand for input data. This in turn means that simulation research are extended and their costs increased, which is one of the most important barriers in the practical application of computer simulation at municipal wastewater treatment plants[4].

4.3.2. Objectives of the study

Computer simulation of high-effective wastewater treatment processes requires **the development of new rules for the application of mathematical models of multi-phase active sludge considering N_2O emissions.** Solving the above problem was the main scientific goal of my work. This required achieving of the following auxiliary objectives corresponding to the consecutive stages of the performed research:

1) performing theoretical studies on the basics of unit processes occurring in a multi-phase activated sludge, taking into account CO_2, CH_4 and N_2O emissions and mathematical description of these phenomena in the form of partial models;
2) determination of the rational scope of application of the partial models in a complex multi-phase activated sludge model taking into account N_2O emissions in the context of conducting simulation research in mechanical-biological wastewater treatment plants;
3) verification of the obtained results by carrying out simulation research according to the developed method in the three municipal wastewater treatment plants.

My contribution to the development of the scientific discipline is to define the principles of rational application of partial models, including models describing N2O emissions, in a comprehensive model of municipal wastewater treatment plant during simulation research. The implemented own research is innovative and the conclusions form the basis for rational planning of simulation studies in municipal wastewater treatment plants. The obtained results allowed to determine the principles of selection of partial models, the scope of their inclusion in the comprehensive model of the treatment plant and the way of performing consecutive stages of the simulation research depending on a purpose of the study. Although such attempts have been made in the past and some recommendations have been formulated on these basis[5], there are still no consistent set of principles for modification of individual test steps in order to simplify or even to abandon them, if this was warranted by research objectives and specific conditions. In addition, the issue of N_2O emissions from the multi-phase activated sludge process was not considered in these works. Modifications, that under certain conditions can be applied during simulation research, can reduce related organizational effort and make them less time-consuming.

[3] Kampschreur, M. J., Temmink, H. i in. (2009) Nitrous oxide emission during wastewater treatment. *Water Research*, 43, 4093–4103.
[4] Hauduc, H., Gillot, S. i in. (2009) Activated sludge modelling in practice: An international survey. *Water Sci Technol*, 60, 8, 1943-1951.
[5] Langergraber, G., Rieger, L. i in. (2004) A guideline for simulation studies of wastewater treatment plants. *Water Sci Technol*, 50, 7, 131-138.

4.3.3. Discussion of results

A. With respect to theoretical aspects

Model of a modern mechanical-biological sewage treatment plant is a very complex system integrating many processes taking place in different devices and connected by a number of complex interactions. For this reason, when modelling, it is presented as a **sum of partial models** that describe the functions and behaviour of individual subsystems. Depending on the purpose of modelling, various subsystems are distinguished and various interactions between them are identified, and then described with varying detail by means of partial models. The most commonly considered partial models include: hydraulic model of the system, inflow model, biological reactor model, sedimentation model and sludge processing model. This description can be further extended and detailed depending on a specific purpose of the simulation research. In the model of biological reactor there can be distinguished a partial model of biochemical transformations, a temperature model describing the reactor heat balance, a hydrodynamic model, an oxygen transfer model, control models and a number of others[6] (Fig. 1). Each of the listed partial models has extensive theoretical foundations, which in-depth knowledge and understanding is essential for its effective application in a comprehensive model.

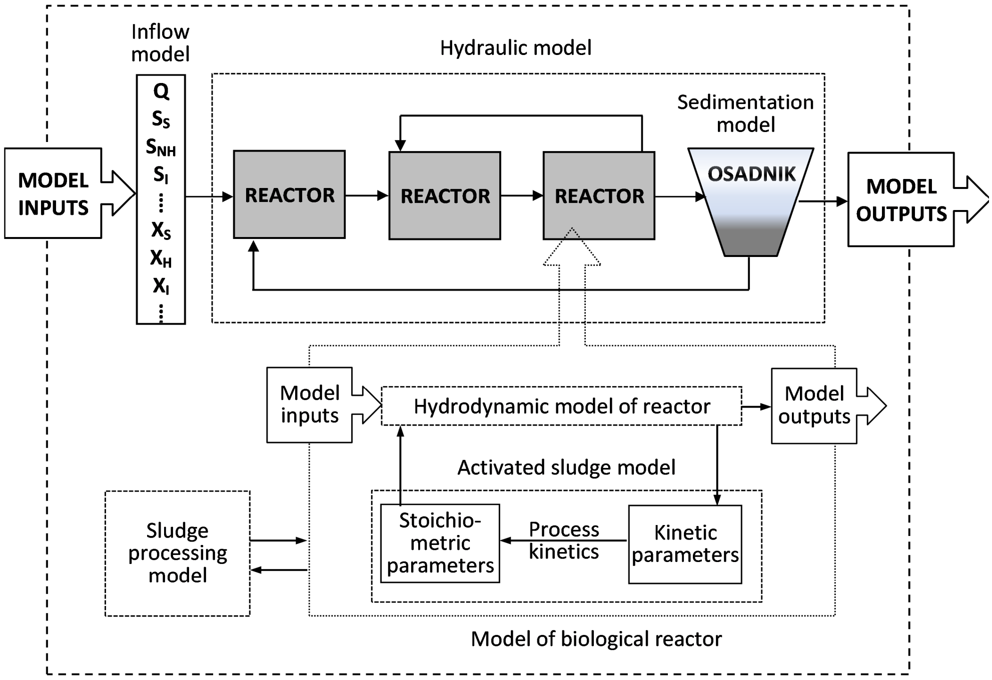

Fig. 1 Diagram describing the model of a wastewater treatment plant as a sum of partial models (developed on the basis of *Meijer 2004*[7])

In the course of my studies of theoretical aspects of modelling multi-phase activated sludge process, I performed analyses of theoretical basis of the most important partial models that are usually applied in complex models of the system „multi-phase reactor-secondary clarifier", such as: hydrodynamic model of a biological reactor, temperature model, a model of sedimentation in secondary clarifier and a model of oxygen transfer to

[6] Gernaey, K.V., van Loosdrecht, M.C.M. i in. (2004) Activated sludge wastewater treatment plant modelling and simulation: state of the art. *Environ Model Softw*, 19, 763-783.

[7] Meijer S. C. F. *Theoretical and practical aspects of modelling activated sludge processes*. Delft University of Delft, Delft, 2004.

activated sludge. With regard to the description of biochemical processes occurring in activated sludge, the analysis concerned the growth and degradation of different groups of microorganisms, hydrolysis of organic compounds and nitrogen compounds, accumulation of intracellular products and production of N_2O.

The results of my studies have shown that correct reproduction of **hydrodynamic** characteristics of a multi-phase biological reactor is essential for the simulation results. For this purpose, a tracer test is carried out on the actual site on the basis of which the hydraulic type of a reactor is determined. Usually, it does not correspond to an ideal model of completely-mixed or plug-flow reactors. Therefore, based on the results of the hydraulic tests, the approximate way of describing it in the model should be determined. For example, a plug-flow reactor is often described in a mathematical model as a system of several smaller completely-mixed reactors connected in series. Performed studies of this topic have shown that hydraulic research should be done at the beginning of the simulation tests because their results determine the planning of further research stages.

Based on the analysis, I have concluded that the way of mathematical description of activated sludge **sedimentation** occurring in secondary clarifier should directly depend on the purpose to which the model is to be applied. This description may include only sedimentation process, understood as a physical phenomenon and presented in more or less detail, or it can consider also construction details of a clarifier, external factors (temperature, pressure), and even biochemical processes occurring in a settling tank (so called reactive settlers). The generally accepted way of describing the sedimentation process is based on the theory of mass streams initiated by *Kynch* and developed in subsequent years[8]. According to this theory, the settler is divided into a number of layers (usually 10) and for each stratum a separate mass balance is calculated on the basis of mass flow theory. In most cases, such a one-dimensional description of the sedimentation process in the secondary clarifier is sufficient and, in exception of special cases, it is not necessary to use reactive settler models

The **biochemical** sub-model describes a series of processes that affect the amount of microorganisms (growth, decomposition) present in the modelled system and the availability of various substrates (fermentation, hydrolysis). In the description of these processes kinetic and stoichiometric characteristics of particular groups of microorganisms, transformations of organic compounds, source of nutrients and accumulation of intracellular products play a particular role. Limited availability of nutrients and growth factors, such as amino acids and vitamins, can limit the growth of microorganisms, even with sufficient availability of carbon and energy. Microorganisms can produce carbon compounds from organic material available in wastewater (heterotrophs) or from carbon monoxide (IV) (autotrophs). The source of energy for most microorganisms in the activated sludge is oxidative-reducing chemical transformations in which electron donors and electron acceptors can be both organic and inorganic compounds. Conducted studies have shown that accumulation of products inside bacterial cells is a very complex phenomenon, and that the control mechanisms are difficult to determine precisely mainly because heterotrophic bacteria can utilize a high variety of different organic compounds as nutrient. It is commonly accepted that accumulation of organic compounds in the form of polymers is the main mechanism responsible for removing readily available carbon compounds from the wastewater. The results I have obtained have shown that the numerous activated sludge models describe the biological processes of carbon, nitrogen and phosphorus removal in a very varied way. This allows the

[8] Vitasovic, Z. (1986) *An integrated control strategy for the activated sludge process*. Houston, TX.

choice of a biochemical model that is best suited to the purpose of study, taking into account the general principle that the simplest mathematical model that allows to achieve the intended objectives should be used.

