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Event-based modelling supporting model predictive control of chemical dosing in sewer networks

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Summary of key findings

In the present work, we propose and apply an event-driven model predictive control (EMPC) methodology for the control of sewage flows at pumping stations. However, one of the main bottlenecks for implementation of EMPC is the determination of the concentration of the dosed chemical at all locations in the sewer network. For this purpose, we develop a so-called network-state model, which is able to predict such concentrations based on the network geometry and sewage flow data. The sewage flow data, and consequently the future operation of the pumping stations, are in turn predicted using an ARMA models that we previously developed (Chen et al., 2014). The control objective was to keep each slug at the discharge of sewer network to contain proper dosed chemicals, while ensure such dosed chemicals above a required level to absorb any surges of H_2S emission, rather than a tight control setting to a set-point in the traditional MPC. To search for an optimal flowrate for the controlled SPS to keep the process operation as economically as possible over the future prediction horizon, a simple greedy algorithm was implemented constrained by the flowrate range. This methodology was validated through a simulation study using a real-life sewer network. A case study -$Mg(OH)_2$ dosing in the Tugun-Elanora sewer network

Background

Due to pipe corrosion, health hazards and odor nuisance resulting from Sulfide, chemicals such as $Mg(OH)_2$ and iron salts are widely dosed to control H_2S levels in sewers (Hvitved Jacobsen et al. 2002). Sulfide control is traditionally focused on single pipes, with chemical dosing being conducted based on constant or profiled dosing strategies. To date, there is still a lack of network-wide control algorithms for the control of chemical dosing in sewers. This is mainly due to the high complexity of this task, for which: i) The location and number of the dosing stations; ii) The chemical dosing rates; and iii) The operation of the different pumping stations within the network; need to be considered. Chemical dosing in sewer networks is usually conducted in upstream locations, which allows the control of sulfide throughout the network. However this means that sulfide generated at downstream locations or in side-streams, both at future times, will need to be considered, which adds an extra level of complexity to the task. There is a very important interplay between chemical dosing and the operation of the pumping stations in the network, with the latest having a critical influence on the outcome of the control. Therefore this work focuses on the development of an algorithm to conduct the adequate operation of networks for sulfide control, assuming known dosing locations and dosing rates at these locations. Such problem would be best addressed through Model-based Predictive Control (MPC). However, sewer networks exhibit a hybrid nature due to the intermittent operation of sewage pumping stations. Such a feature represents an additional challenge to traditional MPC control theories, which were developed for either pure continuous systems or pure discrete systems. Therefore, this paper presents a new concept for network chemical dosing control, based on a new proposed event-based model predictive control (EMPC), allowing more effective control of sulfide on one hand and avoiding chemical over-dosing on the other.

Results and Discussion

To illustrate the performance of the different control strategies(EMPC control, level-control with two different duty levels), A case study was implemented. Magnesium hydroxide-$Mg(OH)_2$-is dosed in a sewer network to increase pH and avoid sulfide transfer from the liquid to the gas phase. The performance of the EMPC-based chemical dosing strategy was tested in a simulation study at the Tugun-Elanora sewer network (Shown in Figure 1.1). Chemical dosing was conducted based on a flow-paced strategy, with dosing rates leading to a $Mg(OH)_2$ concentration of 300 mg/L in the sewage flowing into BT.

The control problem in this case is formulated as: controlling the operation of the SPS at BT such that an optimal flowrate can be delivered to dilute chemical-free sewage pumped by downstream SPS. In this network, all other SPSs are operated based on water levels and cannot be controlled, and hence are considered as system disturbances. The performance of the EMPC methodology was assessed through comparison with the strategy currently applied to the BT SPS (level-based control, with the duty level being 15% (A) and 25% (B), respectively, of the total volume of the BT).

