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SIMULATION AND CONTROL OF A MULTIPLE EFFECT EVAPORATOR

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ABSTRACT

Sugar production contains a number of unit operations in series. The most energy consuming unit is the evaporation process. The aim of this paper is to describe the development of a concept to control the product quality and the energy consumption in the evaporation process. Despite extensive use in sugar production the multiple effect evaporator has been a difficult system to analyze and control. To investigate the control strategies a real time simulator has been developed. Using the simulator, a control scheme has been designed and implemented. The control system is based on the idiomatic concept [1]. The problem is here to derive proper strategies for decomposing the process into smaller independent functions, and to synthesize control actions which achieve and maintain those functional structures [4]. These structures are controlled using well known strategies (idioms).

The control concept has been tested on the real time simulator and with minor modifications it has been implemented in a Danish sugar plant.

INTRODUCTION

The evaporation process under study is essentially five effects (Robert) with five preheaters and four flashtanks, figure 1. Sugar juice with a 15% sugar concentration (brix) is evaporated to syrup with a brix of 74. Steam to the first effect is supplied as steam from the turbine of a power plant (boiler). In the evaporation the juice steam from one effect is used as heating steam in the succeeding effect. In addition the rate of produced juice steam in the second effect is partly controlled by a turbo compressor in parallel with a number of venturis. The amount of steam from the turbo compressor system is feed back in parallel with the turbine steam to the first effect. A part of the produced juice steam in the third and fourth effect is past to the crystallization process, the major part from the third effect. The juice steam flow from the fifth
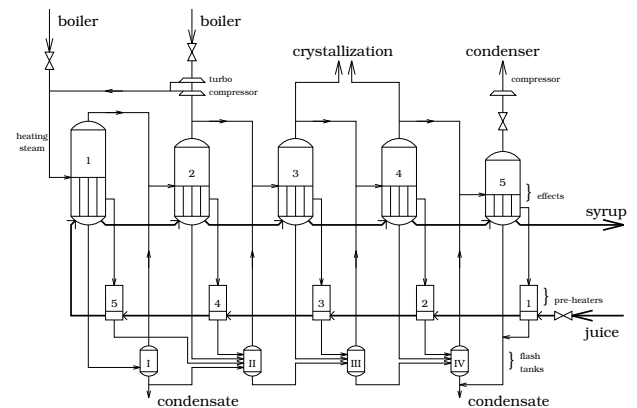

Figure 1: The multiple effect evaporator.

effect is controlled by a compressor.

In each effect a smaller part of the steam passes uncondensed, the preheaters use this steam as a heating source. In the preheaters the steam is condensed and fed to a flashtank where a part of it is evaporated due to a lower pressure. This steam is passed to the next effect.

The evaporation takes place in the Robert effects as well as in the crystallization process, and the most efficiency evaporation is in the Robert effects. The main objective to minimize the energy consumption is obtained by the development of a control scheme for the evaporator in order to control the syrup brix to a high and constant value giving the maximum allowable evaporation. A second control objective is to secure a constant pressure of the outlet juice steam from the third effect [6].

MODEL

The main objective of the model is to describe the significant dynamic behavior of mass and energy

flows. The modelling of the process is based on a lumped parameter approach with describing equations governed by physical laws and constitutive relations. All components are modeled by non-linear differential equations and algebraic equations based on mass and energy balances.

The following basic assumptions have been made:

- In all components the juice and the metal masses are lumped into one effective mass.

- Water and steam are in saturated equilibrium. This assumption permits the use of only one intensive thermodynamic property to completely describe the intensive thermodynamic state.

- The mass of steam in the juice chamber and the mass of steam in the steam chamber in an effect are constant.

- The level of the juice in an effect is constant.

- The heat losses to the environment are negligible.

- The time constants in pre-heaters and flash tanks are negligible compared to the time constants in the effects.

- Any property of steam and juice in the steam and juice chambers is suitably represented by a single effective value (lumped parameter approach).

The modelling results in a set of non linear differential equations and algebraic equations, which can be solved by using the Runge Kutta technique. In the model parameters are calculated using geometric data from the sugar plant. To get reasonable steady-state values, some of the parameters in the model (mainly heat transfer coefficients) have been adjusted to steady-state values measured at the plant.

SIMULATION

To meet the requirements of test facilities for different control strategies a real time simulator for the evaporation process has been developed. The simulator illustrates the dynamics of the mass and energy flows in the plant based on the above mentioned model. It is possible to investigate plant variations due to different input sequences, and in addition a number of measured disturbance sequences can be applied, in order to give a realistic set up.

The simulator consists of a PC and a control board. To facilitate the application of controllers the simulator has been developed with a realistic electric interface representing process instrumentation. The simulator is operating in real time or scaled real time. Control of the simulator is possible either from the control panel or from a computer.

