C-FOOT CTRL-tool: Development of an integrated tool for the assessment of the greenhouse gas emissions in wastewater treatment plants

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Abstract The goal of the C-FOOT-CTRL is the development of a new software tool that is able to conduct online monitoring, control and mitigate greenhouse gas (GHG) emissions in wastewater treatment plants (WWTP). The software tool comprises of three basic components, the online measurements, the database and the dynamic model. The online measurements will be provided by GHG sensors, energy meters and other sensors that are installed in a WWTP and will be imported in the database. Also, the user will be able to record values for all parameters, i.e. design values and hourly or daily values for specific variables. Hence, historical series of carbon footprint will be generated for the whole WWTP and for each individual stage as well. The dynamic model, that will be able to predict the carbon footprint of the WWTP and its various processes, was also developed. The main purpose of the model is to support the user in identifying whether a specific operational change can trigger a significant difference in the GHG emissions and consequently, in the carbon footprint of the plant. The results of the dynamic model will also be imported into the database to compare real-time measurements with the prediction of GHG production.

Keywords: simulation; modeling; greenhouse gases; emission; control

1. Introduction

Various greenhouse gas (GHG) emissions are associated with the operation of wastewater treatment plants (WWTPs) which include, nitrous oxide (N_2O), carbon dioxide (CO_2), methane (CH_4), nitric oxide (NO). N_2O is of particular environmental interest, since it is the most harmful of the aforementioned gases, with 298 times higher global warming potential than that of CO_2 while, in addition, N_2O emissions from wastewater management are estimated to contribute by 26% to the total GHG emissions of the water chain (Kampschreur *et al*., 2009, Mannina *et al*., 2016).

A wastewater treatment plant (WWTP) is a completely integrated system, where primary and secondary sedimentation units, bioreactors, thickeners, anaerobic digesters, dewatering systems and other sub-processes are linked and controlled, not only at local level as separate units, but also considering all interactions between these processes as well. Gaseous emissions are emitted from various stages of treatment in a WWTP and thus τhe main goal of C-FOOT-CTRL project is to develop a new software tool for the online monitoring, control and mitigation of the GHG emissions in WWTPs. The development of a tool that will be able to accurately record on line the carbon footprint during the operation of a WWTP is important in order to (i) track the emissions at the moment of occurrence (ii) immediately apply measures to reduce gaseous contaminants and to (iii) link the gaseous emission with a particular activity in the plant. The on line GHG emissions monitoring and control system will be an innovative, low cost and flexible system based on wireless sensor networks for monitoring and 'supervising' activities aiming to reduce GHG emissions during the operation of WWTPs.

2. Architecture of the tool

The architecture of the software tool Carbon Footprint Tool (CF Tool), which connects the database with the dynamic model and the online measurements, is illustrated in Figure 1, along with its basic components and the interactions between them. According to this design the tool is capable of analyzing data and displaying graphs, while it consists of the following components: 2.1) online measurements, 2.2) database and 2.3) dynamic model which are separately analyzed in the following sections.

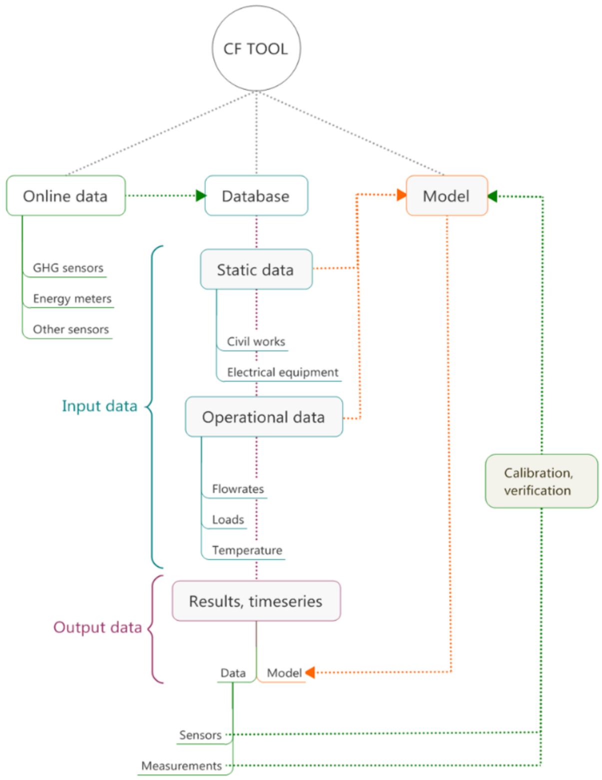

Figure 1. Schematic representation – architecture of the Carbon Footprint Tool (CF Tool)

