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Modelling and Numerical Simulation in Wastewater Treatment
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A CONSISTENT MODELLING METHODOLOGY (CMM) FOR SECONDARY SETTLING TANKS IN WASTEWATER TREATMENT

RAIMUND BÜRGER[1], STEFAN DIEHL[2], SEBASTIAN FARÅS[2],
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Abstract. Benchmark simulations of wastewater treatment plants are performed by numerous research groups in order to acquire knowledge on control and monitoring strategies. The clarification-thickening process in the secondary settling tank (SST) is one of the most difficult subprocesses in a WWT plant to model because of its nonlinear behaviour. For more than 20 years, traditional SST simulators have been used, which works reasonably well during sunshine weather, but may fail severely during storm weather. The reason for such nonphysical behaviour can be traced to the model formulation: The numerical method is written directly by means of physical reasoning. When the underlying model is a nonlinear partial differential equation, it is essential to follow a Consistent Modelling Methodology (CMM), in which the modelling is separated from the numerical implementation. The talk will give an overview of the main ideas and concepts of CMM and the resulting SST simulator. All details can be found in [1, 2, 3].

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PRACTICAL APPLICATION OF THE BÜRGER-DIEHL SETTLING MODEL: STATE OF THE ART

INGMAR NOPENS AND ELENA TORFS

Abstract. Recently, Burger et al. [1] developed a new 1-D SST model which allows for more realistic predictions of the sludge settling behaviour than traditional 1-D models used to date. As the prediction of the sludge settling behaviour will influence the prediction of the biomass inventory throughout the entire treatment plant and as biomass is the driving force for conversion processes, secondary clarifier operation will thus affect the overall performance of the treatment plant. Therefore, the impact of the new, improved settler model on the sludge inventory and related control actions in the entire system is investigated [2].

One important feature of the new 1-D SST model is that it allows the modeler to account for several phenomena (such as sludge compression and inlet dispersion) in a modular way making it very flexible in its application. However, extending the model with extra functionalities will increase the model complexity which will inevitably complicate the calibration procedure. Therefore, this presentation aims to report advances in the calibration of the novel 1-D SST model [3].

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MODELLING BIOLOGICAL WASTEWATER TREATMENT: CHALLENGES AND PERSPECTIVES

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Biological processes are widely applied for the treatment of both municipal and industrial wastewaters. They represent the traditional way of providing real transformation and then stabilization of pollutants. Microorganisms are nowadays used to remove organic matter and nutrients form wastewaters, and are also used for the stabilization of solid waste and sludge. Biological reactors for waste stabilization are extremely complex systems, since they involve the participation of many different species of microorganisms between whom different type of interaction and relations exists. Moreover, waste systems, due to its scale and waste variability, operate under conditions that not always can be carefully controlled. Moreover, under some conditions transport phenomena may play a significant role on these systems, as is for example the case of oxygen transfer in aerobic biological wastewater treatment. Despite this fact, massive amount of research and work has been done in order to advance in the development and application of useful mathematical representation of the phenomena involved in biological treatment of wastewaters. Indeed, past efforts have resulted in the existence of generally accepted models like those from International Water Association (IWA) that provide a framework for future efforts in the field.

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ASSESSMENT OF THE ACTIVATED SLUDGE PROCESS AT BIOBIO WASTE WATER TREATMENT PLANT USING BSM1-BASED MODELING

ALEX SCHWARZ

Abstract. We calibrated and validated a modified BSM1 model of the Biobio WWTP in Concepcin, in order to study plant performance during a whole year. The plant faced periodic settling problems that affected normal plant operation. Our objectives were twofold, first to asses how well the BSM1 model represents plant operation during these episodes, and second, to suggest an operational strategy that could help diminish the frecuency and intensity of settling problems. A dynamic model is needed that accounts for changing settling properties during these events, in order to evaluate adequate operational strategies.

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KALLISTO: COST EFFECTIVE AND INTEGRATED OPTIMIZATION OF THE URBAN WASTEWATER SYSTEM EINDHOVEN

INGMAR NOPENS

Abstract. The KALLISTO project aims at finding cost-efficient sets of measures to meet the Water Framework Directive (WFD) derived goals for the Dommel River (The Netherlands). Within the project, both acute and long-term impacts of the urban wastewater system on the chemical and ecological quality of the river are studied with a monitoring campaign in the urban wastewater system (WWTP and sewers) and in the receiving surface water system. An integrated model, which showed to be a powerful tool to analyze the interactions within the integrated urban wastewater system, was first used to evaluate measures in the urban wastewater system using the existing infrastructure and new RTC strategies. As the latter resulted to be beneficial but not sufficient, this contribution investigates the use of additional infrastructural measures to improve the system cost-effectively and have it meet the WFD goals. Finally, a scenario analysis was conducted to investigate the impact of uncertainty in the main model assumptions and model parameters on the performance robustness of the selected set of measures. Apart from some extreme worst-case scenarios, the proposed set of measures turned out to be sufficiently robust. This work was presented at the World Water Conference in Busan (South-Korea) in 2012 and published [1].

