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

Title:

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

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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
GIS	Geographically Information System

Symbols

Symbol	Description	Units
A	Area	m^2
Q	Water flow	m^3/s
q	Inflow of water m^2/s D	Diameter meter
m		
r	Radius	m
F	Force	N
θ	Angle	rad
v	Velocity	m/s
m	Mass	kg
V	Volume	m^3
ρ	Density	kg/m^3
l	Length	m
g	Gravitational acceleration	m/s^2
T	Temperature	$^\circ C$
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 km. 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 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.

1.1.1 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. [1] 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.

1.1.2 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

[1] FiXme Note: Hvad producere Heteotropic Microorganisms

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. This water is lead back to the wastewater treatment process. The sludge is sent back to the environment or used for agricultural use.

1.2 Sewer construction

Typically the water treatment plant are constructed near rivers or 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 1.1.

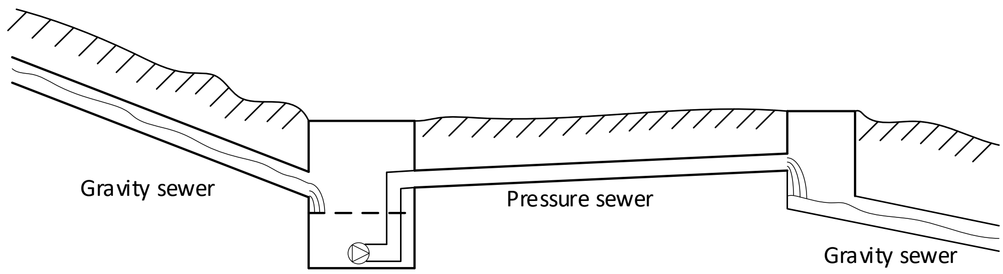

Figure 1.1: Illustrate different methods for transportation of wastewater.

The pipes are most 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 that the friction is less in a polyethylene pipe.

2 System description

This section will go into details of the structure of the sewer network for which the further work of this project will be based upon.

As mentioned in section 1.1 a steady flow of sewage with a fixed level of contaminants is desired such that an optimal utilization of the wastewater treatment plant can be obtained. An area of interest is Fredericia with a sizable population of around 40.000 and industries where some of the largest consists of a brewery, bottling plant, refinery and a dairy plant Statistic$_{D}enmark.Alloftheseindustriesisplacedintheoutskirtofthecity, meaningthatwastewaterdischa$
1001[GIS,].