I have devoted special attention to analysing the theoretical basis of **N_2O production** in the process of multi-phase activated sludge as a phenomenon not yet fully recognized. The magnitude of this emission is estimated at about 2,8-3% of the total N_2O emissions from all anthropogenic sources[9], and in absolute terms as 0,06−0,253 kg N_2O-N per each kg of N denitrified, of which more than 95% is released into the atmosphere[10]. The study I conducted on this subject allowed to identify the following routes of N_2O production in the process of conversion of nitrogen compounds in a multi-phase reactor:

- In the process of <u>incomplete biological heterotrophic denitrification</u>, which can be described as a four-stage nitrate reduction process, where N_2O is one of the produced intermediates on the route of sequential reduction of NO_3^-, NO_2^-, NO and N_2O to nitrogen gas (N_2) gas with simultaneous oxidation of nutrient compounds;
- In the process of <u>two-stage autotrophic nitrification</u> carried out by both bacteria and archaea. First, ammonia (NH_4^+) is oxidized to hydroxylamine (NH_2OH), which is oxidized to nitrites (NO_2^-) in the presence of hydroxylamine oxidoreductase, and then nitrites are oxidized to nitrates (NO_3^-). In this process, N_2O may be formed due to incomplete oxidation of NH_2OH, although some authors state that this only occurs at very high concentrations of NO_3^- which are usually absent in activated sludge[11];
- In the process of autotrophic reduction of nitrite (NO_2^-) to N_2O (or to N_2) by autotrophic oxidizing ammonia bacteria (AOB) that use ammonia or hydrogen as an electron donor. This phenomenon can occur under the conditions of oxygen deficit or at increased concentration of nitrites in activated sludge

The share of the aforementioned processes in total N_2O production in the process of multiphase active sediment is not well recognized. Many authors tend to find that much more N_2O is produced in the autotrophic nitrification process as well as the denitrification carried out by ammonia oxidizing bacteria (AOB) than in the typical heterotrophic denitrification process[12]. These processes have been included to a different degree in the mathematical models developed in recent years by, among others *Hiatt and Grady*, *Ni et al., Mampaey et al.* and *Law et al.*[13] However, only the model presented by Ni et al. in 2014 considers both pathways of N_2O production in the autotrophic process: by partial oxidation of hydroxylamine and by autotrophic denitrification carried out by ammonia oxidizing autotrophic bacteria[14]. My studies in this subject, however, indicate that this model requires further research to verify it, and the results obtained from it still cannot be considered as fully representative.

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[9] Law, Y., Ye, L. i in. (2012) Nitrous oxide emissions from wastewater treatment processes. *Phil. Trans. R. Soc. B*, 367, 1265-1277.

[10] Foley, J., de Haas, D. i in. (2010) Nitrous oxide generation in full-scale biological nutrient removal wastewater treatment plants. *Water Research*, 44, 831-844.

[11] Tallec, G., Garnier, J. i in. (2006) Nitrous oxide emissions from secondary activated sludge in nitrifying conditions of urban wastewater treatment plants: Effect of oxygenation level. *Water Res*, 40, 2972–2980.

[12] Wunderlin, P., Mohn, J. i in. (2012) Mechanisms of N_2O production in biological wastewater treatment under nitrifying and denitrifying conditions. *Water Res*, 46, 4, 1027-1037

[13] Ni, B. J., Yuan, Z. i in. (2013) Evaluating Four Mathematical Models for Nitrous Oxide Production by Autotrophic Ammonia-Oxidizing Bacteria. *Biotechnol Bioeng*, 110, 1, 153-163.

[14] Ni B-J., Peng L. i in. (2014) Modeling of Nitrous Oxide Production by Autotrophic Ammonia-Oxidizing Bacteria with Multiple Production Pathways. *Environ Sci Technol*, 48, 3916−3924

B. With respect to theoretical aspects

The method of applying partial models in a complex model and the way of carrying out simulation studies, in addition to the extensive theoretical basis, must also include a direct reference to the practical aspects of the research. The experience accumulated by me during many years of simulation studies at municipal wastewater treatment plants and the conclusions of various authors on the topic indicate that the research goal should determine the boundaries of the system under investigation, the required accuracy of the model and the planned scope of simulation studies. Certain modifications to the simulation research program are possible without impairing the quality of results, but they must be foreseen at the planning stage. Making such decisions at the research stage should be well thought out and substantiated and should never be the result of time pressure, increasing costs or temporary organizational difficulties caused by poor research planning[15]. Such modifications can be described as "optimizing the scope of simulation research to achieve the intended purpose and taking into account the constraints arising from financial and organizational capabilities" and should not be construed as a relinquishment of the required activities under the influence of the difficulties encountered during the study. Observations from my research conducted at many wastewater treatment plants have shown that the actions aimed at modifications of the typical course of simulation research usually go in two directions: limiting the amount of data needed and simplifying the process of model calibration and validation.

My research shows that the range of data needed to run the simulation can be significantly reduced already at the planning stage. In this case, the scope of simulations and boundaries of the modelled system are of paramount importance. The subject of the study should be only those objects and processes that are necessary for achieving research goals. Taking into account too many components and partial models increases the cost of acquiring the data needed for model's calibration and validation and reduces the relative importance of each next factor involved. This also increases the cost of simulation research and reduces the usability of the model itself[16]. Likewise, the required accuracy of the model is not an absolute requirement and depends on its planned application. It sometimes happens that an overly complicated simulation model which requires a large amount of detailed input data is used to solve a relatively simple operational problem at a treatment plant. This results in a clearly unfavourable ratio of time and efforts devoted to simulations to the obtained results and a limited potential for effective utilization of the simulation results. Reduced model's accuracy does not mean giving up the need to identify and eliminate any system errors according to the procedure outlined in Fig. 2.

The practice of conducting simulation research shows that calibration and validation of a model require the greatest amount of data, and these stages of simulation research have the greatest potential for introducing rational and legitimate modifications to simplify them. Although these stages of research are formalized with "calibration protocols", the detailed scope and course of the calibration of the model is always dependent on the specific purpose of the simulation research and specific conditions. For example, calibration can be significantly simplified when simulations are used for comparative purposes only, to describe

[15] **Mikosz J.** (2013) Symulacja komputerowa w oczyszczaniu ścieków - czy naprawdę jej potrzebujemy? *Technologia Wody*, 31, 11, s. 12-17.

[16] **Mikosz J.** (2007) Badania analityczne jako podstawa symulacji komputerowej w oczyszczaniu ścieków. *Gaz, Woda i Technika Sanitarna*, nr 9, s. 25-28.