2.1. Online measurements

The online measurements which are recorded in real time consist of the CO_2, CH_4, and N_2O emissions at the biological reactors of a WWTP. These are measured in the gaseous state. Furthermore, the energy consumption is recorded at real time using energy meters, placed at the electrical equipment of the plant. This way both direct and indirect GHG emissions can be recorded online. The real-time data are being retrieved with a programmable logic controller (PLC), with the use of VISU UNOS software, a program that displays and evaluates measurements. Conclusively, the online GHG emissions monitoring and control system constitute an innovative, low cost and flexible system based on wireless sensor networks for observing activities aiming to reduce GHG emissions during the operation of a plant.

2.2. Database

A database, where all online measurements described above, as well as other relevant data can be stored, has also been developed. Figure 2 demonstrates the two main subcategories which are distinguished in the input data and the output data. The components of the input data can be divided further into the static data, like electrical equipment and civil works (volumes, heights, etc. of the reactors), and the operational data, such as flowrates, loads, temperature, etc. The static data will be recorded only once manually, but the operational data can present fluctuations during different time frames. The database can also calculate the carbon footprint of a WWTP by converting the GHG emissions to CO_2 equivalents in order to generate the output data. Particularly, the online measurements and some input data will be used to calculate the direct and indirect operational carbon footprint. Moreover, historical series of carbon footprint can be generated for the whole WWTP and for each stage of the plant. Therefore, the software tool can monitor at real time the carbon footprint of nitrous oxide (N_2O), carbon dioxide (CO_2), methane and nitric oxide. The results of the dynamic model can also be imported into the database in order to compare the real-time measurements with the prediction of GHG production. Considering this, an effective mitigation strategy for eliminating the adverse effects of the GHGs emissions is possible by optimizing the operation of the WWTP.

2.3. General layout of the dynamic model

A carbon footprint model has been developed and consists of three main parts, the input data, the simulation and the output data. The model is able to determine the carbon footprint of the WWTP and for each individual stage either on steady-state or dynamic loading conditions depending on the input data from the database. The dynamic conditions refer to the temporal variations of temperature and wastewater flow rates and loads entering a WWTP. The dynamic model developed in this work is able to estimate the time variation of biogas production in the anaerobic digestion of sludge, the oxygen consumption in the aerated compartments of the bioreactors, the energy consumption in each unit of the WWTP and the direct and/or indirect greenhouse gas (GHG) emissions.

Regarding the “simulation” part of the model, that consists of several sub-models, one for each treatment unit. The different sub-models were developed in order to simulate the processes in all stages, the energy consumption and the GHG emissions. More specifically, for the processes taking place in the bioreactor, the activated sludge model no.1 (ASM1) (Henze *et al*., 2000) is used which describes the biotransformation processes in a common activated sludge process with N-removal. Settling processes are described through an one-dimensional model, which is based on the general flux theory for zone settling, while for the anaerobic digestion an anaerobic digestion sub-model was also developed. For the pretreatment, the primary clarifier, the gravity and mechanical thickeners and the dewaterers of the treatment plant, mass balances based on the efficiency of each unit were used, while this was also the case for the by-products of the WWTP (sludge and sludge liquor). The general layout of the wastewater treatment plant that is being simulated in the dynamic model is presented in Figure 3. In the developed dynamic model, the direct emissions are due to the biological treatment of the wastewater, the biogas production and the consumption of chemicals, while the indirect emissions are due to the energy consumption in the plant and the sludge disposal. More specifically, the GHG emissions during the biological treatment of the wastewater were estimated concerning the following processes: (i) CO_2 production due to biomass growth, (ii) CO_2 production due to denitrification, (iii) CO_2 consumption due to nitrification and (iv) N_2O production due to nitrification and denitrification (in CO_2 equivalent). Accordingly, GHG emissions related to biogas are associated to the use of biogas for the production of heat and electrical energy and from the leaks from the digester. Finally, the GHG emissions related to energy consumption depend on the percent contribution of each fuel to energy mix used in the country studied and the emission factor of the respective fuels. The emissions from the total electrical energy consumption in the WWTP are calculated by subtracting the electrical energy produced from biogas from the total energy required in the plant since the emissions from the combustion of the biogas have been already calculated.