This contribution is based on recent joint work with L. Benedetti (Waterways, Italy), Jeroen Langeveld (TU Delft, The Netherlands), Arjen van Nieuwenhuijzen (Witteveen en Bos, The Netherlands), Jarno De Jonge, Tony Flameling, Oscar van Zanten and Stefan Weijers (Waterboard De Dommel, The Netherlands) and Jeroen de Klein (Wageningen University, The Netherlands). Kallisto received an innovation award in The Netherlands and the Honour Award for Applied Research from IWA.

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VERIFYING TRADITIONAL SECONDARY CLARIFIER DESIGN FOR REAL INFLUENT VARIATIONS UNDER DYNAMIC CONDITIONS

JAVIER NANNIG / NÉSTOR ROJAS

ABSTRACT. The objective of this article is to corroborate or refute, that the design of secondary settling tanks (SSTs) based on traditional (or simple) methods, that takes into account only: average flow, SSLM, peak hourly flow and sludge settleability; performs adequately for a influent that varies according a real basis (where average flow and load are the same as those used for design). The authors reviewed several simple design criteria such: Flux Mass Theory, White's equation and ATV Guidelines [1], as well as typical "rule of thumb" criteria (overflow rate and solids loading). Also, an analysis of the different sludge settleability indexes [2], included in simple models, is performed (SVI, DSVI, SSVI3,5), in order to choose the appropriate value for design purposes.

Once selected a design method and sludge settleability, a fictitious clarification area is calculated, using real average flow and load, and a peak hourly flow given (as usual in Chile) by Harmon coefficient. For dynamic simulation, the calculated area is utilized, together with one year hourly data set, developed by adjusting typical hourly curves to available daily data. Simulations are carried out with Biowin®, software that uses de method of Tákacs (multi-layer with double exponential or modified Vesilind settling velocity model) [1]. Results are limited, mainly because the lack of real influent data for different sizes of plants.

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TOWARDS A NOVEL METHODOLOGY FOR THE CALIBRATION OF A COUPLED FLOCCULATION-CFD MODEL

ELENA TORFS AND INGMAR NOPENS

Abstract. The accurate prediction of effluent suspended solids concentrations is still an important bottleneck in current SST models. Classical settling velocity models [1] relate the settling velocity with the sludge concentration. However, at low sludge concentrations, as can be found in the upper region of an SST, the settling velocity will depend on the size and density of each individual floc and not on their concentration. In order to accurately describe the settling behaviour in this region, information on the (dynamic) floc size distribution needs to be included. This can be done by a flocculation model. Since the driving force behind flocculation is the hydrodynamic mixing, this flocculation model is combined with computational fluid dynamics (CFD) [2] [3].

However, for this coupled flocculation-CFD model to be used in practical applications, data need to be collected in order to define the required complexity of the flocculation model. Moreover, for each particle class an individual settling velocity needs to be determined. Therefore, a new measurement device was developed which allows collecting detailed data of changes in Particle Size Distributions (PSD) during settling. This contribution will illustrate the added value of using a coupled flocculation-CFD model with respect to the prediction of effluent suspended solids as well as present some preliminary experimental results to validate these types of models.

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DENOISING EXPERIMENTAL BATCH-SETTLING DATA BY OPTIMIZATION AND NUMERICAL IDENTIFICATION OF THE HINDERED SETTLING AND COMPRESSION FUNCTIONS IN PDE MODELS FOR SEDIMENTATION

STEFAN DIEHL

Abstract. Models of the sedimentation-compression phenomena in industrial clarifier-thickeners are formulated by partial differential equations, which contain constitutive nonlinear functions modelling the hindered settling of particles at lower concentrations and compression at higher concentrations. Parametric expressions for these functions are needed for the calibration of simulations models. This is particularly important in wastewater treatment, since the properties of the alive activated sludge vary between plants and with other variables that depend on time. However, despite many experiments performed with activated sludge in wastewater treatment, there is today no established convincing physically motivated parametric expression for these constitutive functions.

The talk is based on [2], in which a fast and simple method for the identification of nonlinear constitutive functions in scalar convection-diffusion equations is presented. No a priori information is needed on the form of the constitutive functions, which are obtained as continuous piecewise affine functions. Accurate and frequent measurements in space and time are required. The method is demonstrated on synthetic data from batch sedimentation of particles in a liquid and traffic flow. Real data from a batch sedimentation test should first undergo a preparation and denoising procedure. The preparation consists in modelling and removing the initial induction period. The denoising consists of a sequence of convex optimization problems, whose constraints originate from fundamental physical properties. The methodology is applied on data from a batch sedimentation experiment by De Clercq et al. [1].

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ON THE CONTROL OF CLARIFIER-THICKENER UNITS USING MATHEMATICAL MODELS

FERNANDO BETANCOURT

Abstract. It is the purpose of this presentation to give some results concerning the control of clarifier-thickeners units. Using the model of the dynamics of a flocculated suspension in a clarifier-thickener advanced by Bürger, Karlsen and Towers (2005), nonlinear PI controllers are introduced which are able to stabilize the operation by using a simple structure. Moreover it is showed the convergence of the controlled system to the desired state along with numerical examples. In addition some guidelines concerning controllers tunning are also provided.