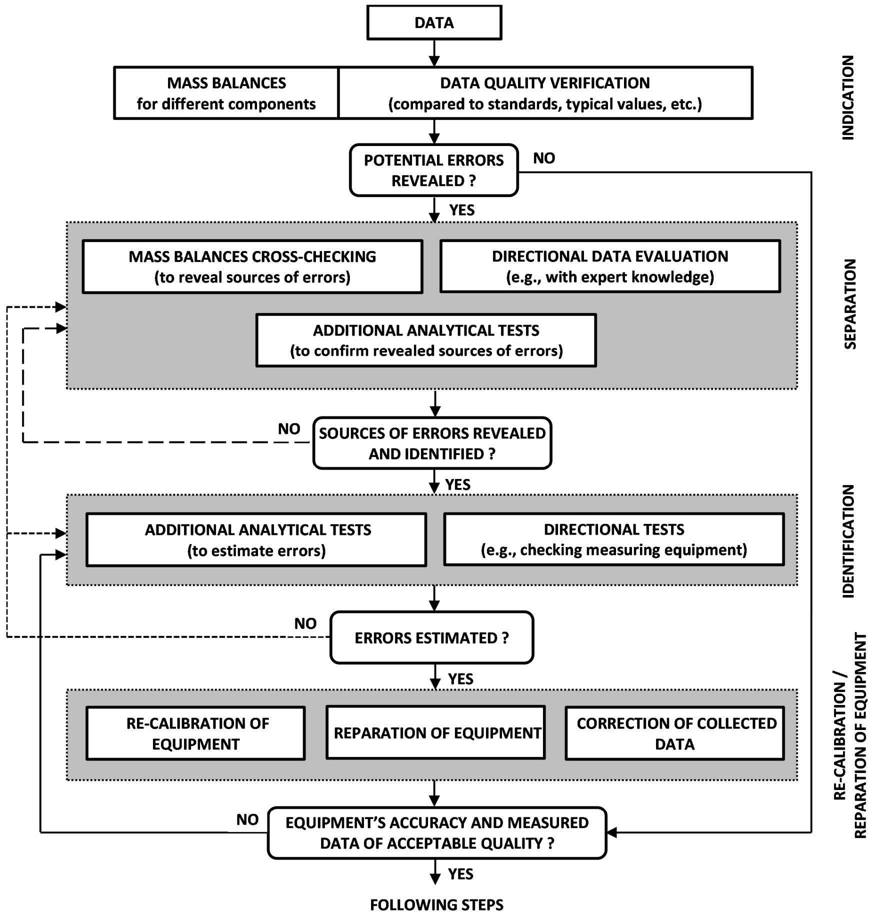

Fig. 2 The procedure to identify system errors and their sources in simulation studies (developed on the basis of *Rieger* at al. 2010[17])

the "directional" effects of the changes being introduced, to train plant operators, to develop emergency procedures, or to verify design solutions at the conceptual stage. The obtained results show that modifications made at various stages of simulation research may take the form of:

- reducing the range of processes (partial models) considered in a complex model,
- application of the simplest biochemical model that allow to meet the objectives,
- selection of an inflow model that well fits the available data on wastewater composition and minimizes the need for additional analytical tests,
- utilization of historical data routinely collected at a wastewater treatment plant while enhancing the monitoring of the processes taking place in the treatment plant in advance of the commencement of the simulation research,
- reducing of the scope of analysis of biomass composition and its parameters performed before the initial simulations,
- application of such calibration procedure that makes the best use of the available data,
- omission of dynamic calibration stage, if justified by purpose of the research,
- omission of hydrodynamic calibration of the system or only verify its hydraulic properties if a studied system has a simple hydraulic flow-scheme,
- determination of sludge sedimentation velocity based on sludge index value instead of conducting column testing.

[17] Rieger L.,Takács I. in. (2010) Data reconciliation for wastewater treatment plant simulation studies-planning for high-quality data and typical sources of errors. *Water Environ Res*, 82, 5, s. 426-433.

Modifications aimed at simplifying individual stages of research, which in certain circumstances may be permissible in the course of conducting simulation research with the resulting benefits and possible risks, were presented in detail in the attached monograph (Att. 5.1, tab. 10)[18]. These must be based on rational basis in such a way that they do not adversely affect the reliability of the research and do not increase the uncertainty of the results. The results of my research have shown that if such an effect is observed, a typical simulation procedure, compliant with the applied calibration protocol should be restored.

C. Practical verification of results

Formulated by me the principles of application of partial models in the complex model of a wastewater treatment plant leading to simplification of simulation research, enable the use of computer simulation as an effective tool in operational and design practice. These principles have been practically verified by me during the simulation research carried out in 3 wastewater treatment plants: one benchmark (hypothetical) and two existing (municipal wastewater treatment plants in Pruszków and Jasło). All the studies ended up achieving the set objectives, but in each of the described cases, the research plan was appropriately modified for the purpose of the study, in line with the principles developed by me for the application of partial models. The differences in the research plans developed for each wastewater treatment plant were as follows:

- In the case of tests conducted on the **benchmark plant model (verification study I)**, the model calibration and validation phases were omitted since the subject of the simulations was a specifically described hypothetical object that did not exist in reality and therefore there was no reference data for calibration of the model.
- Simulation studies at the **wastewater treatment plant in Jasło (verification study II)** were conducted using a previously developed model that already was used in the past. Therefore, during simulations, the calibration of the model has been significantly simplified, limiting it to validating the operation of the complex model and only re-calibrating the partial biochemical reactor model. In addition, N_2O production in the activated sludge reactor was not included in the study.
- The research conducted in the **wastewater treatment plant in Pruszków (verification study III)** was the most comprehensive and included all relevant stages of simulation studies as defined in the universal GMP calibration protocol. The model included description of N_2O production in the process of multiphase activated sludge.

Details of my research are presented in the publications that make up the scientific achievement (respectively: Att. 5.3, 5.2 and 5.1 chapter 7), and the concise description of the results is shown below.

Verification study I

The purpose of my simulations conducted with the benchmark model of a wastewater treatment plant was to demonstrate the potential for reducing greenhouse gas (CO, CH_4 and N_2O) emissions at municipal wastewater treatment plants while improving energy balance of the plant. The wastewater treatment plant was configured according to the Benchmark Simulation Model no. 2 (BSM2)[19], including some minor modifications for practical reasons.

[18] **Mikosz J.** (2017) *Theoretical and practical aspects of mathematical modeling of multi-stage activated sludge process including N_2O emission*. Monograph 543 (in Polish), Cracow University of Technology Publishing Office.
[19] Jeppsson U., Pons M.-N. i in. (2007) Benchmark simulation model no. 2—General protocol and exploratory case studies, *Water Sci. Technol.* 56, s.67–78.

As factors affecting greenhouse gas emissions and energy balance at the plant I have chosen: dissolved oxygen concentration in the reactor's aerated zone, process temperature, solids retention time (SRT) and availability of organic substrate in influent expressed as COD:TN ratio. The energy balance included energy demand for: pumping, aeration and mixing of activated sludge, sludge processing along with its heating, and recovery of energy from biogas produced during anaerobic sludge fermentation. The developed model was based on the "*Mantis2*" model included in the GPS-X v.6.1 program supplemented by the greenhouse gas emission module based on models presented by *Hiatt and Grady* and *Ni et al*. A detailed description of the studied wastewater treatment plant, the conducted research and the obtained results I have provided in the attached publication (Att. 5.3)[20].

The results showed that, among the analysed factors, the DO concentration in the aerobic zone of the bioreactor plays an essential role in GHG emissions. When DO concentration in the aerobic zone was kept at 0.8 gO_2/m^3 or more, the total GHG emission was maintained at almost a constant level of approx. 24 tCO_2eq/d. At lower concentrations, a rapid increase in the amounts of N_2O and CH_4 produced in the bioreactor was observed. On the other hand, the increase in the DO concentration adversely affects the plant's energy balance through the increase in energy consumption for aeration at an almost unchanged level of the energy recovery from the biogas. This effect is observed for both the tested process temperatures, 10 and 20˚C, however it should be noted that at 10˚C the plant's overall energy surplus is by approx. 30 kW larger than at 20˚C. Another factor that clearly affects the N_2O emissions is the availability of organic substrate for the nitrogen heterotrophic reduction process. The simulations showed that an amount of the organic substrate in the influent, described by a value of COD:TN ratio, should be equal to 10 or more. At smaller values of the COD:TN ratio, increased N_2O emissions were reported. The effect of this factor on the plant's energy balance was negligible. The biochemical activity of the activated sludge biomass strongly depends on its SRT. The effect of this parameter on N_2O production was negligible. The simulations showed that the increase in the biomass retention time above the typical value of 16–20 d increases mineralization of activated sludge and is detrimental to biogas production during anaerobic digestion od sludge.

Results of computer simulations performed using the above-mentioned values of the aforementioned factors (DO=1.0 gO_2/m^3, COD:TN=10, SRT=17 d) have shown that it is possible to simultaneously reduce greenhouse gas emissions and improve the energy balance of the wastewater treatment plant at the same time. The results showed that, after the optimization, the total production of the GHGs had been reduced by 1,446 kg CO_2eq/d, with N_2O emissions reduced by 1,103 kg CO_2eq/d, CH_4 emissions by 87 kg CO_2eq/d and CO_2 emissions by 256 kg CO_2/d. This was accompanied by an increase in excess energy at the plant by approx. 34 kW. Even more benefits can be achieved if the "saved CO_2 emissions" due to the reduced purchase of non-renewable energy from outside are considered. Then, assuming an emission coefficient of 1.0 kg CO_2eq /kWh excess energy of 816 kWh/d can save GHG emissions by approx. 816 kg CO_2eq /d in addition to the direct emissions reductions presented above. The results of the simulation study indicate significant potential for reduction in GHG emissions existing at many municipal wastewater treatment plants with multi-stage activated sludge that can be revealed by optimization of the operational parameters.

