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ORIGINAL ARTICLE

Coagulation process control in water treatment plants using multiple model predictive control

Oladipupo Bello *, **Yskandar Hamam**, **Karim Djouani**

Electrical Engineering Department/F'SATI, Tshwane University of Technology, Pretoria X680, South Africa

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Abstract A multiple model predictive control (MMPC) strategy is proposed for coagulation control in water treatment plants. The proposed control strategy is developed to work effectively with different local operating regions of the chemical dosing unit where coagulation takes place. The surface charge and pH values of the chemically treated water are controlled at the same time to reduce waste, operational costs and improve the quality of portable water distributed for public consumption by manipulating the flow rates of the chemical reagents. The simulation results show that coagulation control can be effectively controlled by using the proposed control strategy.

1. Introduction

Coagulation is an important unit operation in the water treatment plants. Coagulation is described by complex chemical reactions and coagulation chemical dosing unit exhibits nonlinear behaviour [1]. Thus, coagulation control is quite challenging. Furthermore, in the operations of chemical dosing unit, irregular variations in the water quality and demands, depletion of chemical reagents stock, system faults and plant operators' errors often lead to multiple operating regimes resulting to either underdose, normal or overdose operating condition. In order to reduce the transition time from one operating regime to another and thereby reduce wastage of chemical reagents, minimise production cost and meet the final water quality target, an effective control strategy must be implemented at water treatment plants.

Model predictive control (MPC) is a widely accepted and useful control strategy for industrial process applications as a result of its ability to re-formulate the control problem as an optimisation problem and demonstrate satisfactory performance when satisfying operational and safety constraints. However, MPC is an ineffective approach to design local controllers for systems with strong nonlinearities and sudden changes in the operating conditions [22]. In order to address this problem, MMPC strategy has been identified as a viable solution in the literature [6,13,18,20,26,12,10,24].

MMPC as an optimal control strategy is developed using several linear models that represent separate local regions or regimes of a nonlinear system. Each linear model effectively describes its local region of the nonlinear system. Corresponding

* Corresponding author.
E-mail addresses: engroobello@gmail.com (O. Bello), hamama@tut.ac.za (Y. Hamam), djouanik@tut.ac.za (K. Djouani).

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MPC local controller is designed for each linear model. All the models are computed in parallel and the best model/controller pair is selected based on the identification error at each instant [22]. The switching scheme engaged for the model/controller pairs operates when another pair yields smaller identification error than the current pair. The global control input is thus generated using the parameters of the selected pair.

In Yu et al. [25], MMPC control strategy was proposed for the simultaneous regulation of mean arterial pressure and cardiac output in heart failure patients by adjusting the infusion rates of inotropic agent and vasodilator. However, the computation using Bayes theorem was immense and involved several stages. Zhang and Morris [27] proposed MMPC control strategy using a recurrent neuro-fuzzy network to identify the local linear models of a pH neutralisation process.

Porfirio et al. [20] examined the application of a multimodel predictive control to an industrial distillation system of a refinery (C3/C4 splitter). The proposed MMPC performed significantly better than the conventional MPC controller. In Li et al. [13], the authors proposed MMPC strategy based on Takagi–Sugeno modelling for a nonlinear process control. The proposed controller was applied successively to regulate a MIMO pH neutralisation process.

A study by Zeng et al. [26] on the application of MMPC strategy to control dissolved oxygen concentration in wastewater treatment process was performed. The authors of Mazinan and Sadati [15] proposed a multiple model predictive control based on fuzzy decision mechanism. The validity of the proposed control strategy was verified using a water tubular heat exchanger system. Guolian et al. [10] proposed MMPC based on fuzzy adaptive weighted algorithm to control the steam temperature of a thermal power plant under a wider range of load changes.

