Aalborg University

Model Predictive Control of a Sewer System

Control and Automation: Master Thesis

Group: CA9-1030

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AALBORG UNIVERSITY
STUDENT REPORT

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Title:

Model predictive control of flow and concentration of sewage in a sewer system

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Abstract:

Preface

This report has been created by Jacob Naundrup Pedersen. The project is performed on the 3rd semester of the master control and automation at Aalborg University. The project is constructed in an internship at Grundfos. Grundfos has contributed with the test setup for the project. The student has followed two courses at Aalborg University, non-linear systems and machine learning.

The report is intended for people with a background knowledge corresponding to a third-semester master student at Control and Automation, Aalborg University. The following programming languages MATLAB and Simulink are used in the project. All graphical elements in the report are constructed by the author. Otherwise, a reference to the source, is stated in the figure text.

Sources are indicated by [name,year], and can be found in the bibliography list at the given [name,year].

Jacob Naundrup Pedersen

Contents

Nomenclature

Abbreviation

Abbreviation	Definition
AAU	Aalborg University

Symbols

Symbol	Description	Units
A	Area	m^2
q	Water flow	m^3/s
D	Diameter meter	m
r	Radius	m
ω	Velocity	rad/s
U_a	Voltage	J/C
N	Gear ratio	
τ	Torque	Nm
i_a	Current	C/s
R_a	Resistance	Ω
L_a	Inductor	H
K	Electromotive force	$\frac{V \cdot s}{rad}$
F	Force	N
θ	Angle	rad
Δp	Differential pressure	bar
K_{vs}	Conductivity for fully-open valve	m^3/h
v	Velocity	m/s
m	Mass	kg
V	Volume	m^3
ρ	Density	kg/m^3
l	Length	m
f	Friction factor	
h_f	Surface resistance	m
g	Gravitational acceleration	m/s^2
k_L	Form-loss coefficient	
h_l	Form resistance	m
h	Pressure	m
J	Inertance	kg/m^4
a_n	Pump parameters	
T	Temperature	$^{\circ}C$
c	Specific heat capacity	$\frac{J}{kg \cdot K}$
m_n	Mass flow	kg/s

Introduction 1

Sewers were created to solve the seemingly simple problem of removal of wastewater. The first sewers, registered, dates back to 7000 B.C. in urban settlements and were created to remove wastewater from houses and surface runoff created by rain water. To avoid clogging and wear of the sewers grit chambers was constructed. They work by slowing the flow of sewage in long narrow channels making the solids, such as sand, end up as sediments in the channels due to gravity. Complexity of sewers increased in ancient Rome where large underground systems were created leading to the the main sewer system called "Cloaca Maxima" making it possible to have latrines with running water within households, though mostly made available for the rich.

Waste were still thrown onto streets as the population, without immediate access to a latrine in their household, during night time did not want to put in the effort to properly dispose of the waste. Because of this the ancient Rome suffered from illnesses related to waste lying in the streets. The hygienic aspect of proper disposal of wastewater in relation to drinking water were not considered until the 19th century, where several European cities saw large outbreak of cholera causing the deaths of millions.

The growth in waste furthermore caused the expansion of 26 kilometer sewer network in Paris to 600 km during the 19th century. But it is not until the start of the 20th century that the chemical and microbial processes in sewers are considered. The microbial cause of cholera were identified by the German doctor Robert Koch in 1883, a discovery for which he in 1905 received the Nobel Prize in physiology and medicine. The growing industries and technological progress in the 20th century meant that more chemicals were disposed into the sewers having severe consequences for the organic life downstream of the receiving waters. Wastewater treatment plants were introduced to reduce the pollution, but several countries did not have any wastewater treatment plants before after World War II. Today disposal of sewage and setup of wastewater treatment plants is a given part of construction of new settlements, even in poor regions of the world [Hvitved-Jacobsen et al., 2013].

1.1 General sewer construction

An illustration of the process wastewater undergoes from it is used at the consumer to it is treated at the plant will be explained. Furthermore the general construction of sewers will be elaborated.