Verification study II

[20] **Mikosz J.** (2016) Analysis of greenhouse gas emissions and the energy balance in a model municipal wastewater treatment plant, *Desalination and Water Treatment*, Vol. 57, Iss. 59, s. 28551-28559.

The research conducted by me in the municipal wastewater treatment plant in Jasło were aimed at determining the maximum permissible pollution load from the industrial plant, which can be delivered to the treatment plant connected to the combined sewage network while maintaining its assumed technological effects. For this purpose I have used the previously developed simulation model of the treatment plant, which allowed me to significantly shorten the research, mainly by limiting the calibration of partial and complex models. The modifications introduced by me in the standard course of conducting simulation research concerned:

- simplifying the calibration of the biochemical model of a reactor by recalibrating a previously developed model using less input data,
- replacing the sludge treatment model with the model of process water supply,
- modeling of sedimentation as a non-reactive 1-dimensional process,
- omission modelling of N_2O production in multi-phase reactors.

I conducted the research according to a specially developed methodology, assuming their multi-staging and acceptance of partial research objectives. Organization diagram of the research is presented in Fig. 3, and a detailed description of the research and the results obtained is contained in the enclosed publication (Att. 5.2)[21].

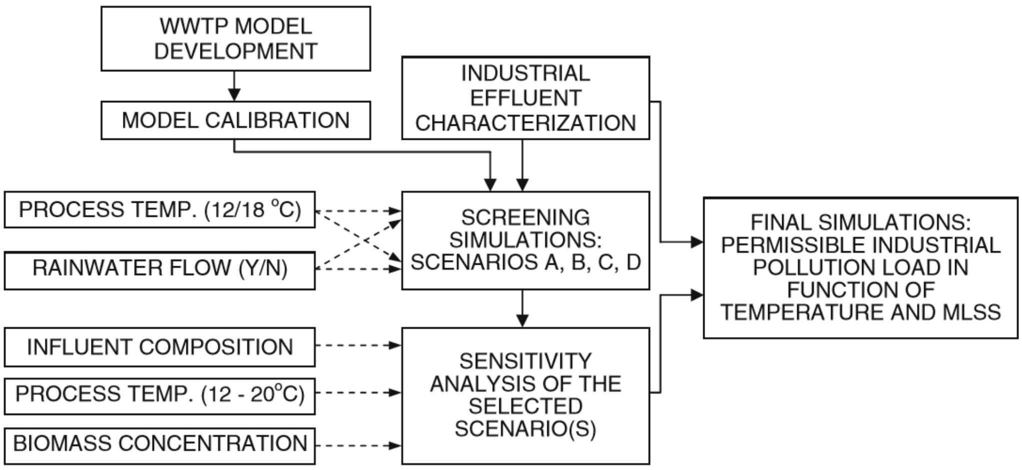

Fig. 3 Organizationa diagram of the research at wastewater treatment plant in Jasło.

As a result of the simulations I have determined the relationship between the permissible COD load and the concentration of activated sludge in the multi-phase reactor as a function of the process temperature. I presented this relationship graphically in the form of a graph (Fig. 4), showing the required concentration of activated sludge (dashed line) for different values of COD load at the treatment plant (continuous line) at varying process temperatures. Simulation results have shown that the adoption of an increased organic pollution load at a level of just over 9000 kg COD/d is possible when the activated sludge temperature is in the range of 14-19 °C and the activated sludge concentration is maintained at 3600-5400 g MLSS/m^3, according to the curves in Fig. 4. When the process temperature is beyond the above range, the permissible organic pollution load in the feed gradually decreases down to a value of 7500 kg COD/d.

[21] **Mikosz J.** (2015) Determination of permissible industrial pollution load at a municipal wastewater treatment plant, *International Journal of Environmental Science and Technology*, Vol. 12, Iss. 3, pp. 827-836.

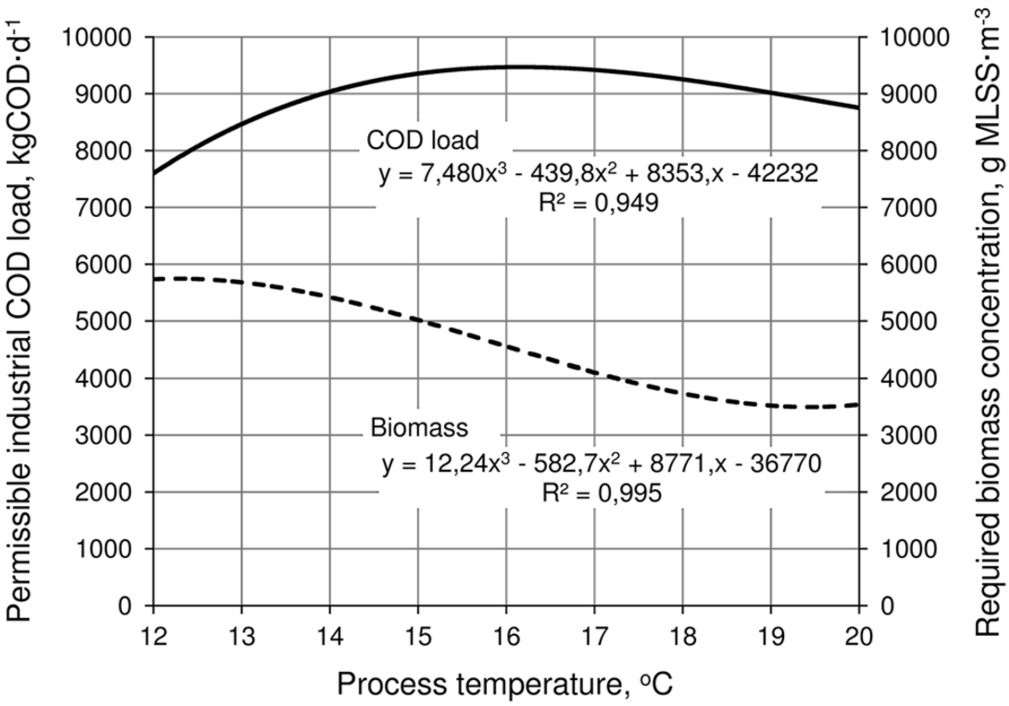

Fig. 4 Permissible industrial pollution load and the required biomass concentration as a function of process temperature.

Verification study III

The purpose of my research at the wastewater treatment plant in Pruszków was to develop and implement a mathematical model of a treatment plant, which in the long term was supposed to allow the use of computer simulation for its operational optimization and verification of plans concerning possible extension of the facility. This task involved the development of a number of partial models and a comprehensive model, followed by calibration and validation. This required gathering large amounts of input data, and thus carrying out extensive programs of hydraulic and analytical studies under conditions of routine operation of the facility. The research at the treatment plant was conducted in years 2010-2011 according to the plan developed by me and under my continuous supervision. The studies, together with the results obtained, have been described in detail in the attached monograph (Att. 5.1 chapter 7)[22]. Program GPS-X® v. 5.02 developed by Hydromantis ™, Inc. has been selected as the software platform for computer simulations. The scope of the simulation research involved the development of a comprehensive model of the system "biological reactor-secondary tank" with its full calibration and validation. Primarily it required the design and implementation of detailed analytical programs for wastewater composition and sludge properties, the development and calibration of partial models and the development, calibration and validation of a comprehensive model of the system under study. At the next stage of research, I developed the description of N_2O emissions from the multi-phase activated sludge process, incorporated it into the developed model and implemented the final model into the new GPS-X® v. 6.1 software platform. Plan of the simulation research was based on the GMP Universal Protocol (Annex 5.1, Table 13), to which I introduced a number of modifications as shown in Table 1.

[22] **Mikosz J.** (2017) *Theoretical and practical aspects of mathematical modeling of multi-stage activated sludge process including N_2O emission*. Monograph 543 (in Polish), Cracow University of Technology Publishing Office.