In order to control the sediment level in a clarifier-thickener unit an extension of the previous model is presented as a system of two nonlinear partial differential equations describing the solids volume fraction and the varying settling velocity of the solids as functions of depth and time. Operating charts are calculated to be used for the control of steady states, in particular, to keep the sediment level and the underflow volume fraction at desired values. A numerical scheme and a simple regulator are proposed and numerical simulations are performed.

This contribution is a work in cooperation with R. Bürger, F. Concha and D. Sbárbaro (Concepción, Chile) and S. Diehl and S. Farås (Lund, Sweeden).

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NUMERICAL SIMULATION OF SEDIMENTATION IN CLARIFER–THICKENERS FED BY SUSPENSIONS WITH TIME-DEPENDENT SETTLING PROPERTIES

SEBASTIAN FARÅS†

Abstract. In a recent work, [1], the authors presented a 1D model of continuous sedimentation capturing the effects of both sediment compressibility and time–varying settling properties of the feed suspension. Such variations could, for example, be caused intentionally by a plant operator adjusting the flocculant dosage for the purpose of control. The mathematical model was formulated from the conservation of mass, which yields a system of two strongly coupled, nonlinear partial differential equations (PDEs) of convection–diffusion type. The numerical scheme proposed for this system includes a convective numerical flux suggested in [2], while a novel approach was used for the discretization of the diffusion term.

In this talk, a short introduction to the model will be followed by a motivation of the numerical scheme and a discussion on its stability properties. Furthermore, some illustrative simulations generated with the numerical scheme will be presented.

Acknowledgements. This contribution is based on a joint work with R. bürger, F. Betancourt and S. Diehl and the participation of the presenter in this focus seminar was made possible by support from project BASAL PFB03 CMM and Conicyt project Anillo ACT 1118.

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A STABILIZED FINITE VOLUME ELEMENT FORMULATION FOR SEDIMENTATION-CONSOLIDATION PROCESSES

HÉCTOR TORRES

Abstract. We are interested in the simulation of the sedimentation of monodisperse suspensions. A model of sedimentation-consolidation processes in so-called clarifier-thickener units is given by a parabolic equation describing the evolution of the local solids concentration coupled with a version of the Stokes system for an incompressible fluid describing the motion of the mixture. A novel finite volume element method is introduced for the spatial discretization, where the velocity field and the solids concentration are discretized on two different dual meshes. The method is based on a stabilized discontinuous Galerkin formulation for the concentration field, and a multiscale stabilized pair of $\mathbb{P}_1$-$\mathbb{P}_1$ elements for velocity and pressure, respectively. Numerical experiments illustrate properties of the model and the satisfactory performance of the proposed method.

This contribution is a collaboration with R. Bürger (Concepción) and R. Ruiz-Baier (Lausanne, Switzerland).

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A GENERAL MATHEMATICAL MODEL AND NUMERICAL APPROXIMATION OF MULTIPHASE FLOW IN POROUS MEDIA

IVAN LUNATI AND RICARDO RUIZ BAIER

Abstract. Many studies, employing experimental observations along with physical and mathematical theoretical considerations, have substantially advanced the understanding of the basic mechanisms that drive multiphase flow in porous media. Here we focus on a consistent derivation of a general mathematical framework capable to describe and predict flow patterns in permeable media, which exhibit high degrees of heterogeneity and are intrinsically of multiscale nature. We consider the interaction between fluid flow and a porous matrix and concentrate on cases when non-equilibrium and/or non-local effects are relevant. We are also interested in the construction of accurate, robust and reliable mixed and finite volume element methods for the discretization of the underlying flow equations. Some numerical results, illustrating the validity of the approach proposed herein, are presented and discussed in detail. We finally comment on the applicability of the proposed framework in the study of other related systems of interest. This contribution is also based on recent joint work with R. Bürger and G.N. Gatica (Concepción, Chile), S. Kumar (IIST, India) and H. Torres (La Serena, Chile).

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SYSTEMS OF WATER-SOLUBLE POLYMER AND METAL IONS

ERWAN HINGANT

Abstract. The purpose of this talk is to introduce some features about a class of polymers containing metals. These polymers have emerged for their potential applications in various fields, such as superconducting materials, liquid crystal and biocompatible polymers. Among these, we focus on a particular application which applies both in environmental science and to some industrial processes: water purification or deionized water. The concept relies in the use of soluble polymers which retain metal ions into their structure from an aqueous solution [2].

We motivate the problem of deionized water and propose an overview of the techniques developed by chemists to obtain purified water with the help of polymeric solution [3]. We exhibit some of their main issues and models they use. Finally, we would present a new model recently developed in a close collaboration with chemists which apply to their experimental procedures. It consists in an evolution equation on the configurational density of polymers, with a non-linear transport term and a quadratic source term. We mainly aim at the derivation of the model and give some mathematical results obtained in [1].

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