S2 - Validation and application of a three-phase simulation model for odour and corrosion control in sewer systems

Doctoral student: Abhinav Dixit

Supervisors: Prof. Dr.-Ing. Reinhard Hinkelmann, Prof. Dr.-Ing. Matthias Barjenbruch, Prof. Dr. rer. nat. Dietmar Stephan, Prof. Dr. rer. nat. Gunnar Nützmann

Introduction / Background

Biological corrosion of sewers and sewage treatment plants constitutes a serious problem and its effects result in the loss of billions of dollars a year [Stanaszek-Tomal & Fiertaka 2016]. Changing demography and more efficient use of water resource on one hand and climate change (reduction in rainfall, warmer temperatures etc.) on the other hand has led to the reduction of the average volume of wastewater. For more than 70 years, researchers have been committed not only to study the processes for odour and corrosion but also creating empirical and conceptual models for explanations (e.g. Gilchrist 1953). However, within the last 20 years a deeper understanding has been gained thanks to the efforts of carpetresearch groups in Australia and Denmark (Rootsey & Yuan, 2010; Rootsey et al., 2012; Hvitved-Jacobsen et al., 2013) [Teuber et al. 2019[a]]. All current models are confined to a one-dimensional approach. Although 1D approach is aptly applicable for modelling the water phase, there are several processes discussed in the following where a 3D approach should be preferred.

Aims

For processes which are affected by the concentration profiles (e.g. H_2S formation, mass transfer) and the air flow as well as for the surroundings of drops, steps and hydraulic jumps, a three- dimensional approach should be devised accounting for water and gas phase. For this purpose, a high-resolution three-dimensional model in OpenFOAM for water and air flow, multi-component reactive transport and mass transfer between the water and air phase will be developed and validated to counteract the problems of odour and corrosion in sewer systems.

Methods

Surface water and air flow is calculated by using the two-phase flow solver in OpenFOAM, interFoam, based on a volume of fluid approach for one- and two-phase flows. Both phases are considered as one fluid with rapidly changing fluid properties. A standard advection-diffusion equation in the water phase and mass transfer have been implemented by Teuber et al. 2019[b]. These will be analysed regarding the capability to describe transport in both phases and mass transfer processes. In next steps, the validation of air flow and mass transfer using experimental data from literature (e.g. Kristensen 2015) and data collected from the pilot plant of our partner Berliner Wasserbetriebe (BWB) in collaboration with the project S1 will be carried out.

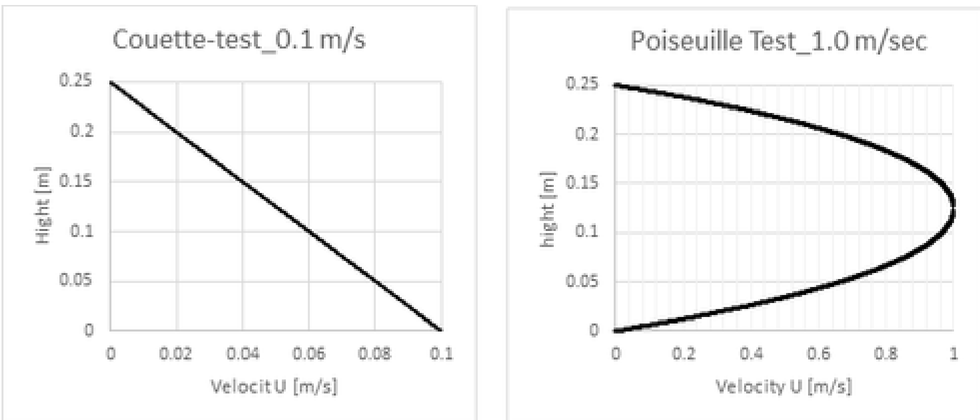
Results

Most part of the first year was utilized in knowing the platform OpenFAOM and other complimentary software.