Table 1 Partial models included in the final model of the wastewater treatment plant along with the range of implemented modifications

Lp	Partial models	Range of implemented modifications
1	Influent model	Based on the results of the research carried out. Takes into account the effect of mechanical treatment of wastewater.
2	Primary sludge fermentation model	A replacement model was adopted describing the inflow of supernatant from the fermenter to the reactor.
3	Hydraulic model of „biological reactor-secondary settler" layout	Calibration based on the results of the performed hydraulic tests with a tracer.
4	Temperature model	No calibration (default parameter values accepted).
5	Biochemical model of activated sludge	Static and dynamic calibration based on the results of performed tests and analytical studies.
6	Chemical precipitation model (P)	Simplified calibration based on routine operational data.
7	N_2O emission model	Simplified calibration (based on indicative values).
8	Aeration system control model	Simplified calibration.
9	Control model of recirculation systems and removal of excess sludge	No calibration (parameter values based on design data and results of measurement).
10	Model of secondary sedimentation	Simplified calibration (static only) based on the results of measurements.
11	Sewage sludge processing model	Considered only the influence of sludge processing waters on the reactor (calibration based on operational data).
12	Biochemical model of secondary settler	Not included. A model of a non-reactive settler was adopted.

The developed model was subjected to sensitivity analysis in reference to a number of input variables as well as to uncertainty analysis. Sensitivity analysis of the calibrated model showed that the model is susceptible to changes in the values of all parameters that were varied during calibration (Att. 5.1, Table 25). The influence of parameters describing the biomass of autotrophs and P-heterotrophs (growth and degradation rates) is clearly observed on, respectively, nitrification and biological removal of phosphorus, as well as BOD_{5filtr}/COD_{filtr} in influent to the reactor on heterotrophic processes and the production of N_2O in the biological reactor (Tab. 2).

The model uncertainty analysis was performed for a number of indicators in effluent using the Monte Carlo method, assuming a normal distribution of values of the tested parameter x in the range x ± 50% of a value used in the model and the number of calculations was set to n = 1000. The results of the analysis showed that only for BOD_{5filtr}/COD_{filtr} the uncertainty about the actual value of a tested parameter within the assumed limits is significant for the obtained results. This had an impact on such output variables as biomass concentration, COD value and Kjeldahl nitrogen concentration. In the case of $N\text{-}NH_4$, $P\text{-}PO_4$ and $N\text{-}NO_3$, as well as N_2O production, the uncertainty of estimating the value of the tested indicator has little effect on the results obtained (Att. 5.1, Fig. 25).

Table 2 Values of sensitivity coefficient ($S_{i,j}$≥0,25) for various variables in the model of the studies wastewater treatment plant.

Parameter	Values of $S_{i,j}$ for an output variable							
	COD	**COD_{filtr}**	**TKN**	**$N\text{-}NH_4$**	**N-NOx**	**$P\text{-}PO_4$**	**MLSS**	**N_2O**
Maximum specific growth rate for autotrophic bacteria, μ_A			-1,798	-5,008				2,578
Half-saturation coefficient for ammonia in autotrophic growth process, K_{NH4}			0,575	1,621				-0,496
Decay and lysis rate for heterotrophic bacteria, b_H	-0,366		-0,512			1,343		
Half saturation coefficient for soluble substrate S_S, K_S								-0,492
Half saturation coefficient for oxygen (in different processes), K_{O2}					-0,252	-0,686		
Half saturation coefficient for N_2O in heterotrophic denitrification, K_{N2O}								0,433
Maximum specific growth rate for heterotrophs-P, μ_{PAO}	-0,598		-0,779			6,862		
Decay rate for heterotrophs-P, b_{PAO}	-0,344		-0,500	-0,262		2,681		
Wastewater temperature			-0,300	-0,399				-0,359
BOD_{5filtr}/COD_{filtr} in influent to the reactor	-2,431	-5,008	-1,738				0,340	-2,038

The research I have conducted has shown a practical course of action leading to the development of a functional simulation model of the biological part of a large municipal wastewater treatment plant. For the developed model I have defined directions of its potential application in the operational practice of the treatment plant. They included, among others:

- checking the behaviour of biological part of the treatment plant under conditions of increased rainfall,
- optimization of the internal recirculation rate in biological reactor to increase the efficiency of denitrification,
- verification of the possible increase in effectiveness of biological phosphorus removal by dosing supernatant from fermenter into biological reactor,
- checking the possibility of increasing the efficiency of denitrification and biological phosphorus removal by dosing external carbon source into reactor,
- using the model to assess condition of diffusers in biological reactor,
- evaluation of the possibility of limiting N_2O emissions from the treatment plant.

On the basis of my research, I have formulated a number of conclusions regarding planning and conducting simulation studies which can be summarized in the following way:

- The purpose of the research must be precisely defined and the boundaries of a modeled system must be clearly defined.
- When planning simulation studies available calibration protocols should be used to ensure the correct procedure of the research.

- During simulation studies, it is possible to apply rational modifications that do not compromise the quality of the developed model and simplify the research by reducing organizational effort, saving time and reducing costs.
- Hydrodynamic properties of the studied system should always be determined. This can be accomplished by carrying out hydraulic tests with a tracer or, in cases of simple hydraulic systems, by analysing available data. The studies should be carried out at very beginning of the simulation research is such way that the obtained results could become the basis for planning further stages of the research (e.g. sampling sites, frequency, time, etc.).
- Analytical correctness of wastewater quality measurements, their representativeness and consistency have a major impact on quality of the model being developed. Measurements and analyses performed during simulation research must guarantee analytical accuracy, representativeness, repeatability and consistency, and their quality must be verified by means of mass balances.
- As a general rule, calibration of the model should be conducted as an iteration process by repeating static and dynamic calibrations until reaching the assumed level of consistency of measurements and simulation results.
- Model sensitivity and uncertainty analysis should be an integral part of any simulation research program, as it provides important information on its quality and the range of applicability.

4.3.4. Practical application of the results

The results of my research can be directly applied in the operational practice of municipal wastewater treatment plants and as a basis for further research in this area. In their theoretical aspects they point to the need for further research on incorporation of partial models of N_2O production into multi-phase activated sludge models. The obtained results should be used as a starting point for the development of an easy-to-use and comprehensive model of multi-phase activated sludge. Such model should be based on the existing standard activated sludge models and the models describing N_2O production taking into account all the pathways of its production. In the next stage, this model should be subject to a versatile practical verification. On the other hand, it is also necessary to develop new analytical tools and methods for fast and cheap determination of wastewater composition and sludge parameters with respect to requirements of simulation research conducted in municipal wastewater treatment plants.

In their practical aspects, the results of my research indicate a new direction in the use of multi-phase activated sludge models, which is based on a more flexible and practical approach to their application. Up to now, one of the major barriers in the practical application of computer simulation at wastewater treatment plants has been the time-consuming and costly nature of simulation research, particularly the collection and analysis of input data and the calibration and validation of the model. Identifying consistent principles by which simulation research can be simplified while ensuring that the research goal is achieved should contribute to the widespread use of computer simulation in municipal wastewater treatment plants.

5. Presentation of other scientific accomplishments

5.1. Prior to receiving Ph.D.

Since very beginning of my work at the Division of Water and Wastewater Treatment of the Cracow University of Technology in 1988, my professional interests have been related to **the problems of high-effective removal of nutrients from wastewater**, which was then a new subject in Poland and demanding detail research. The first research project I participated was the NCB project 0120 88 86 "Water renovation technology for industrial needs"(Att. 3, B.10.26). After an annual break for compulsory military training, since 1989 I have been actively involved in the research on a model water renovation station from municipal wastewater installed at the Kraków-Płaszów wastewater treatment plant under the CPBR no. 13.1 topic 4.1 "*Determination of synergistic effects of nutrient removal processes in multiphase reactors and sludge properties for needs of wastewater treatment* " (Att. 3, B.10.25). The purpose of the study was to determine values of the most important technological parameters and design guidelines of a multi-phase biological reactor for integrated removal of nutrients from municipal wastewater. The research were conducted on a physical model of the biological reactor installed at the Kraków-Płaszów wastewater treatment plant and it lead to my first individual conference paper (Att. 3, B.12.15). A similar research subject I continued in years 1991-92 during the research project financed by KBN "*Optimization of the biological process of removal of nitrogen and phosphorus compounds under operating conditions for municipal wastewater with organic matter deficiency*" (Att. 3, B.10.24). By participating in these studies, I focused on optimization of operational parameters needed for effective removal of carbon, nitrogen and phosphorus from wastewater in a single-sludge multi-phase reactor. The obtained results were presented in a conference paper (Att. 3, B.12.14).