3. Results and discussion

A series of simulations with the integrated tool have been implemented so far. In the present study, the results of two alternative assessments are presented: a) the effect of solids retention time on WWTP's performance, energy consumption and emission produced was examined under steady state conditions and b) the effect of the gradual decrease of temperature over a period of four weeks on system's performance, energy consumption and emission produced was examined under dynamic conditions.

The results of the first scenario are illustrated in Figures 4-5. Based on the results it is anticipated that the increase of SRT results in the increase of the share of energy consumed for aeration purposes leading at the same time to an increase of of-site emissions for energy consumption which is counterbalanced by the decrease of emissions due to sludge handling and disposal.

Figure 6 presents the results of a four-week dynamic run with decreasing mixed liquor temperature from 20°C to 17.3°C with a step of 0.1°C per day. Based on the results it is concluded that the gradual decrease in mixed liquor temperature resulted in a gradual decrease of the nitrification capacity of the plant which resulted in a gradual decrease of the effluent quality (mainly due to the increase of total nitrogen concentration). Finally, the hourly fluctuation of the incoming wastewater flow resulted in a respective variation of the total emissions which are gradually increased due to the gradual decrease of the nitrification.

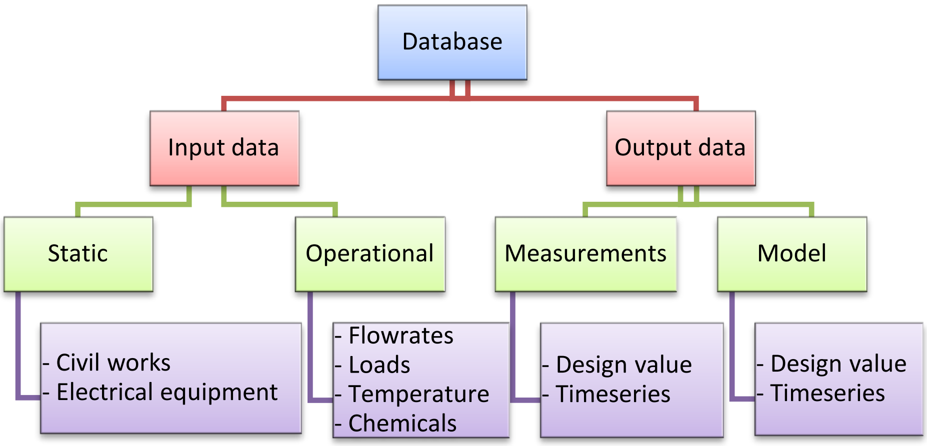

Figure 2. Database components

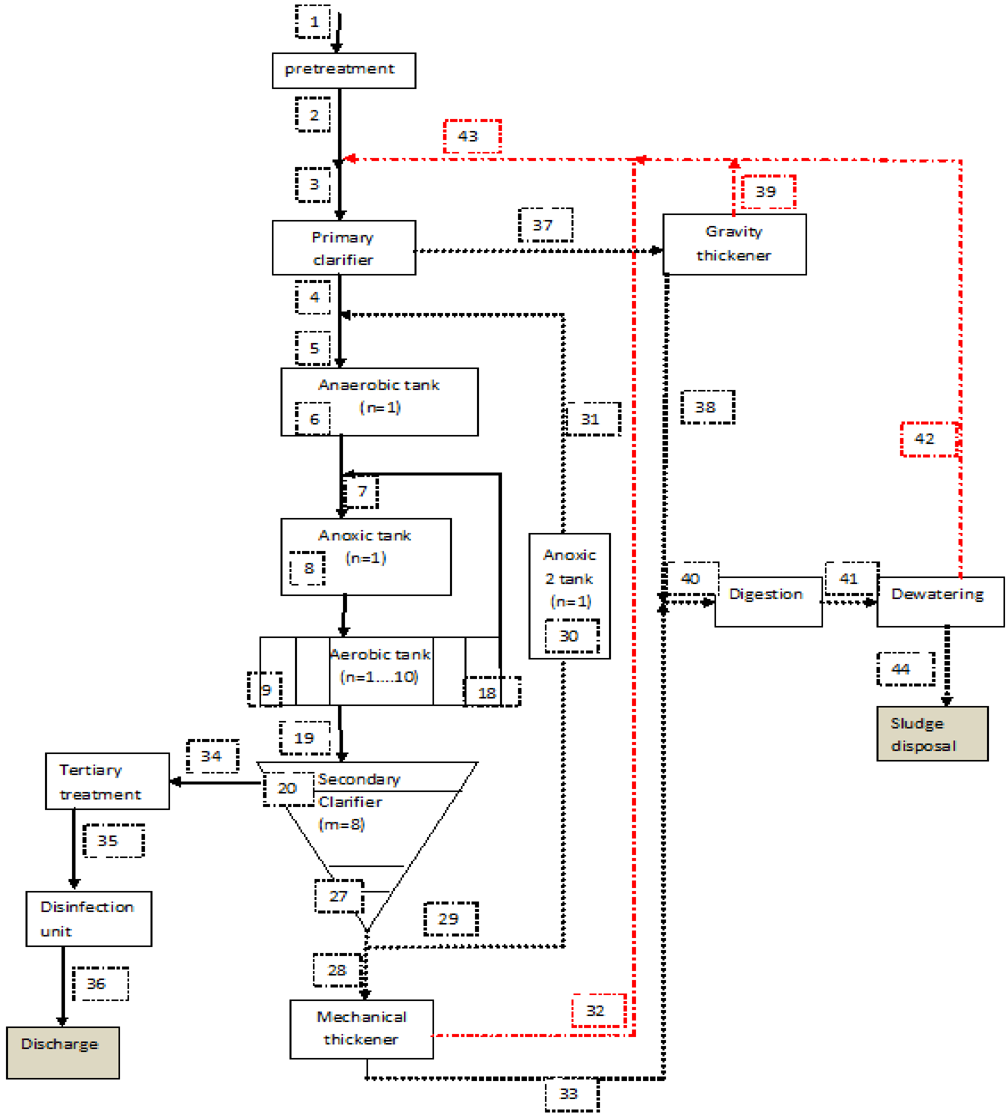

Figure 3. Layout used in the model to describe the simulated WWTP (numbering refers to points where physicochemical characteristics of the stream are assessed)

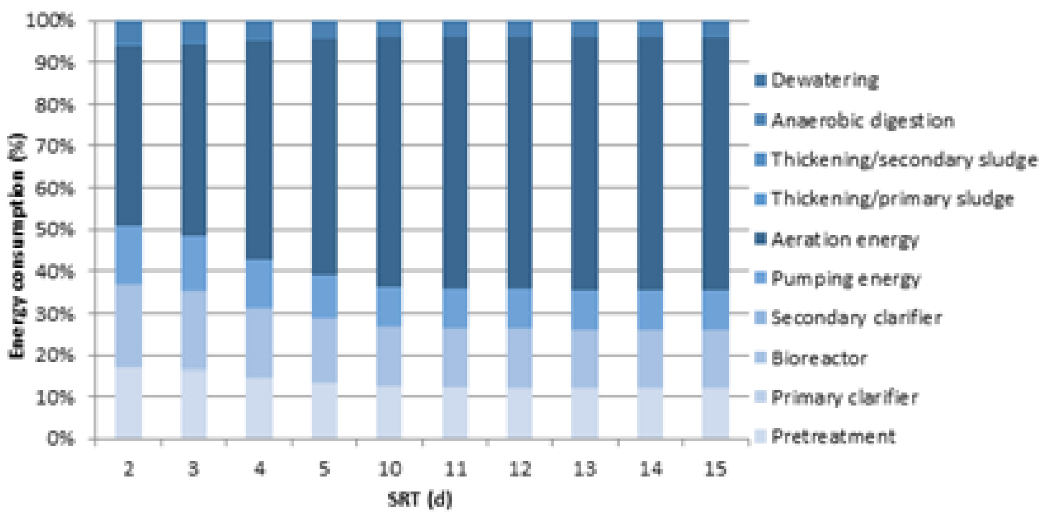

Figure 4. The effect of different SRT on percentage energy consumption at each unit of the WWTP

