The Difficulties of Designing Technical-Economic Models for Czech Wastewater Treatment Plants

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Abstract This paper describes the main points that must be faced when preparing a methodology for a techno-economic model of a wastewater treatment plant (WWTP). The model and the design are meant to be applied to real WWTP technologies in the Czech Republic. Most of Czech WWTPs combine mechanical and biological processes to treat wastewater. The main waste product of all wastewater treatment processes is sewage sludge (SS), which is typically a semiliquid mixture of organic and inorganic substances. The paper summarises the basic research on the WWTP models, presents the basic structure of the techno-economic model and describes the basic input data sets, which are crucial for the analysis of real WWTPs. The aim is to propose the structure and design of a techno-economic model that will be sufficiently variable and can evaluate the mechanical equipment of the WWTP together with the variable composition of wastewater.

Keywords: circular economy, wastewater treatment plant, technical-economic model, pollution, pollution prevention.

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1 Introduction

An analysis of the current state of technologies used at municipal WWTPs in the Czech Republic in connection with corresponding energy efficiencies is one of the objectives of our research activities. Our aim is to create a mathematical tool that will enable the analysis of different WWTPs systems. This paper discusses the available background materials and selects the key input data needed to create the relevant computational model.

1.1 Motivation

The tightening of rules on surface water quality (EC, 1991) led municipalities in the Czech Republic to build or to adjust their own WWTP over the past decade. Rules requiring cleaner effluent of WWTP entering surface waters also brought the need for adjustment to and modernisation of existing WWTP technology and equipment. Moreover, it is expected that current and upcoming European directives (EC, 2018) reflecting the circular economy principles, which aim to maximise the energy and material utilisation of waste materials, will call for further adjustments to and investment in municipal WWTP technologies. Newly built operating technologies, mainly those with lower treated water volumes, are nevertheless facing problems with the fulfilment of limits given by surface water protection rules, problems that needs to be solved prior to further technology adjustment. It is a common practise in central European countries, for the operator of WWTP to be the municipality itself, where the responsible officers are often not experts in available technologies. In such a system, it is difficult for an operator to identify causes of operating trouble or to find a suitable solution (Fiala, 2017). Operators of larger WWTPs (usually more than 10,000 inhabitants equivalent) are then often interested in energy savings and in seeking energy sustainable processes at the operated WWTP. Over dimensioning of WWTP technology is a widespread problem among Czech WTTPs. This is commonly caused by original assumptions of a greater burden of treatment plants by industrial wastewater from different companies, which, however, in many cases don't work today. Implementation of the new European directives seems very complicated in the context of this situation.

1.2 Problem analysis

To identify the causes of existing problems, it is necessary to analyse thoroughly the current situation, which will help to identify appropriate measures as well as to define space for potential investment.

Although analyses with similar objectives have been made in the past (Estrada, 2011), materials available for our study were very limited. The previously available analysis was related either to the evaluation of a specific WWTP or to a comparison of a certain part of the technology among several WWTPs being operated by one operator. In some cases, available analyses of a specific WWTP containing many different tests were made to evaluate possible modernisation or optimisation of a specific WWTP. Other available materials are typically WWTPs annual reports (Sedláček, 2017). The available materials used mathematical models to assess the efficiency, operating costs, and economic return of selected modernisation options. The comparison of the different technological options may be used as feedback for basic design of future technology adjustments. Another available source is a study by Nesměrák (2010) containing a statistical evaluation and characterisation of measured flows, concentrations and material composition of influent and effluent water from several dozen WWTPs. Data on wastewater pollution by medicines were processed similarly (Svoboda et al., 2009). In terms of energy balance, attention in the Czech Republic is focused mainly on small WWTPs (Holba, 2017) and also on modern sludge management approaches by requirements of the circular economy (Hartig, 2018). Materials available from other European countries consider, for example, a modernisation of WWTP operations in Italy, which was done in accordance with the objectives of the circular economy and was described by Bianco (2018). The problem of selecting the most suitable innovative equipment was addressed in a study that describes the development of a programming tool for the analysis of WWTPs flows according to data from two real Danish WWTPs (Bozkurt, 2016). Spain assessed the complex efficacy of 49 WWTPs, where operating costs were not related only to the amount of pollutants removed but also to the pollutants' environmental importance (Castellet, 2016). All of these studies made analyses of the WWTP processes, but their motivations were different from our purposes.