In years 1992-94 I completed my Master's degree in Lyndon B. Johnson School of Public Affairs at the University of Texas at Austin (USA), and then I held a year-long research internship at this university. That time has been used by me to carry out detailed studies on issues related to the prevention of environmental pollution in context of operation of wastewater treatment plants and the problems of sustainable management of water resources. I participated in two research projects: "*Managing Environmental Risks in Texas*" and "*Implementing Watershed Management in Texas*" (Att. 3, B.10.23-24), and I was also the initiator and principal researcher of two educational and dissemination projects directed by prof. David Eaton, and financed by the US Government (Att. 3, B.6.22-23; Att. 4, I.14-16). Among scientific results of my work performed during the stay in the USA is my individual article on the reform of water management system in Poland (Att. 3, B.5.19) and two collective works co-authored by me: one on assessment of the state of environment and the other on environmental hazards in Texas (Att. 3, B.5.20-21).

After returning to Poland in 1995, I continued to develop my research interest in biological methods for removal of nutrients from wastewater, but **over time my attention has increasingly focused on the use of computer methods in wastewater treatment**. For simulations I used simple programs like ASIM® and EFOR®, and then SimWorks®. In 1996 my supervisor, prof. dr hab. inż. Jerzy Kurbiel received a doctoral grant from the Committee for Scientific Research (KBN) for the project: "*Application of dynamic computer simulation for selection of strategy of biological nutrient removal from municipal wastewater*". The results of the research conducted by me within this project included, in addition to the doctoral dissertation defended by me in 1999[23], the conference papers (Att. 3, B.12.12-13). However, the research work done by me in during preparation of my doctoral dissertation dealt with a very narrow area connected with the use of computer simulation in wastewater treatment, and I clearly realized the need to further deepen and develop them.

In the period before Ph.D., I actively participated in international cooperation. In 1996 I held a short-term internship abroad at Anglia Polytechnic University in Cambridge (UK) as part of the TEMPUS-PHARE JEP program. Between 1996 and 1999 I held a number of one-month internships at the Royal Institute of Technology in Stockholm (Sweden) where, under the supervision of Dr Elżbieta Płaza and her research team, I worked on computer simulation of carbon and nitrogen removal processes in activated sludge reactors. The results of this collaboration included a number of research papers and unpublished teaching materials, as well as a joint paper presented at the international conference in Milan (Italy) in 1998 (Att. 3, B.12.11). As part of deepening of my knowledge and developing new skills in mathematical modelling of wastewater treatment processes, in 1998 I participated in an intensive training course *„Modelling of Environmental Bioprocesses”* organized by Eidgenössische Technische Hochschule (ETH) Zürich in Switzerland. During this course I managed to deepen my knowledge of mathematical modelling of multi-phase activated sludge process and gained new skills in application of numerical methods.

My knowledge about removal of nutrients from wastewater and the use of computer simulation for optimization of wastewater treatment processes I have tried to apply to solve actual problems occurring at Polish municipal wastewater treatment plants. This resulted in my participation in a number of projects ordered by administrative institutions or by commercial entities (Att. 4, M.14-22), some of which contained important research components (e.g. Att. 4, M.14, 19, 21). This particularly applies to the project ordered by Zakłady Azotowe S.A. w Mościcach, which required extensive microbial biomass analyses, investigations on composition of wastewaters from originating from various industrial processes, and studies of interactions between different organic compounds present in these effluents (Att. 4, M.19).

5.2. After receiving Ph.D.

5.2.1. Domestic activities

After receiving Ph.D., my research interest remained in the broad area of application of computer methods in high-effective wastewater treatment, but over time they were gradually evolving and focused on more specialized issues, going from the simple use of computer simulation, through the in-depth study of theoretical bases of activated sludge mathematical modelling, to practical aspects of the use of computer simulation in wastewater treatment plants. Subsequent areas of scientific interests that I have been discovering have always been inspired by the results of my previous research and the on-going developments in this field in Poland and in the world.

During initial period of my research, I was concentrated on the **ways in which computer simulation could be efficiently used as a tool to solve specific operational and design problems**. My research works were specifically directed at:

[23] **Mikosz J.** (1999) *Application of dynamic computer simulation for selection of strategy of biological nutrient removal from municipal wastewater*. Ph.D. dissertation (in Polish), Cracow University of Technology, Faculty of Environmental Engineering, Kraków.

- technological verification of the multi-phase activated sludge process during design, modernization (Att. 3, B.6.20) and operation (Att. 3, B.6.19) of wastewater treatment plants;
- evaluation of technological benefits resulting from the practical application of simulation programs at medium-sized municipal wastewater treatment plants (Att. 3, B.6.18);
- evaluation of technological and economic effects of rainwater inflow into a municipal wastewater treatment plant (Att. 3, B.6.16-17).

The results obtained by me allowed confirming that properly applied computer simulation can be a valuable tool for solving various design and operational problems at municipal wastewater treatment plants. It allows you to get information about your system that would be difficult or even impossible to obtain using other methods. This is especially true for research conducted to determine the behaviour of a given system in dynamic conditions (e.g. rainwater inflow, discharges of large pollutants into sewage system, etc.). The results of my research also showed that application of computer simulation in practice encounters various barriers, the most serious of which is the lack of experience in conducting simulation, and time consuming and high cost of those stages of research, which are related to collecting, analysing and verifying input data. Operational practice shows that without the overcoming of these barriers, the use of computer simulation at wastewater treatment plants cannot be effectively propagated. The results of the studies conducted and the conclusions drawn from them were presented in one article in JCR journal (Att. 3, B.1.4), two papers delivered at national conferences (Att. 3, B.12.8; B.12.10), three papers at international conferences (Att. 3, B.12.3; B.12.7; B.12.9), as well as two chapters in foreign monographs (Att. 3, B.5.16-17)[24].

The conclusions of the above-presented research and my experience in conducting simulation research have led my further research and development activities to the subject of **increasing the efficiency of simulation studies conducted in urban wastewater treatment plants by their rationalization**. I assumed that these actions should go both, towards reducing the complexity of the applied mathematical models (especially the activated sludge models) through the proper application of partial models, and rationalization of simulation research planning. I raised these tasks in the form of research on the following specific issues:

- evaluation of the existing calibration protocols for activated sludge models with a view to their simplification (Att. 3, B.6.8-9),
- analysis of practical aspects of application of computer simulation at municipal wastewater treatment plants (Att. 3, B.6.2; B.6.5),
- verification of the feasibility of rationalization of simulation research at municipal wastewater treatment plants to propagate their use (Att. 3, B.6.3-4).

The results of my research have shown that existing calibration protocols can be a helpful tool in "normalizing" the methodology of conducting simulation research and thus reducing the uncertainty of the model's performance. However, individual protocols widely vary among themselves and the decision to use one of them must be preceded by an analysis of its specific characteristics from the point of view of the expected research goal. In addition, regardless of the type of calibration protocol used, there are often opportunities for rational

[24] Excluding the publications included in the presented scientific achievement.

simplification or even abandonment of certain stages of research if this is justified by the intended purpose of the research and ensures their reliability. This may concern in particular the stage of collecting, analysing and verifying the data used to calibrate the model, as well as the data for its validation, and to some extent also the stages of the model calibration and validation themselves. It was found that the consistency and representativeness of input data used in simulation studies is their most important feature, even dominating their accuracy. The importance of sensitivity analysis and uncertainty analysis performed for major model parameters was also confirmed to determine the area of the model validity. The results of the research were disseminated in the form of one paper in a JCR journal (Att. 3, B.1.2), six papers in journals from the MNiSW list (Att. 3, B.5.1; B.5.4-6; B.5.10; B.5.15), two chapters in foreign monographs (Att. 3, B.5.8; B.5.12) and three papers presented at conferences and published in conference proceedings (Att. 3, B.12.1-2; B.12.6)[25].