Bagheri et al. [2] proposed MMPC based on adaptive weighting matrices to improve the performance of a general predictive control (GPC) applied to a multivariable pH neutralisation process. Shamasaddinlor et al. [21] proposed MMPC algorithm using the fuzzy weighting decision making scheme for single-input and single-output pH neutralisation process control. However, the application of their proposed scheme to multiple-input and multiple-output (MIMO) systems was recommended. In all these previous studies, researchers have demonstrated the capabilities of MMPC to control nonlinear systems with interesting results.

In this paper, the design, application and performance of MMPC strategy to coagulation chemical dosing unit for water treatment plants are examined and studied. The motivation of this study is to demonstrate that MMPC is suitable for effective coagulation control and optimisation of chemical reagents that are used for water treatment process. The control approach includes the development of MPC local controller for each distinct operating region of a chemical dosing unit. A switching scheme is developed to select the appropriate model/controller pair that could adequately represent the current operating condition of the unit from the model/controller bank. The surface charge and pH level of the chemically treated water are regulated to meet the desired target quality levels by manipulating the flow rates of the primary coagulant, co-coagulant and hydrated lime flow rates. Rietvlei water treatment plant, South Africa is selected for this study. The process modelling of the chemical dosing unit of the plant is presented. The simulation studies on the MMPC performance on the chemical dosing unit show promising results.

2. Materials and methods

2.1. Description of Rietvlei water treatment plant

Rietvlei water treatment plant, City of Tshwane, South Africa was built between 1932 and 1934. From inception, the plant has undergone a number of upgrade projects to ensure that safe and portable drinking waters are supplied for public consumption in Pretoria. The typical production capacity of the plant is about 40 ml per day. The plant draws raw waters from Rietvlei Dam. There are three different abstraction points at different levels on the dam tower, namely: top; middle and bottom draw-off points. Only one point is used at a time depending on water level in the dam. Raw water quality is typically low in turbidity but with high algal content. However, the turbidity level may be high due to discharges from floods and rainfall. These changes in water turbidity often lead to difficulties in coagulation. A pumping station and transport system are available to lift water from the dam and to convey it to the treatment plant. Raw water flows through the intake pipe into the chemical dosing unit. The flow of water through the intake pipe is measured using flowmeter. The amount of water abstracted is also used to determine the amount of chemicals that should be applied during the subsequent process. Raw water inlet valve is placed after the flowmeters to control the quantity of water flowing into the plant.

Fig. 1 illustrates the coagulation chemical dosing unit of Rietvlei water treatment plant. It is made up of a concrete mixing tank with inlet and outlet channels. There are four metring or dosing pumps that are used for dosing chemicals into the influent raw waters flowing into the treatment plant. Two of the pumps are on active position and the remaining two pumps are on redundant position. One of the active pumps feeds polyelectrolyte solution while the other feeds ferric chloride solution into the concrete mixing tank. The polyelectrolyte solution is referred to as sudfloc 3835, a blend of epichlorohydrin/dimethylamine (polyamine) and aluminium chlorohydrate [17]. The pumps are controlled by programmable logic controllers (PLCs) that are connected to the plant's supervisory control

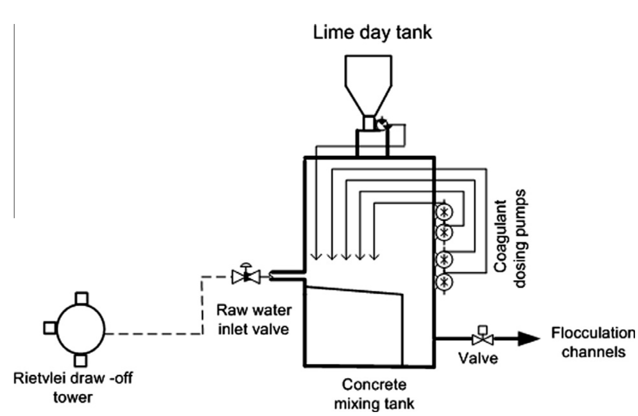

Figure 1 Coagulation chemical dosing unit of Rietvlei water treatment plant.