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Optimisation of the resource efficiency in an industrial evaporation system

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ABSTRACT

This work deals with the problem of resource efficiency monitoring in a multiple-effect evaporation process. The approach considers first a grey-box nonlinear stationary model of the process and data-reconciliation methods to compute efficiency indicators and to update such model if necessary. The updated model is used in a real-time optimisation layer to compute operation points of the process. Then, some patterns for optimal operation have been identified and implemented by a self-optimising controller to drive the process. In a second step, the fouling, which reduce the heat-transfer efficiency in heat exchangers, is also considered as a function of time and control decisions, in order to optimally drive the process considering the long-term effect. This fouling behaviour forces periodic stops for cleaning, which will be also object of optimisation. Finally, the overall problem is formulated as a real-time optimisation to search for the optimal decisions during a whole operation cycle.

1. Introduction

Resource efficiency in production has arisen as one of the main requirements to achieve in modern industrial sites [1]. Recent advances in the control field help in reducing the cost and the environmental impact, thus reducing the waste of resources and simultaneously keeping the quality of products. In this framework, optimisation problems naturally arise when dealing with process efficiency [2]. They appear in a problem hierarchy that involves production planning, scheduling, *real-time optimisation* (RTO) and control. In particular, RTO searches for the best operation conditions in large-scale systems such as petroleum refineries and chemical plants [3].

With the above goal in mind, there exist a bunch of approaches to quantify the performance of a production process like, for instance, the very extended one called *Key Performance Indicators* (KPI) [4]. However, these indicators are usually computed for long-time periods like months or after the production campaign is finished. So, they are not suitable to support operational decisions. This need has led to the recently developed set of the so-called *Resource Efficiency Indicators* (REI) [5]. The aim of these indicators is computing resource-efficiency measurements in short periods of time (even online), so they can be used for decision support to improve process operation in real time.

In this paper, we make use of these ideas to address a problem of resource efficiency in a multiple-effect evaporation process. This kind of process is very common in many industries like pulp and paper, fibre production or sugar factories, in which the goal is concentrating a certain solution of water with chemicals plus suspended organic substances.

First, a data pretreatment, gross-error detection and further reconciliation is performed before optimisation. The objectives of this step are (A) obtaining a coherent set of measurements to compute resource efficiency, assuming that sometimes biased or faulty information can come from the plant sensors, and (B) parametrising a candidate plant model to be used in later optimisations. This customisation task is also done by an optimisation problem which fits the corrected measurements to the sensor values under the constraint of the process physical laws.

Once we got a reliable steady-state nonlinear model for the evaporation plant, it can be used to suggest the right control set points in real time, with the goal of reducing the fresh-steam consumption (utility), ensuring the operation constraints. Thanks to

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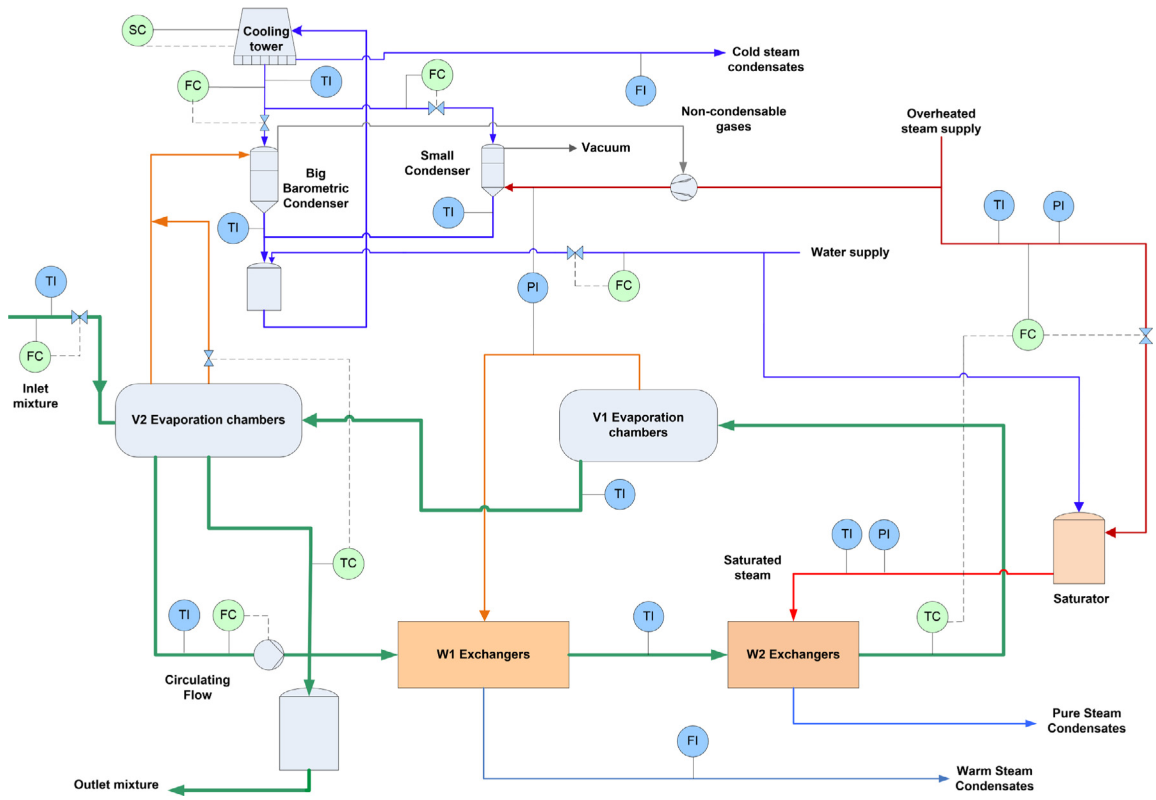