The above-described issues of rationalization of simulation research were accompanied by my research on **mathematical modelling of greenhouse gas emissions from wastewater treatment processes**. My interest in the subject was the result of both, the experience accumulated during my research at various wastewater treatment plants, and the analysis of the evolution of mathematical models of activated sludge in the world, which has been stimulated in recent years by growing interest in the emission of greenhouse gases from anthropogenic sources. Since 2006, when the first model describing production of N_2O in activated sludge process appeared[26], the mathematical descriptions of different N_2O production mechanisms were gradually incorporated into the multi-phase activated sludge models. I considered this to be a new and very developmental direction of the evolution of activated sludge models, which would greatly extend the possibilities of practical use of simulation research at wastewater treatment plants. This problem is closely related to my previously described research area, both in its theoretical and practical aspects. In my works on this subject I focused on the following specific topics:

- development of an integrated model of sustainable operation of a municipal wastewater treatment plant in the environment (Att. 3, B.6.11-15),
- computer simulation as a tool to improve energy balance of a mechanical-biological wastewater treatment plant, including greenhouse gas emissions (Att. 3, B.6.6; B.6.10),
- assessment of greenhouse gases emission reduction opportunities at municipal wastewater treatment plants (Att. 3, B.6.1).

The results of my research have shown that mathematical modelling of N_2O emissions from biological wastewater treatment processes is difficult for two important reasons. The first is still insufficient knowledge of the processes that lead to production of N_2O, especially in processes carried out by autotrophic bacteria. The other reason is the limited possibility of practical verification of results obtained from the developed models, resulting from measurement difficulties of actual N_2O emission in technical scale under operating conditions of wastewater treatment plants. In spite of this, the existing mathematical models of N_2O production can be more or less effectively integrated into commonly used models of biological wastewater treatment. Thus, N_2O can and, in some cases, even should be considered as an important component of a wastewater treatment model during simulation research. Such models allow a more complete assessment of the effects of a

[25] Ibid.

[26] Hiatt, W. C., Grady, C. P. L. Jr. An updated process model for carbon oxidation, nitrification, and denitrification. *Water Environ Res*, 80 (2008), 2145–2156.

wastewater treatment plant on both, the aquatic environment and the emission of gaseous pollutants into the atmosphere. This will bring the opportunity to develop a comprehensive model for the impact of urban waste water treatment on the environment, which was one of the themes of my earlier research. The results of my research were disseminated in the form of one article in a journal from the JCR list (Att. 3, B.1.1), two articles in domestic journals (Att. 3, B.5.2-3), two chapters in foreign monographs (Att. 3, B.5.7; B.5.13), two papers delivered by me at national conferences (Att. 4, B.1-2) and one paper published in the proceeding of an international conference (Att. 3, B.12.5)[27].

In addition to the three research areas outlined above, my scientific interests also included other topics that were not directly relevant to the mainstream of my research activities. These included, among the others the following topics:

- use of membrane techniques in wastewater treatment (Att. 3, B.6.7),
- selection of the best wastewater treatment technologies to be applied at small wastewater treatment plants,
- sustainable management of water resources, especially in the context of water quality (Att. 3, B.10.4).

The results of these studies have been disseminated by me in a number of articles in the journals from the JCR list (Att. 3, B.1.3) and the MNiSW list (Att. 3, B.5.9; B.5.14), in chapters of the foreign monographs (Att. 3, B.5.11; B.5.18) and in the form of conference presentations (Att. 4, B.5-10; B.15).

Cooperation with industry

The above described research issues are also the subject of my works in the framework of industrial cooperation. Such studies were carried out, among others, at municipal wastewater treatment plants in Łódź, Warsaw, Jasło and Zamość. The research performed by me at the Group Wastewater Treatment Plant in Łódź (Att. 4, M.11-13) have shown the important role that computer simulation can play in the process of designing new technological systems or modernizing the existing ones. The subject of my research was to determine the feasibility and conditions for increasing the load of a single technological line in the biological treatment part of the plant to 100 000 m^3/d using the MUCT system instead of the previously used UCT and Phoredox systems. Simulation studies have allowed verification of the design assumptions under the both, averaged (static) and varying (dynamic) conditions. Similar studies were conducted for the wastewater treatment plants in Warsaw (Czajka) (Att. 4, M.14) and Zamość (Att. 4, M.1). Computer simulation was repeatedly used by me to solve operational problems at the wastewater treatment plant in Jasło. These problems concerned determination of the maximum loading of the biological reactor (Att. 4, M.9), influence of rainwater collected in the combined sewage system on the wastewater treatment plant's operational costs (Att. 4, M.10), evaluation of the efficiency of the activated sludge aeration system (Att. 4, M.7) and estimation of permissible pollution loads and concentrations of pollutants that can be delivered to the wastewater treatment plant under various dynamic conditions (Att. 4, M.2; M.6). My latest research on the use of computer simulation was concerned with the assessment of the possibility of increasing technological efficiency of the Zamość wastewater treatment plant in the context of effective treatment of sludge waters in a side stream.

[27] Excluding the publications included in the presented scientific achievement.

5.2.2. International activities

From the very beginning of my research activity I attach great importance to active cooperation with foreign research centres and international institutions. Since 2003 I am an independent **expert at the European Commission**. During this period, at the invitation of the Executive Research Agency (formerly Directorate I Environment) in Brussels, I actively participated in 11 week-long sessions during which I performed substantive evaluation of the research project funding proposals submitted by research teams from different countries under the 6th and 7th EU Framework Programs and the Horizon 2020 program. Up to now, I have **personally reviewed 134 projects** in the field of innovation, research, demonstration and researchers' mobility within the EU (Marie Skłodowska-Curie Action) (Att. 4, O.1-8; O.10-12). In addition, in 2010 I reviewed one project commissioned by the Research Promotion Foundation (Cyprus) under the EU program "*Technological Development and Innovation (DESMI)*" (Att. 4, O.9). Quantitative description of my activity as an EU project reviewer is presented in **Att. 4, pkt. O.**

As part of my cooperation with foreign research centers I am developing intensive relations with the wastewater technology team at the Royal Institute of Technology in Stockholm (Sweden), directed in the past by doc. Bengt Hultman, and now by prof. Elżbieta Płaza. The result of this collaboration is one joint article in a journal from the JCR list (Att. 3., B.1.4), 8 chapters in foreign monographs (Att. 3, B.5.7-8; B.5.11-13, B.5.16-18) and numerous conference presentations (Att. 4, M.6-7; M.11; M.13; M.15-16; M.18-19). Since 2007 I have been cooperating with prof. Alessandra Carucci of the Università degli Studi di Cagliari (Italy) and with the National University „Politechnika Lwowska" (Ukraine) under the VISBY programme. By joining SCOPES program "*Network for environmental assessment and remediation in aquatic systems: towards excellence in teaching and research (NEAR4)*" I established cooperation with the Institute F.-A. Forel at the University of Geneva (Switzerland). As a result of this cooperation, three papers were presented at the international symposia in Tbilisi (Georgia), Mangalia (Romania) and Kharkov (Ukraine) organized under the NEAR4 program (Att. 4, M.5, M.8, M.10). Within the aforementioned cooperation I have repeatedly held the scientific supervision over the foreign students from various research centres who carried on research at the Cracow University of Technology (Att. 4, J.1-9).

I actively support the exchange of experience and research results through participation in large international conferences and seminars. In 2001 at the 2nd IWA International Symposium "Sequencing Batch Reactor Technology" in Narbonne (France) I presented my paper entitled „*Use of computer simulation for cycle length adjustment in sequencing batch reactor*" (Att. 4, B.20). I was **the co-chair of the session** at the IWA International Conference "Nutrient Management in Wastewater Treatment Processes and Recycle Streams" held in Krakow in 2005. When participating in the 10th IWA International Conference on Design, Operation and Economics of Large Wastewater Treatment Plants in Vienna (Austria) in 2007, I presented the results of my research on the use of computer simulation in wastewater treatment (Att. 4, B.14). In 2008 I actively participated in the IWA World Water Congress and Exhibition in Vienna, presenting the results of my research (Att. 4, B.12). In 2011, I was invited to give a **plenary presentation** entitled "*Wastewater management in small communities in Poland*" at the inaugural session of the 3rd SmallWat11 International Congress "Wastewater in Small Communities: Towards the Millennium Development Goals and the Water Framework Directive" held in Seville (Spain) (Att. 4, B.9).