Figure 1.2 depicts the pH profiles (Figure 1.2A) and H_2S (i.e. molecular hydrogen sulfide) concentration (Figure 1.2B) at the end of the network over a period of 24 hours.
In this study, EMPC control achieved a very stable pH at the discharge, with an average level of 8.62 and a standard deviation of 0.07. This arises from the accurate control of the BT operation by the EMPC, which ensured that sewage from other SPSs is properly mixed with the $Mg(OH)_2$-containing sewage delivered by the BT SPSs. On the contrary, the other two strategies relying on the level-based operation of the BT SPS performed much poorer. pH level was significantly above 8.62(reaching 9.0) in some periods and substantially lower in the other periods (even below 7.5for part of the day). The low pH was due to the fact that some fresh sewage from SPSs downstream of BT did not receive a sufficient amount of $Mg(OH)_2$. Since the concentration of dissolved hydrogen sulfide (H_2S) is strongly dependent on pH, the EMPC control strategy is able to achieve stable H_2S concentrations at low levels (0.1-0.3 mg S/L) at the discharge point (Figure 1.2B). In comparison, significant H_2S peaks (up to 1.5 mg S/L) were observed in the other two scenarios.

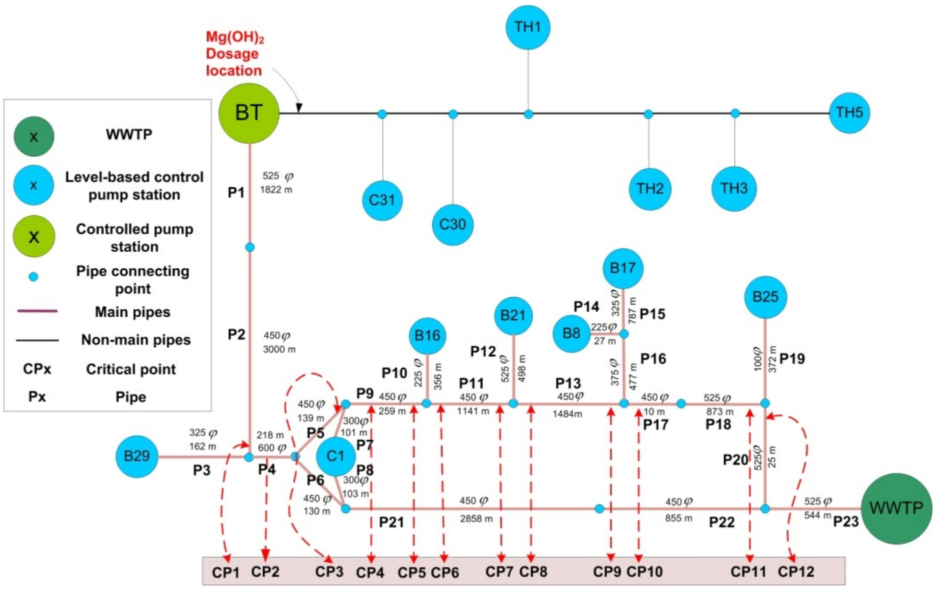

Figure 1.1 The scheme of the Tugun-Elanora sewer network

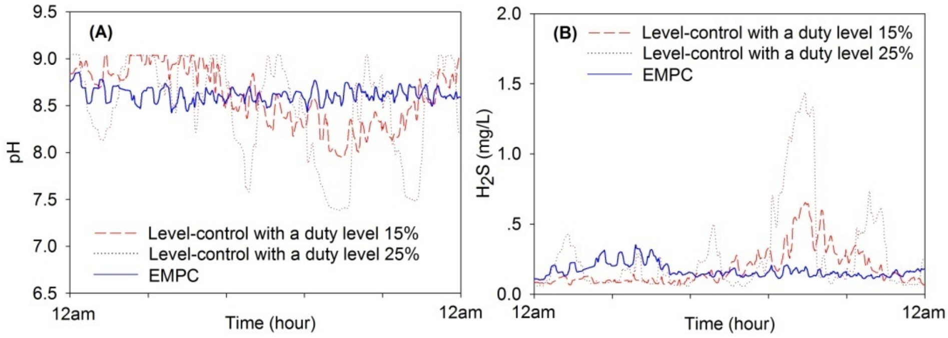

Figure 1.2 pH andH_2S concentration for all scenarios

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