In figure 1.3 a block diagram of the process wastewater undergoes is illustrated.

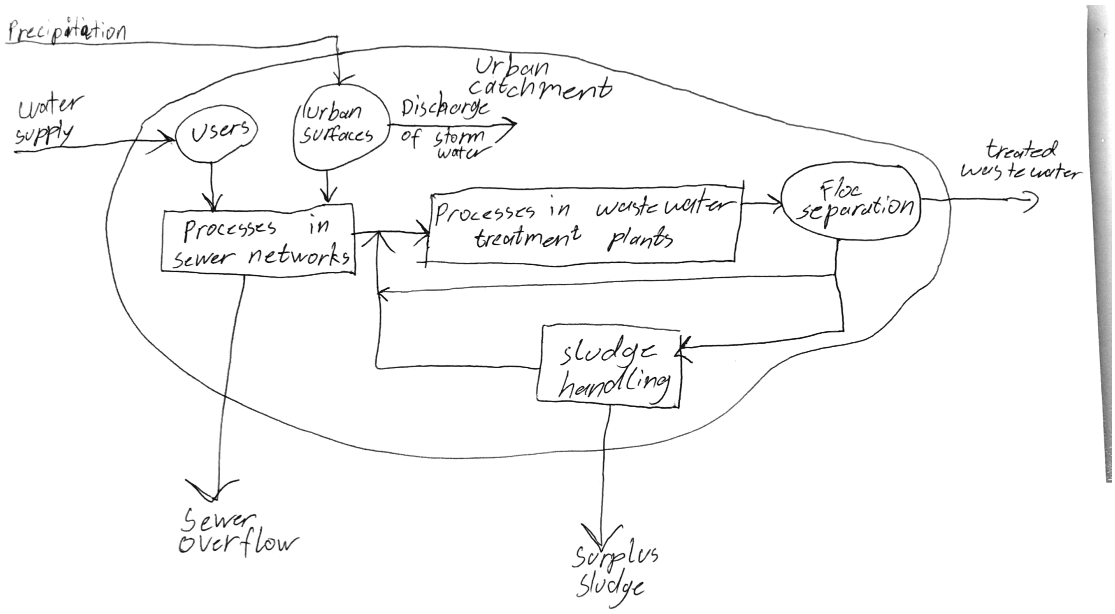

Figure 1.1: Arbejdsblad billede, inspiration er taget fra hvitved. Fjern sludge handling of floc separation og forklar det nede ved afsnittet.

From the left the precipitation over urban surfaces are collected in the sewers. If the precipitation are to much for the sewer to handle it will be discharged in a storm water sewer, which will lead the water into small rivers or be collected in tanks [1]. Furthermore from the left the water supplies goes into the consumers of the water, such as the industry or households. These will produce wastewater that is lead into the sewers. Within the sewers chemical and microbial reactions occurs, which will be explained in section 1.2.1. If the sewer is overfilled the wastewater is lead into rivers and fields to prevent flooding in households, industry and on the urban surfaces. The sewer leads the wastewater to the wastewater treatment plant, where the wastewater will be filtered before sending it back into the environment, which will be explained in greater detail in section 1.2.2. And as previous mentioned due to flooding in the sewer, the wastewater will be lead into some receiving waters.

Typically the water treatment plant are constructed near rivers or a fjord which is typical at a lower geographical location, thereby enabling the force of the gravity to transport the wastewater in a sewer. If the industry or the households are at a lower geographical location than the water treatment plant, then pumps are used to transport the wastewater as illustrated in figure 1.2.