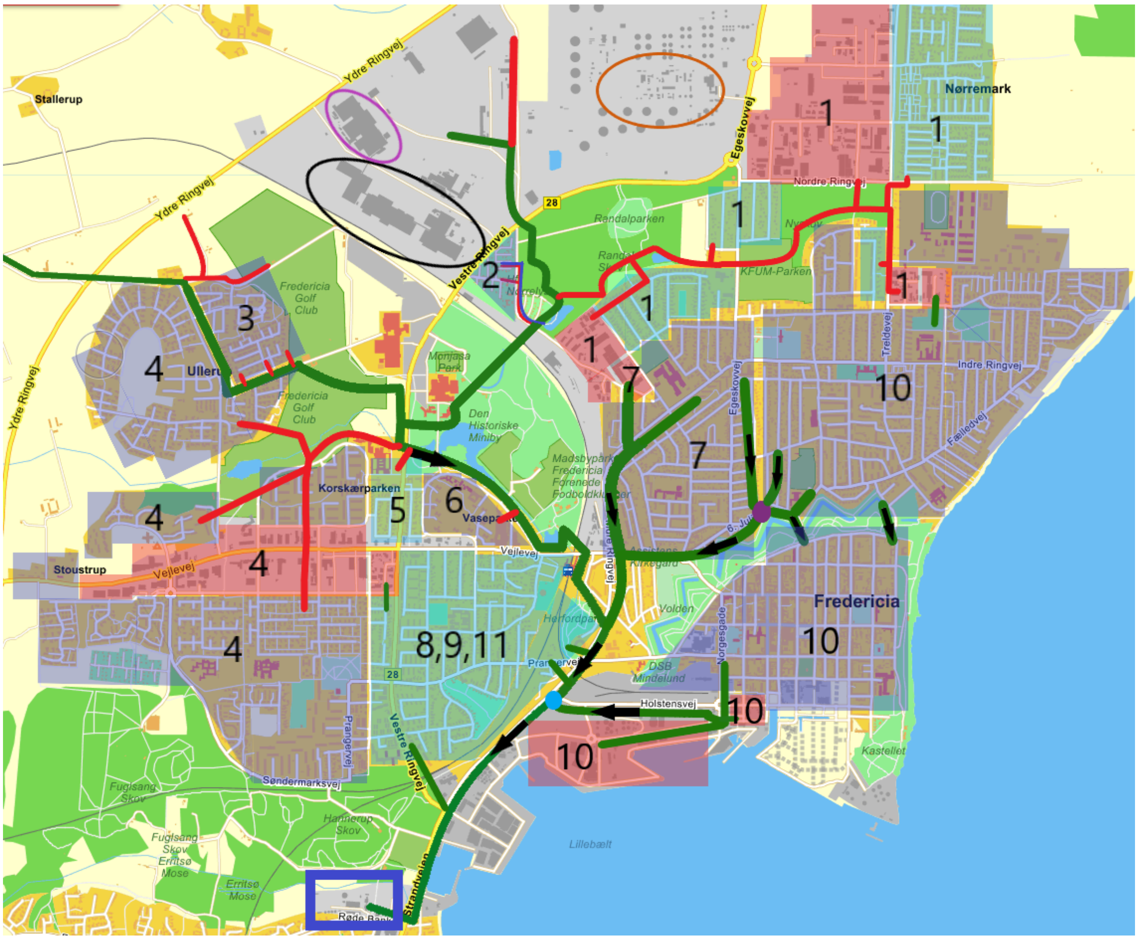

Figure 2.1: Mapping of part of the sewer network in Fredericia. The red and green lines indicate sewers where the red sewers has flows of sewage only and the green line is combined sewage and runoff from urban surfaces. Transparent parts indicate that the area has a connected sewer grid within and the red/green lines from this grid indicates the output from this area. Two shades of transparent blue is used to illustrate sewer systems in populated areas. The red transparent areas indicate minor industry and the black, brown and purple rings is brewery, refinery and bottling plant respectively. The purple dot indicate a connecting point with several incoming and outgoing sewer pipes. The blue dot is a sewer reservoir [1] before wastewater is led to the wastewater treatment plant indicated by the blue rectangle.

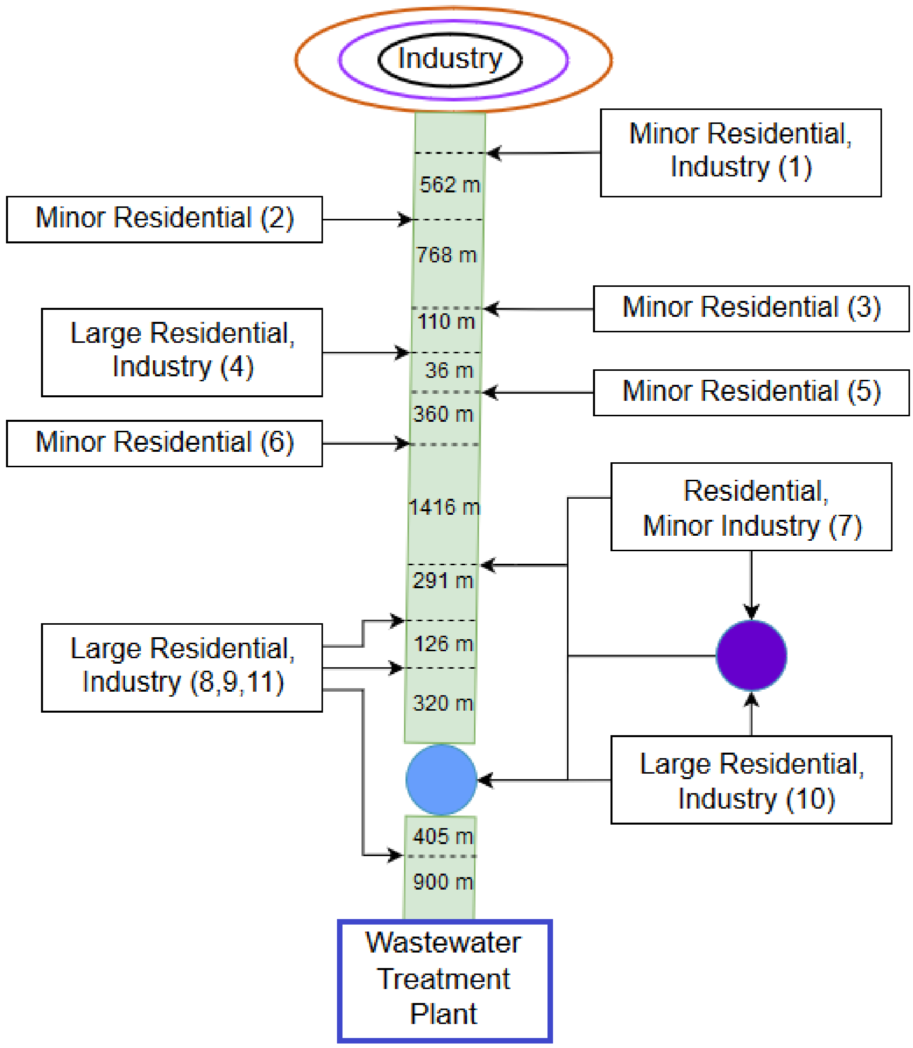

Figure 2.2: Simplification of the map shown in figure 2.1 where the numbers correspond to which area is connected to the main sewer line furthest from the wastewater treatment plant and the distance between the connections.

Bibliography

[GIS,]

[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