6. Summary of achievements

6.1. Research activity (including items listed in section 4)

Type of achievement		Before Ph.D.	After Ph.D.	TOTAL
Domestic activity				
Monographs (in Polish)		-	1	1
Articles in domestic journals **listed in JCR**		-	1	1
Articles in domestic journals **other** than listed in JCR		1 (1)*	10 (6)*	11 (7)*
Papers in proceedings of domestic conferences		4 (3)*	4 (3)*	8 (6)*
Presentations at domestic conferences		3	5	8
Plenary presentations at domestic conferences		-	1	1
Participation in domestic research projects **		4	1	5
Managing of research project		-	1	1
Reviewing of domestic articles and conference papers		-	24	24
Scientific support for Ph.D. students		-	1	1
Awards for scientific activity		-	1	1
Participation in projects commissioned by industry and local authorities *(as a project leader)*		8 (0)	14 (9)	22 (9)
International activity				
Chapters in international monographs		-	8 (6)*	8 (6)*
Articles in international journals **listed in JCR**		-	5	5
Papers in proceedings of international conferences		1 (0)*	6 (4)*	7 (4)*
Presentations at international conferences		-	16	16
Plenary presentations at international conferences		-	1	1
Participation in international research projects		2	1	3
Reviewing of articles to international journals		-	3	3
Reviews of international research projects				
Reviewing the **European Union projects** , including: - 6. Framework Programme - 7. Framework Programme - Programme "Horizon 2020"		- - - -	**134** 23 42 69	**134** 23 42 69
Reviewing **other international** projects		-	**1**	**1**
Major bibliographic indicators				
Total IF according to Web of Science *(according to publication*		-	**7,361**	**7,361**
Number of citations (excluding self-citations) *(as on 11.04.2017)*	**Web of Science** SCOPUS Publish or Parish	- - 9	**29 (24)** 30 88	**29 (24)** 30 97
Hirsch index *(as on 11.04.2017)*	**Web of Science** SCOPUS Publish or Parish	- - 2	**4** 4 6	**4** 4 6
Sum of MNiSW points *(according to publication year)*		**6**	**258**	**264**

**) as the only or the first author*

***) excluding "statutory activities" (DS) and "own research" (BW)*

6.2. Teaching activity and scientific dissemination

In Polish

My teaching activities are closely connected with the area of my research interests. Since very beginning of my professional career I have conducted teaching activities that were thematically related to high-efficient methods of wastewater treatment and water renovation, and then to mathematical modelling of technological processes, application of computer methods in wastewater treatment and the issues of sustainable development. This allows me to use my scientific knowledge and research experience in my direct contact with students and to transfer to them the most knowledgeable subjects taught. This allows me to use my scientific knowledge and research experience in my direct contact with the students and to pass on to them the most up-to-date knowledge of the subject. I am the leader of the specialized modules: "*Advanced wastewater treatment*" and "*Computer methods in water and wastewater treatment*" offered at the 2nd level studies in Environmental engineering, and of the other 2 modules, including one taught in English. In addition, I give lectures and conduct project assignments within several other modules at the Faculty of Environmental Engineering. The most important ones are presented in the table below. I attach great importance to postgraduate and continuing education. In the years 2006-2011 I taught "*Computer methods used in the design and monitoring of water supply and sewage systems*" as part of the postgraduate studies conducted at the Faculty. In 2008, I lead a 5-day training course on the use of the GPS-X® simulation program for the group of employees of the MPWiK in Warsaw S.A.

In English

Apart from the courses in Polish, I have been teaching a number of courses in English for the both, Polish and foreign students. Among the most important are the modules offered at the Cracow University of Technology: "*Sustainable wastewater treatment*" (30h), offered as a module for Polish and foreign students and a semester module "*Environmental science and technology in Poland*" (90h) offered to foreign students from Swarthmore College (USA) under the cooperation agreement between the both universities (Att. 4, I.1). Every year, within the framework of the Erasmus program, I give lectures in advanced wastewater treatment and computer simulation at the Royal Institute of Technology in Stockholm (Att. 4, I.2). In years 2007-2009, I was the initiator and director of the three international projects under the common title "*Reduction of wastewater treatment contribution to global warming*" financed with the framework of the Erasmus Intensive Program scheme. Total of about 80 students and 10 teachers from the Cracow University of Technology, the Royal Institute of Technology in Stockholm and the Universita degli Studi di Cagliari (Italy) participated in these courses (Att. 4, I.9). In 1995, as a research fellow at the University of Texas at Austin, I was coaching a group of administration staff from Texas in the topic of pollution prevention. This was done in form of the three training course funded by the US EPA Region 6 (Att. 4, I.14-16). Between 1995 and 1998, I was managing the project "*US-Poland transfer of management skills in local government*" program funded by the US Information Agency and co-organized by the University of Texas at Austin, the Cracow University of Technology and the National School of Public Administration. Project leader was prof. David Eaton. This project has allowed 20 local government employees from Poland to receive training and apprenticeship at administrative offices in Austin (Texas). Since 2008 I have been a member of the Scientific Council of the International Centre of Education (MCK) at the Cracow University of Technology, and in 2007-2012 I was Faculty Coordinator of the ERSAMUS programme.

Summary of teaching activities (by a place of teaching)

Course title	Activity type	Comments
Cracow University of Technology		
Advanced wastewater treatment *(60h, Master's programme)*	Lectures, projects	present (**course leader**)
Computer methods in water and wastewater treatment *(30h, Master's programme)*	Lectures, comp. lab.	present (**course leader**)
Sustainable development rules in environmental technologies *(30h, 1st level programme)*	Lectures, sem., exerc.	present (**course leader**)
Sustainable wastewater treatment *(30h, Master's programme)*	Lectures, sem.	present (**course leader**)
Wastewater technology *(30h, 1st level programme)*	Lectures	present (**course leader**)
Advanced methods for water treatment *(30h, Master's programme)*	Projects	present
Recovery of materials from wastewater and sewage sludge *(2h, Master's programme)*	Lectures	present
Environmental science and technology in Poland *(*90h, *semester course for students from Swarthmore College, USA)*	Lectures, exerc.	annually, since 2001 (**course leader**)
Reduction of wastewater treatment contribution to global warming *(60h, intensive course within the ERSAMUS IP framework)*	Lectures, projects	2007 (**course leader**)
Basics of wastewater treatment technology *(10h, cycle of classes for the group of students from Afghanistan)*	Lectures	2010
Mathematical modelling in wastewater treatment (30h, *Master's programme*)	Lectures, comp. lab.	discontinued (**course leader**)
Mathematical modelling in water protection and wastewater treatment *(30h, Master's programme)*	Lectures, comp. lab.	discontinued (**course leader**)
Computer aided design in sanitary engineering *(8h, Master's programme)*	Comp. lab.	discontinued
Water renovation *(15h, Master's programme)*	Projects	discontinued
Royal Institute of Technology in Stockholm (Sweden)		
Advanced wastewater treatment (2h, Master's programme)	Lectures	annually, since 2004
Computer simulation in wastewater treatment (8h, Master's programme)	Lectures, comp. lab.	annually, since 2004
Reduction of wastewater treatment contribution to global warming (60h, intensive course within the ERSAMUS IP framework)	Lectures, projects	2009 (**course leader**)
Universita degli Studi di Cagliari (Italy)		
Reduction of wastewater treatment contribution to global warming *(60h, intensive course within the ERSAMUS IP framework)*	Lectures, projects	2008 (**course leader**)
University of Texas At Austin (USA)		
Pollution prevention in public agencies (16h)	training course	1995
Pollution prevention in urbanized areas (16h)	training course	1995
Pollution prevention as an element of Total Cost Assessment (16h)	training course	1995

6.3. Organizational activities

1. Vice Dean at the Faculty of Environmental Engineering (WIŚ), Cracow University of Technology (2 terms: 2002 - 2005 and 2006 - 2008).
2. Faculty Board member at the Faculty of Environmental Engineering - 4 following terms: 2002 - 2005, 2005 - 2008, 2008 - 2012 (elected), 2012 - 2016 (elected).
3. Deputy Director for Scientific Affairs at the Institute of Water Supply and Environmental Protection, Cracow University of Technology (2009 - 2013).
4. Manager of the Water and Wastewater Technology Team at the Chair of Environmental Technologies (2013 - present).
5. Member of the Scientific Council of the International Centre of Education (MCK) at the Cracow University of Technology (2008 - present).
6. Representative of the Dean for Student International Exchange – Erasmus Coordinator (2007 - 2012).
7. Representative of the Rector of Cracow University of Technology for Cooperation with the University of Texas at Austin (1995 - 2005).
8. Representative of the Rector of Cracow University of Technology for Cooperation with the Universita' Politecnica delle Marche (since 2012)
9. Deputy Head of the Recruitment Commission at the Faculty of Environmental Engineering (2003, 2004).
10. Representative of the Director of the at the Institute of Water Supply and Environmental Protection for International Cooperation (1997 - 2002).
11. Member of the Commission for Statutory Activities, Commission for Statutory Activities of Young Researchers, Commission for Awards at the Faculty of Environmental Engineering (2009 - 2013).

11/04/2017