Model-Based Dosing Control of a Pellet Softening Reactor

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Abstract: The control of a drinking-water treatment plant aims to produce the correct quantity of water, with a constant quality. Achieving constant water quality is not an obvious task, since the online water-quality measurements and possible control actions are limited. Applying model-based control improves disturbance rejection and online process optimisation. For the softening process step, the integral control scheme is shown with multiple controllers for different time scales and process detail. The dosing control is elaborated and verified using simulation experiments. The control is implemented and tested in the pilot plant of Weesperkarspel (Amsterdam). It shows that in the case of accurate state estimation, quick changes in setpoint can be tracked.

Keywords: multivariable control; MPC; crystallisation

INTRODUCTION

In the last decades, most drinking-water treatment plants have been automated. During these first automation realisations, the goal was to operate the treatment plant in the same way as the operators did before. Therefore the control configurations consisted of a heuristic control strategy, based on historical operator knowledge. The controls are designed for the static situation, including extra safety margins to take operator response into account. This was a logical and practical solution. However, this heuristic solution does not optimise the control of a treatment plant.

The heuristic control is based on static local control objectives, without taking the current state of the treatment plant into account. Therefore it is necessary to adopt a new control strategy, which can take into account quality-related and economic criteria and optimise the overall performance of the plant, based on the current state of the processes.

Since the treatment steps are coupled, local changes affect other treatment steps and therefore local optimisations should be considered in a global context. It is necessary that operational actions do not introduce new disturbances to other processes. This must be considered in all levels of control, from basic valve controllers to plant-wide quantity control. At the same time, the control should consider the actual state of the process and optimise plant operations.

The information density in the online measured data of water treatment plants is limited and multiple measurements have to be used to obtain a good view of the actual treatment performance (van Schagen et al., 2006b). By using white or grey models, the process knowledge is no longer stored as historical heuristic rules of thumb or static local control objectives. The local control objectives evolve from applying the new criteria to the existing models in the case of changes to the process, such as boundary conditions, influent properties and desired treated water quality.

The model-based dosing control is part of the new model-based control configuration for the pellet-softening treatment step, consisting of a number of pellet reactors and a bypass. The pellet softening process step at the Weesperkarspel treatment plant is described in the first section. The model-based control configuration is elaborated in the second section. Finally the model-based dosing control scheme is validated in simulation experiments and finally validated in the pilot plant of Weesperkarspel (Amsterdam).

PROCESS DESCRIPTION

In the Netherlands, softening of drinking water in treatment plants is mainly carried out with fluidised pellet reactors. The pellet reactor consists of a cylindrical vessel that is partly filled with seeding material (figure 1). The diameter of the seeding grain is small, between 0.2 and 0.4 mm and consequently the crystallisation surface is large. The water is pumped through the reactor in an upward direction at high velocities, maintaining the seeding material in a fluidised condition. In the bottom of the reactor, chemicals are dosed (caustic soda, soda ash or lime). Calcium carbonate then becomes super-saturated and crystallises on the seeding material, resulting in the

formation of pellets. At regular intervals, pellets at the bottom of the reactor are removed. These pellets can be re-used in industry (van Dijk and Wilms, 1991).
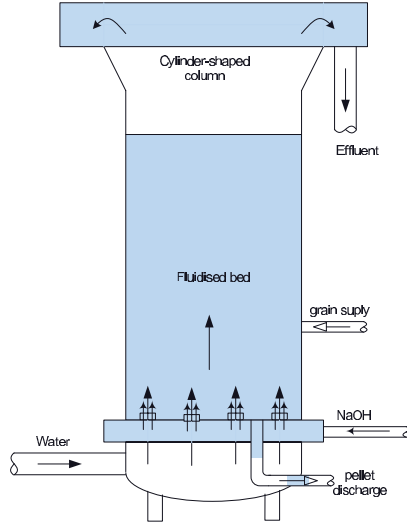

Fig. 1. Fluidised bed reactor for water softening.