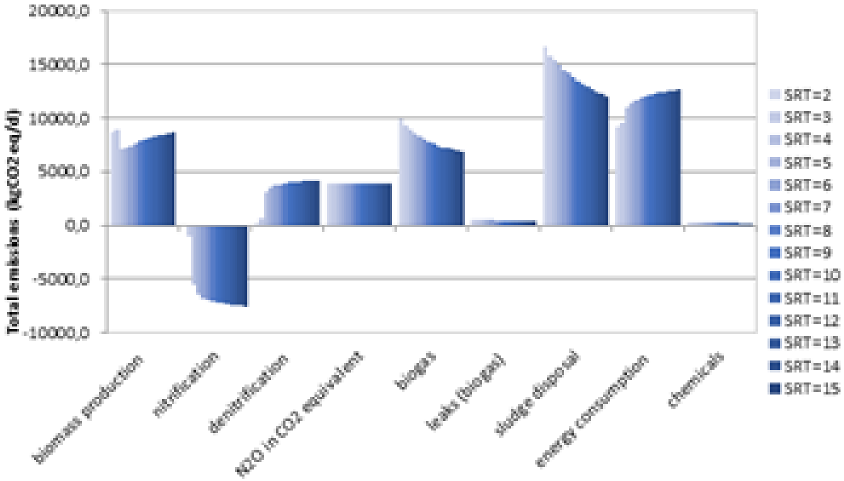

Figure 5. The effect of SRT on GHG production from different processes taking place in WWTP

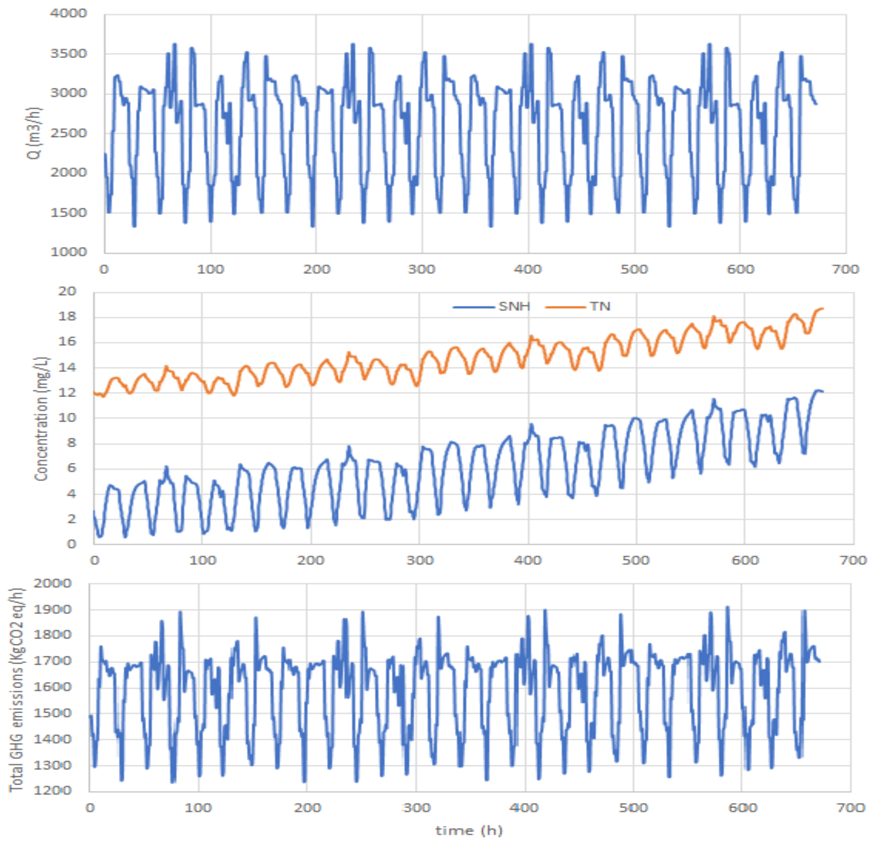

Figure 6. The effect of the gradual decrease of mixed liquor temperature on (a) effluent wastewater quality and (b) total GHG emissions

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References

Henze M., Gujer W., Mino T., van Loosdrecht M. (2000), Activated Sludge Models ASM1, ASM2, ASM2d and ASM3. *IWA Publishing*, ISBN: 1 900222 24 8.

Kampschreur M.J., Temmink H., Kleerebezem R., Jetten M. S.M., van Loosdrecht M.C.M. (2009), Nitrous oxide emission during wastewater treatment. *Water Research*, **43**, 4093-4103.

Mannina, G., Ekama, G., Caniani, D., Cosenza A., Esposito G., Gori R., Garrido-Baserba M., Rosso, D., Olsson, G. (2016) Greenhouse gases from wastewater treatment - A review of modelling tools. *Science of The Total Environment* **551–552**, 254–270.