Fig. 1. Schema of an evaporation plant with location of existent instrumentation: transmitters (blue) and controllers (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of the article.)

the efficiency monitoring and the stationary optimisation, some patterns for optimal operation have been identified for this process. In fact, the result of the optimisation has been implemented by a self-optimising controller (SOC) [6] which does not require solving an optimisation problem at each sample time.

Additionally, this process suffers from loss of efficiency due to fouling inside the heat exchangers, which is also a common issue in many industries. Indeed, there are recent advances in the control literature devoted to such issue at different scales. For instance, [7] proposes a fuzzy-polynomial observer to measure the heat-transmission coefficient, based on the Lyapunov theory and sum-of-squares programming, [8] scheduled the cleaning actions during a time horizon considering a constant fouling rate, or [9] which proposes an adaptive real-time scheduler. However, introducing the fouling dynamics into an optimisation problem which predicts the optimal control set points over a long time is a problem often disregarded. Thus, in a second step, this paper deals with this problem of considering the slow dynamics of fouling in order to achieve optimal long-term behaviour.

In order to efficiently solve these large optimisation problems in real time, modern nonlinear programming (NLP) software is usually used [10,11]. These tools require a precise computation of Jacobians and Hessians to achieve efficient solutions. Despite there exist several options to compute such derivatives in an automatic way, e.g., the common approximation by finite differences or symbolic calculus (see [10] and references therein), the best option is to make use of the automatic (or algorithmic) differentiation (AD) [12] because of the less CPU and memory usages to obtain accurate computations [13].

The rest of the paper is structured as follows: next section describes the evaporation plant and the modelling procedure; Section 3 presents the proposed approach for efficiency monitoring and optimal operation plus the implementation of the suggested optimal control and some experimental results; the optimal operation taking fouling into account and the proposed policy to perform cleaning tasks is addressed in Section 4; and, finally, the main conclusions and future work are highlighted together in the last section.

2. The industrial evaporation system

The industrial evaporation system considered in this work is a large-scale system owned by Lenzing AG, an industrial site located in Austria which is one of the leading producers of man-made cellulose fibres using wood as raw material. In one part of the main production process, the spinning machines, a bath of water mixed with some salts and acids is used to increase the mechanical properties of the fibres. These chemical components have a sensible economic value. Consequently, they cannot be overlooked. In order to recover them, these mixtures (called products henceforth) go to the evaporation process in order to extract as many water as possible, and then they enter into a crystallisation process.

The evaporation system is formed by several plants, which can be arranged accordingly with the goal of concentrating different products coming from the spinbath machines. Each single plant of this system is formed by a set of evaporation chambers plus some heat exchangers in serial connection, a barometric steam condenser and a cooling tower. Fig. 1 depicts a simplified scheme of a plant, in which several individual equipment (evaporators and exchangers) have been lumped due to lack of measurements between them.

Evaporation is achieved by a multiple-effect process, as follows. First, the product flow goes through the heat exchangers in order to reach an adequate temperature (prefixed set point). Some of the heat exchangers (W_1) reuse steam from the first stage of evaporation and others (W_2) use fresh steam provided by steam boilers, which is indeed the main source of energy consumption. Then, the