There is no existing universal tool to help analyze the efficiency of the machinery in wastewater treatment plants in the Czech Republic. Creating this tool is the key aim of our research activities. This article deals with finding and analyzing key parameters that are common to most WWTPs in the Czech Republic.

2 Model description

To design a properly working technical-economic model, the individual computational sections must correspond fully to real technological processes and machinery. WWTP combining mechanical and biological stages of treatment are the most common utilities for municipal wastewater treatment in the Czech Republic. However, the type and dimension of each machine are unique for each WWTP. Similarly, equipment for sludge handling technology is unique to each WWTP, and the choice of technology depends on the size of the WWTP. The aim of our research is to create a model to cover the entire portfolio of equipment that could potentially be used in the Czech Republic. This will allow the creation of a model from the real scheme of any Czech WWTP. If the resulting computational model is to be universal, it is necessary to thoroughly decompose the individual sections of the whole process and describe all interaction links. In the first step, it is necessary to create relevant material balances of real Czech WWTPs and subsequently link these with corresponding energy balances.

2.1 Mass balance

Analysis of the pollution of influent wastewater is necessary to properly analyse the role and significance of the individual WWTP facilities. The influent water of municipal WWTP generally contains in four wastewater sources (parts of mass balance):

a) Domestic wastewater
b) Wastewater from agriculture
c) Industrial wastewater
d) Rainwater.

The ratio between these four streams depends on the location of the plant. The proportion of streams can be estimated only by indirect calculations. It could reasonably be presumed that there will be a significant proportion of agricultural wastewater in a small rural WWTP, while an urban WWTP plant will include a larger share of industrial wastewater. The proportion of rainwater depends primarily on the type of sewerage system. To design the WWTP technology, it is very important to thoroughly analyse potential pollution sources and their proportional ratio in influent water. However, the presumed sources of pollution considered when the WWTP was built may have changed or be defunct at this moment. This situation causes operating problems and often has adverse effects on the overall economy. For the technical-economic model, it is crucial to know the presumed influent water pollution when WWTP was designed, as well as the current composition of the influent wastewater. Figure 1 illustrates transforming individual types of pollution in the purification process.

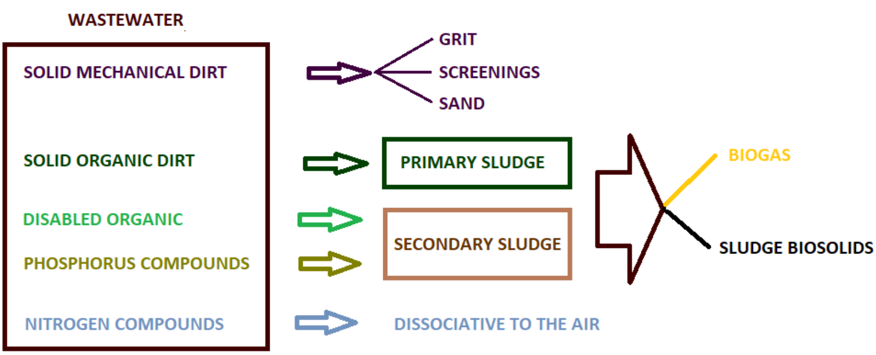

Figure 1: Transforming individual types of pollution in the common wastewater purification process.

The contaminants suggested in Figure 1 are typically present in all municipal wastewater, regardless of the origin. Therefore, it is appropriate to include these in the formation of the primary model. Other types of pollution do not have to occur in all wastewaters, or occur to such a small extent that these are not relevant for the WWTP technology — lately, medicine contamination of municipal wastewater has increased. However, no relevant treatment technologies are available, to the author's knowledge. Therefore, technologies allowing for minimisation of medicine contamination are not included in the proposed model.

After determining the standard pollution of the wastewater, it is possible to focus on the WWTP technology itself. As already mentioned, in the Czech Republic the process of municipal wastewater treatment could be divided into a mechanical stage, a biological stage and sludge processing. A diagram of a standard municipal WWTP is shown in Figure 2. The scheme in Figure 2 proposes all individual operations, their common order in WWTP technology as well as their mutual material links.