[1] FiXme Note: Skriv hvad det bliver brugt til

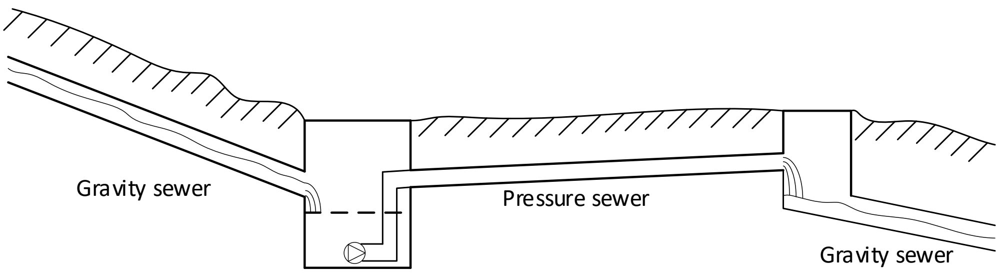

Figure 1.2: Illustrate different methods for transportation of wastewater.

The pipes are often constructed in concrete or polyethylene. Where concrete pipes are used for gravity sewers and polyethylene are used in a pressure sewer due to a lower roughness height which means less friction from the surface of the pipe.

1.2 Chemical process

This section will analyse the chemical process that wastewater undergoes from the water is used to it is cleaned at the water treatment plant. The processes in a wastewater treatment plant will be investigate to get an understanding of the different processes. Furthermore a illustration will be presented to elaborate the details in a sewer.

In figure 1.3 an illustration is shown to explained the processes that wastewater undergoes within the sewer.

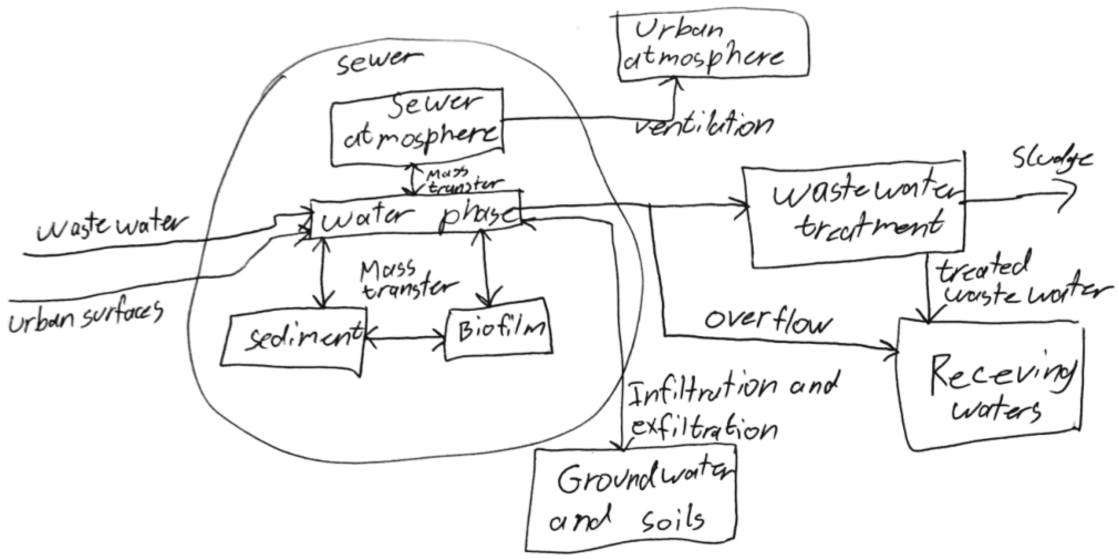

Figure 1.3: arbejdsblad billede. [2]

Wastewater are subject to a verity of changes in the sewer, due to free electrons in the wastewater different kinds of compounds are created which will be elaborated in 1.2.1. Therefore the concentration that are at the beginning of the water phase has changed at the wastewater treatment plant. These chemical reactions can create gases that can be free into the urban atmosphere. Besides chemical reaction in the sewer there are also microorganisms that eat the sludge that sediments in the sewer. These microorganisms are breeding on the biofilm that is created on the surface of the pipe. Microorganisms are also used in the wastewater treatment plant to clean the wastewater. The wastewater in the pipes can sink into the groundwater and the soils due to small leaks in the construction of the sewer. The wastewater ends up at the wastewater treatment plant this process will be explained in 1.2.2.