Computational domain *.stl file (left) and output mesh prepared in SALOME Meca (right)

© Dixit

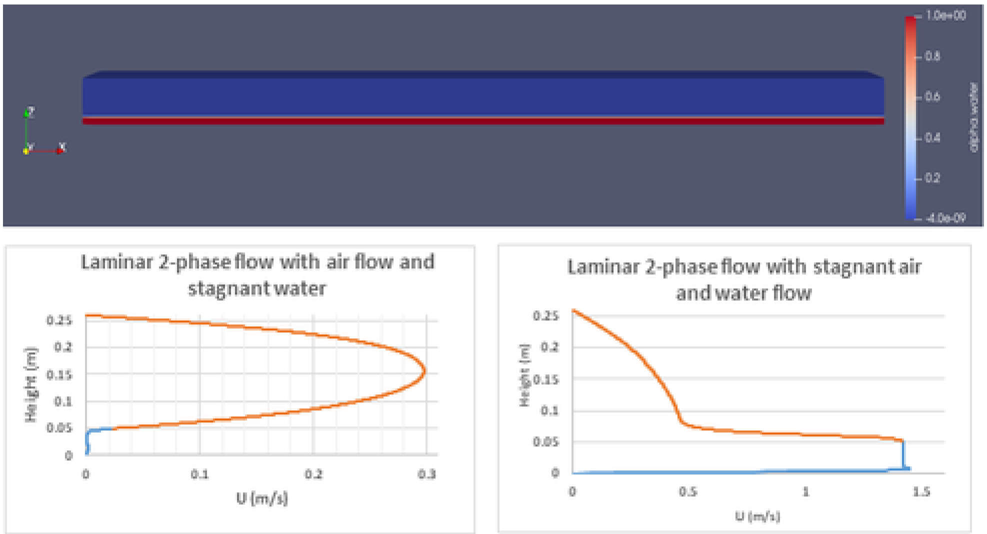
Initial simulations were comprised of a simple geometry in order to make single phase Couette flow test and Poiseuille flow test using icoFOAM solver. For this purpose, a simple 2D geometry is taken with all the boundary conditions defining the respective flows. Results of the simulations follow the same regime as expected through empirical solutions.



Test results from OpenFOAM simulations for Couette (left) and Poiseuille (right) flow

© Dixit

Proceeding further with making test cases with two phase laminar flow in a square pipe with few variations such as air flow due to pressure difference and its induced effect on stagnant water. Second case is similar but this time water is flowing with a constant velocity and we study its induced effect on the air phase. The final case corresponds to a flow regime made by combining the above two cases.



Test case set up for 2-phase laminar simulations (top), velocity profile for 2-phase flow with moving air and stagnant water (bottom left) and with stagnant air and water flow (bottom right)

© Dixit

Next step includes simulating a two phase flow building on a study from Bentzen et al. (2016) in order to better understand and validate the air flow in gravity sewers. The aim of this study is to improve the data basis for numerical models of natural sewer ventilation. The data collected and the empirical formulas generated in this paper will be used to validate the model generated in OpenFOAM using the adapted interFOAM solver.