DECOMPOSITION

In order to control large industrial processes a number of different control strategies are available. The evaporation process has mainly been controlled manually. Due to the complexity of the process it is preferred to use a control scheme which makes a successive commissioning possible. In this context the idiomatic control described by Bristol is appropriate [1]. Idiomatic control is a decentralized control scheme using SISO controllers including feedforward, cascade, gain scheduling etc. The control concept demands a decomposition of the process into subsystems. The decomposition must be carried out concerning the control goals for the plant and the manipulator inputs. The concept is chosen because of its simplicity concerning installation and on-line tuning.

As a starting point for the specification of the requirements for the evaporator process a preliminary analysis of the task is needed. The goal for the control system is to minimize the energy consumption, which is obtained by a minimization of the variations of the syrup brix and the crystallization steam pressure [7]. As seen in figure 1 no natural hierarchy exists in the evaporator process. The layout of the interconnections of the evaporators, the pre-heaters and the flash-tanks implies a co-current nature of the process. In spite of the co-current nature simulation results shows only a small coupling among the Robert evaporators and the pre-heaters and a minor coupling to the flash tanks.

The above mentioned weak couplings makes it possible to decompose the evaporation process into subsystems in series. In order to decompose the process the inputs (manipulators) and the disturbances are identified. From the view point of a control engineer, the process has four inputs namely the steam flow to the first effect, the juice steam flow through the turbo compressor, the juice steam flow from the fifth effect and the mass flow through the evaporator. The main disturbances are variations in the steam flow to the crystallization process and the variations in the juice brix and flow. Another subject to be considered in the decomposition is the long time delay in the process.

A small variation in the sirup brix may be obtained by controlling either the output juice brix of effect 3 or effect 4. The main disturbance from the crys-

tallization is the juice steam flow from effect 3. To compensate this disturbance the system is divided into two subsystems namely effect 1 - 3 and effect 4 - 5.

CONTROL CONCEPT

In the previous section the evaporation process has been divided into two separate subsystems leading to units with smaller time delays and fewer inputs and outputs. These two subsystem will be treated separately.

The first part of the system including effect 1 - 3 and the corresponding pre-heaters and flash tanks is a two input two output system. The inputs are the heating steam and the turbo-compressor steam flow, the outputs are the brix after effect 3 and the juice steam pressure to the crystallization. The heating steam is a mixture of steam from a boiler and comprimized effect 2 juice steam, forming the energy supply for the entire station. The heating steam pressure is controlled by a valve in the steam supply.

The selected idiomatic concept mainly uses SISO controllers. To identify the SISO control loops the relative gain array technique is used, resulting in the fact that the brix of the third effect is controlled by the steam flow, and the juice steam pressure from the third effect is controlled by the turbo compressor flow. Due to the couplings in the system a dynamic decoupling is necessary. Supplemental two feed forwards from the effect 2 juice flow and from the effect 3 juice steam flow are enclosed. The concept is illustrated in figure 2. In the feedback controllers - all of the PI type - gain scheduling is used to ensure a constant open loop gain. The heating steam control valve position is set by a heating steam pressure feedback and is an inner loop in the dynamic decoupling scheme. In addition a feedforward from the varying effect 2 juice steam flow is inserted.

The second sub-system including effect 4 - 5 is a SISO system. The input is the compressor juice steam flow and the output is the syrup brix. Evaporation is more effectively implemented in effect 4 than in effect 5 and the juice steam flow to the condenser is not re-circled in the factory. Consequently a minimizing of this juice steam flow is desired. Therefore the effect 5 evaporation makes up the final adjustment, indicating that the brix-4 must be nearby the outlet reference. Control of the effect 5 brix is obtained by regulation of the juice steam flow to the condenser. A feedback loop from the effect 5 brix is introduced. Input variations to this control loop are compensated by inserting feed
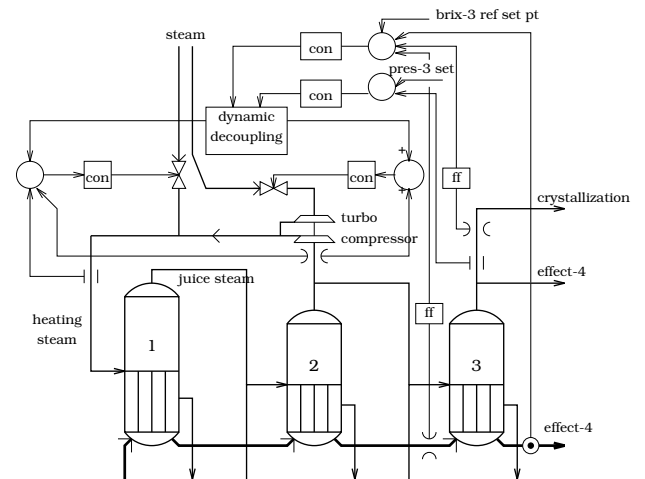

Figure 2: The control sceme for effect 1 - 3..

forwards from the effect 4 brix and the effect 4 juice flow.