The mechanical stage should be able to catch all the floating impurities that come with the wastewater. In terms of model creation, it is remarkable that the composition of machinery in this stage is practically the same for all sizes of WWTP. They differ only in their rated capacity, i.e. the volume of wastewater that can be cleaned and the volume of individual impurities that can be separated. Some differences then occur in additional treatment equipment and possible handling of the trapped dirt.

Given this simplification of the considered water pollution, it can be stated that elimination of dissolved pollution by microorganisms is the aim of the biological stage. There are many variations in composition and shape of the activation tanks and their machinery (mixers and aeration) used in WWTPs. The size of the technology depends on the level of wastewater pollution. As a consequence of increasing pollution, WWTPs were forced to adapt the biological stage technology and increase its efficiency (in what is called intensification). This has often brought the need to add additional chemical agents (e.g. iron salts or methanol) into the process. The action of microorganisms leads to the formation of activated sludge, which is separated in settling tanks. Part of this sludge is returned to the process, while the rest of the sludge (referred to as excess or secondary) is discharged to sludge processing.

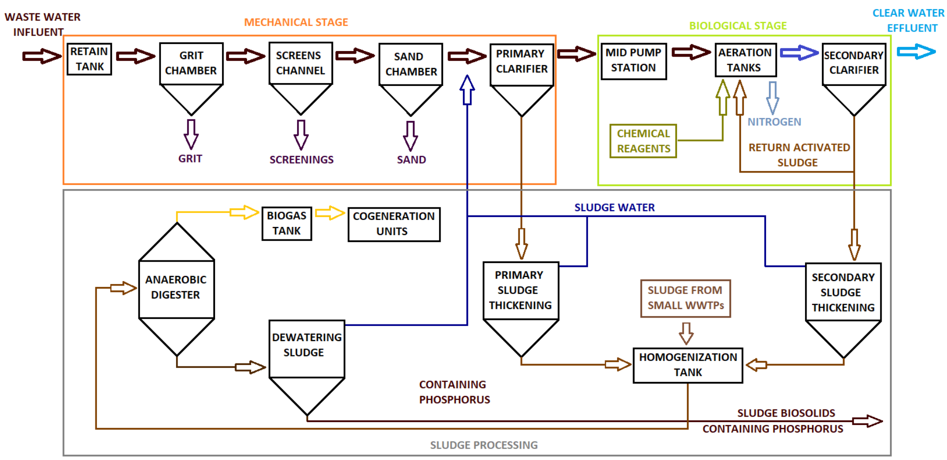

Figure 2: Scheme of a standard urban wastewater treatment plant.

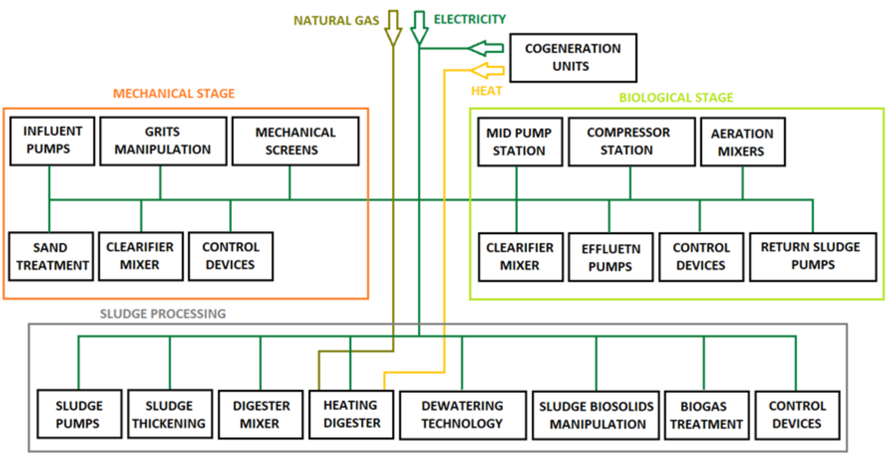

Figure 3: Energy consuming operations.