Softening in a reactor is normally deeper than the required levels. Therefore, part of the water can be bypassed and mixed with the effluent of the reactors. In general, several identical parallel reactors are installed to increase the reliability of the system and the flexibility in operation. Reactors can be switched on and off in case of flow changes, maintaining water velocities between 60 and 100 m/h.

The mixture of the effluent of the reactors and the bypass water must be chemically stable to avoid crystallisation in the filters after the softening step.

At Weesperkarspel caustic soda (NaOH) is dosed for softening. The seeding material is garnet sand. The dosing of caustic soda in the pellet reactor is adjusted to realise the mixed effluent hardness of 1.5 mmol/l. The pellet removal is based on the hydraulic resistance of the fluidised bed (head loss) and the goal was to keep the hydraulic resistance constant. The garnet sand dosage was a manually set percentage of the mass of discharged pellets. The pH, flow, water temperature and hydraulic resistance were measured every minute, while hardness, calcium, bicarbonate, super saturation, pellet diameter and bed height were measured at longer intervals (Rietveld, 2005).

The characteristics of the softening process at Weespekarspel are given in table 1.

Table 1. Characteristics of softening reactors at Weesperkarspel.

Number of reactors	8	-
Surface area of reactor	5.3	m^2
Maximum bed height	5	m
Typical water velocity	60-100	m/h
Grain size of seeding material	0.25 10^{-3}	m
Density of the seeding material	4114	kg/m^3

CONTROL CONFIGURATION

The aim of the control of the softening process is to achieve a desired calcium concentration and, at the same time, minimise the use of dosage material (caustic soda, seeding grains and acid). The available control inputs are the water flow through the bypass and for each reactor the water flow through the reactor, the grain supply rate, the pellet discharge rate, the caustic soda dosage and the acid dosage.

To control the complete treatment step, a modular control setup is chosen. In this way, the controller complexity is minimised, maximising operator understanding of the control structure. Due to the diverse time constants in the process, these controllers are implemented on different platforms, with appropriate performance for the controllers. Figure 2 shows the control modules that are related to the softening process step. On the vertical axis represents the typical time constant of the controller and the horizontal axis shows the process level of the controller.
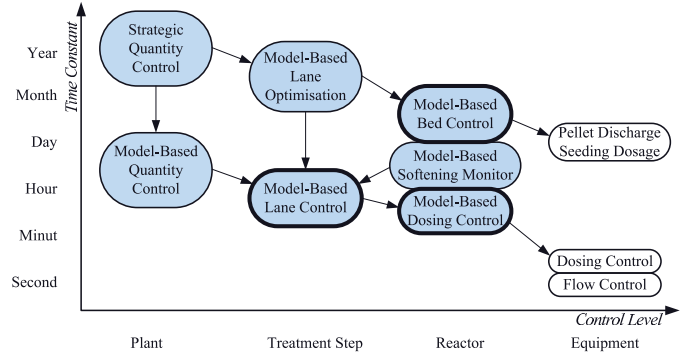

Fig. 2. Control setup for the pellet-softening treatment step. Modular controllers for different time constants and control levels.

The *Strategic Quantity Control* determines the amount of water, which has to be produced at the treatment plant. This is based on yearly consumption patterns, available resources at this plant and, in a multiple plants setup, the other treatment plants. The amount of water to be treated, is then passed to the Model-Based Quantity controller and the Model-Based Lane Optimisation.

The *Model-Based Quantity Control* determines the actual production rate of the entire plant, based on expected daily consumption pattern and the available water in the storage tanks. Restrictions in production rate, due to short-term maintenance, are taken into account and fluctuations of production rate are minimised (DHV, 2008).

The *Model-Based Lane Optimisation* determines the ideal pellet size, bypass ratio and the optimal number of reactors in operation, based on the expected production rate from the Stategic Quantity Control and the expected temperature variations. Changing bed configurations is a long term optimisation, due to the retention time of seeding material in the reactor of approximately 100 days. An extensive description of this optimisation scheme can be found in (van Schagen et al., 2008c).