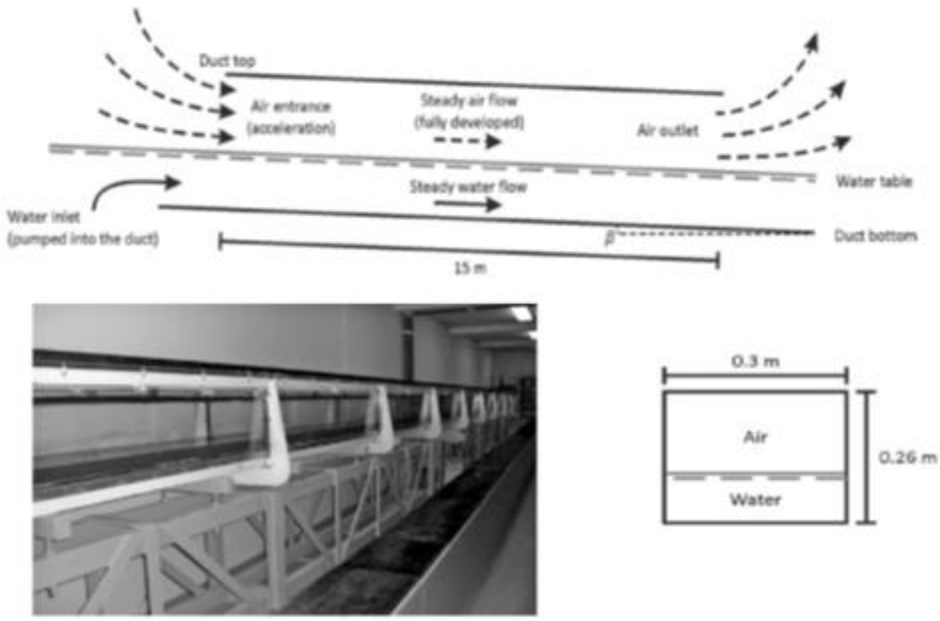


Photo of the experimental duct and a principal outline (@Bentzen et al. 2016)

© Dixit

References

- Bentzen, T.R., Østertoft, K.K., Vollertsen, J., Fuglsang, E.D., & Nielsen, A.D. (2016). Airflow in Gravity Sewers – Determination of Wastewater Drag Coefficient, Water Environment research, Volume 88, 2016.
- Gilchrist, F.M.C. (1953). Microbiological studies of the corrosion of concrete sewers by sulphuric acid producing bacteria. South Afr. Chem., 214–215.
- Hvitved-Jacobsen, T., Vollertsen, J. & Nielsen, A.H. (2013). Sewer processes: microbial and chemical process engineering of sewer networks (Vol. 2). CRC press.
- Rootsey, R. & Yuan, Z. (2010). New insights into sewer odour and corrosion. 6th International conference on sewer processes and networks, Queensland, Australia.
- Rootsey, R., Melchers, R., Stuetz, R., Keller, J., & Yuan, Z. (2012). Taking control of odours and corrosion in sewers. Australia's national water conference and exhibition (OzWater 2012), Sydney, Australia.
- Stanaszek-Tomala, E. & Fiertaka, M. (2016). World multidisciplinary civil engineering-architecture-urban planning symposium 2016, Biological corrosion in the sewage system and the sewage treatment plant, PK Cracow University of Technology, 24 Warszawska St., 31-155 Cracow.
- Teuber, K., Broecker, T., Bayón, A., Nützmann, G. & Hinkelmann, R. (2019a). CFD-modelling of free-surface flows in closed conduits, Progress in Computational Fluid Dynamics, accepted.
- Teuber, K., Broecker, T., Bentzen, T.R., Stephan, D., Nützmann, G. & Hinkelmann R. (2019c). Using CFD to describe H2S mass transfer across the water-air interface in sewers, submitted to Water Science and Technology in accepted version.
- Teuber, K., Broecker, T., Jaydev, S.D., Goitom, G.M., Sielaff (née Grüneberger) M., Despot, D., Stephan, D., Barjenbruch, M., & Hinkelmann, R. (2019b). Multiphase CFD-Simulation of Transport Phenomena in Sewer Systems, in: Mannina G. (ed) New Trends in Urban Drainage Modelling. UDM 2018. Green Energy and Technology, 584-853, Springer.

Collaborations

- Other UWI projects: Modelling with openFOAM - H2 (Vahid Sobhi Gollo), N7 (Tabea Broecker); Pilot plant- S1 (Micaela Pacheco Fernandez)
- Common topic: Interfaces in sewer systems
- Kollegiate: Pilot plant- Daneish Despot
- Guest researcher: Prof. Mohammad Zounemat-Kermani, University of Kerman, Iran