Sludge management facility design is individual for each WWTP. The common practice in the Czech Republic is that sludge from a small WWTP is transported for subsequent processing to a larger facility. Sludge dewatering technology represents practically the entire sludge management at small WWTPs. This causes problems when making the balance of large WWTP sludge processing, as it is practically impossible to distinguish between the sludge produced by a large WWTP's own technology and the sludge brought from the surrounding small WWTPs. In a balance of larger WWTPs, the amount of sludge processed by sludge management facility will correspond to the sum of its own sludge production and sludge delivered from smaller WWTPs. At larger WWTPs, sewage sludge is commonly treated by anaerobic digestion, where biogas is produced as a secondary product of the reaction. The resulting biogas is further utilized as a source of energy at the WWTP. The digested sludge is dewatered and analysed. If the level of contaminants present in sludge complies with the rules given for agricultural use of sludge, the sludge is then transported to farmers.

2.1 Energetic balance

To build an energetic balance, it is essential to identify the key machine components that are necessary for the operation of the WWTP. These are shown in Figure 3. The number of pump stations is individual for each WWTP and depends on the geographical location. A WWTP built on a slope wouldn´t need any pump stations, in contrast to a treatment plant built on the plain.

It is evident that electricity consumption plays a crucial role in energy balance. The energy intensity of specific operations is highly individual. Since there are mainly rotary electrical machines at WWTPs , their power input depends on the equipment power output and on their efficiency, which is negatively affected by outdated concepts and insufficient maintenance.

The heat energy is added to electricity consumption in the large WWTPs for heating of anaerobic digesters. Commonly, heat energy from combustion produces biogas is used in the cogeneration unit. However, no Czech WWTP has yet managed to create enough energy from biogas to completely cover WWTP energy consumption.

3 Resulting knowledge

The analysis of the material and the energy balance resulted in the following findings, which must be taken into account for the creation of a technical-economic model. It is important to give the input parameters appropriate significance for the device at the beginning. The real parameters of the influent wastewater and the real volume of collected impurities are important parameters for the design model at the mechanical stage. The dissolved pollution load, which is essential to determine the amount of air supplied and the mixing rate, is important for designing a model of the biological treatment stage. The amount and composition of sewage sludge are crucial for sludge management. The high content of organic substances has a positive effect on the production of biogas and thus on the subsequent energy balance.

The composition of mechanical-technological treatment equipment may be considered uniform for all WWTP types, but several possible variants must be considered for the biological treatment stage. However, machinery in sludge management could be so variable that global typing is unrealistic. It follows that the mathematical model of the mechanical stage can only be simplified by listing machines installed and their dimensions according to the flow capacity and the amount of collected impurities. Several technology modifications with different variations of the particular installed equipment need to be considered for the biological treatment stage model. In the case of sludge management, it will be necessary to mathematically analyse each operation separately, even in several variants according to a particular technical design. It would be possible to create a real sludge management scheme of any WWTP from these modelled operations with sufficient credibility.

The energy consumption of individual devices would need to be converted to a certain characteristic power parameter for the energy model. However, it is necessary to obtain a large amount of data on specific devices from real plants, but only by comparing such specific wattages could one assess the energy condition of a given plant.

4 Discussion

As mentioned above, several simplifications have been made to create the primary model. The first proposed simplification is a shortening of the list of pollutants in wastewater. An even greater simplification could be made in the context of the circular economy. Only pollution with organic substances and phosphorus compounds is interesting from the point of view of secondary material utilisation of waste materials. One of the main goals of intensive research activities worldwide is to identify the most efficient means of wastewater treatment processing. Our technical-economic model will be a useful tool to define the best possibilities for implementing the results of this research into specific WWTP operations. It can be assumed that it is not possible to predict the economic impact of any adjustments to a particular operation without an assessment of the energy and technological level of the given technology.

5 Conclusions

The paper deals with the potential for creating a universal technical-economic model of WWTP. The goals that the model aims to fulfil were defined. Furthermore, common wastewater pollution was analysed, and the consequences of present pollution on WWTP technology were described. The technology itself was then thoroughly analysed in terms of material and energy balance. The resulting conclusions clearly defined possibilities for modelling the specific technological units and outlined the input data necessary to create an initial technical-economic model.

We are still receiving input data from WWTP operators, and this study is very helpful to define the necessary and key parameters that will be crucial for further activities.

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