1.2.1 Chemical reactions in a sewer

A wastewater treatment plant does not only contain what is discharged into the sewer from the industry and households but also the chemical and microbial reactions that occurs in a sewer. These reaction occurs as redox reactions between the different compounds. Redox reaction is the transfer of electrons between two compounds at a atomic or molecular scale. By transferring electrons from one compound to another new compounds will rise, such as hydrogen sulfide which is know for it malodorous smell of rotten eggs. Theses reactions are determined by the electron acceptors that are present in the wastewater. The electron acceptor is the compound that receives electrons in a redox reaction. Examples of dissolved acceptors are oxygen (O_2), nitrate (NO_3^-) and sulfate (SO_4^{2-}), which determines whether aerobic, anoxic or anaerobic processes may occur. The redox reaction reduces these three compounds in the wastewater by changing them to new compounds as water H_2O, molecular nitrogen (N_2) and hydrogen sulfide (H_2S). Redox reactions are determine to a great extend by the design of the sewer where different conditions such as aerobic, anaerobic and anoxic exist, where the last only occurs if nitrate is artificially added to the wastewater. If the process is aerobic the typical characteristics for the sewer are either partly filled gravity sewer or a aerated pressure sewer which means that there are free oxygen (O^+), and these will be connected with hydrogen to create water. In the case of anoxic the wastewater is pumped and there are added nitrate resulting in molecular nitrogen. In a anaerobic sewer the characteristic of the sewer is either a pressure sewer or a full flowing gravity sewer, then the redox reaction will result in hydrogen sulfide. Therefore sewers can actively be designed to achieve a specific process. This knowledge is used to make simulation that is able to express the chemical and microbial reaction which occur in the wastewater. As previous mention these are examples of some of the reactions that occur in the wastewater. Furthermore turbulence in the flow of the wastewater affects reaeration and can release odorous and corrosive particles into the atmosphere.

1.2.2 Wastewater treatment plant

At the wastewater treatment plant the wastewater undergoes several process before the chemicals, dirt, etc. is removed from the water and it is lead back into the nature. The first stage in clearing the wastewater is screening, where larger objects are remove from the wastewater. Some of the objects that are filtered from the wastewater are bottles, plastic bags, diapers, etc. all items that are to big that would either block or damage the equipment.

Stage two is the primary treatment where the separation of organic matter (human waste) from the wastewater. By leading the wastewater into a large settlement tank the organic matter will sink to the bottom of the tank. The matter that have sedimented is now called sludge. At the bottom large scrappers are scrapping the floor moving the sludge to the center of the tank where it is pumped away for further treatment. From here the separated water is pumped into the secondary treatment.

In this stage the water is pumped into large rectangular tanks where air is pumped into the water to make the bacteria consume the sludge that have passed on from the previous stage. When the bacteria have consumed the sludge it will start to sediment at the bottom of the tank. This process takes 3-6 hours.

After these treatment processes there are still some diseases in the water. If the water is lead in to sensitive or fragile ecosystems the water is further treated. It is disinfected for at least 20-25 minutes in tanks where a mixture of chemicals are used to cleanse the remaining water before leading it into the environment. If the water is not lead to a fragile ecosystem the last phase is passed through a settlement tank where the remaining particles will sediment at the bottom of the tank creating more sludge. From here the water is lead through a filter the remove any additional particles. Hereafter the water is lead into the environment.

The sludge that is collected in the process undergoes further treatment, where the remaining water in the sludge is separated from it. The water is lead back to the wastewater treatment process where it will undergo the same process again. The sludge is collected and used for agricultural.

System description 2

Bibliography

[Hvitved-Jacobsen et al., 2013] Hvitved-Jacobsen, T., Vollertsen, J., and Nielsen, A. H. (2013). *Sewer processes: microbial and chemical process engineering of sewer networks.* CRC press.

Appendix A

Rettelser