Brix variations near the crystallization level is critical and the control signal has a limited operating range. To achieve a better control, a fifth input is added as a preheated juice flow to the syrup flow between the fourth and fifth effect. According to energy economy the amount of inlet juice must be minimized. The supplied inlet juice is controlled by a feedback loop using the effect 4 brix and a feedforward from the effect 3 brix.

The production flow is set by the amount of juice manufactured in the evaporation process. To keep the effect 5 controller out of saturation at different production flows the reference of the effect 3 brix controller may be changed according to the juice flow. Set point adjustments in the case of flow variations are tabulated.

The control loops are illustrated in figure 3

RESULTS

Data sequences measured at a sugar plant are used as input to the evaporator simulator. Figure 4, 5 and 6 illustrates the variations of the effect 3 juice steam pressure, effect 3 brix and the effect 5 brix using constant and controlled heating steam, effect 2 juice steam flow and effect 5 juice steam flow.

As seen the control system causes considerable reductions in the output signal variations. Stabilizing the effect 3 outputs results in less input disturbances to the fifth effect and a better control of the brix-5 is obtained.
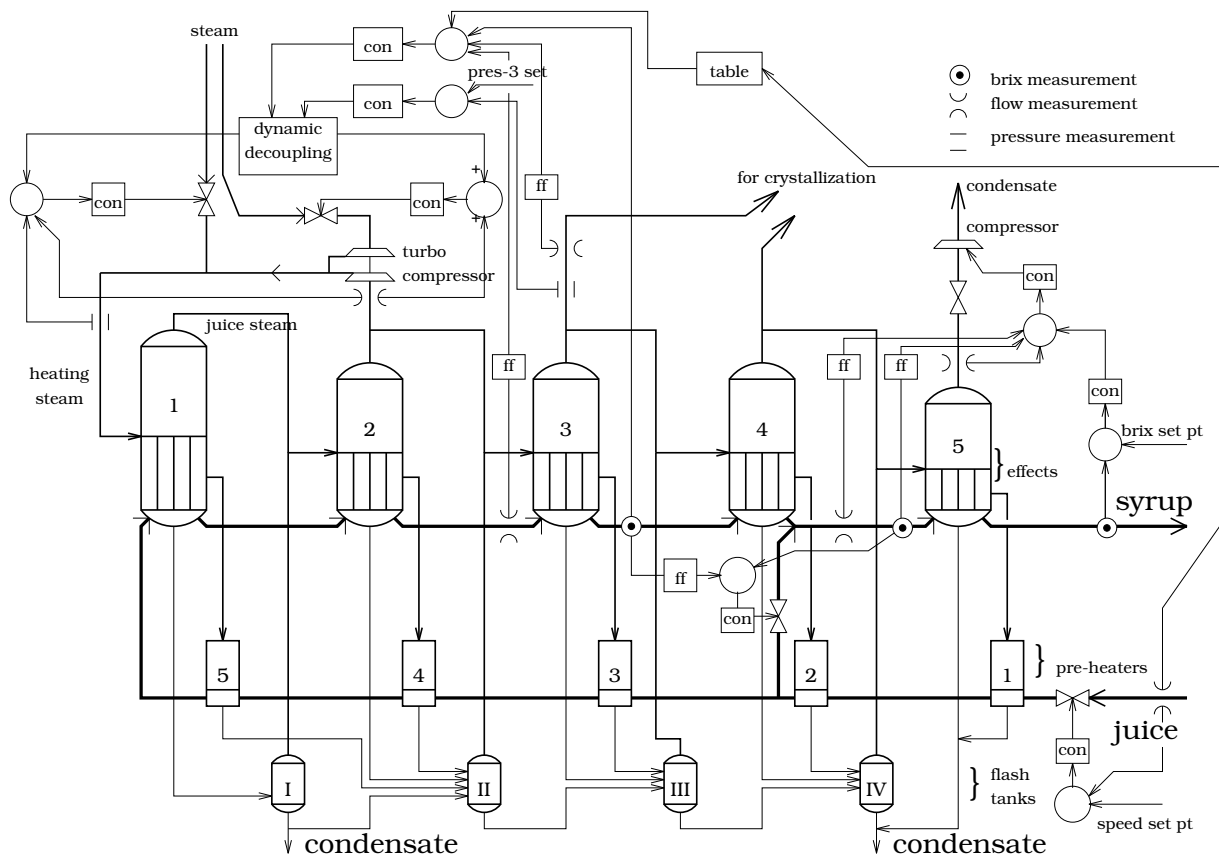
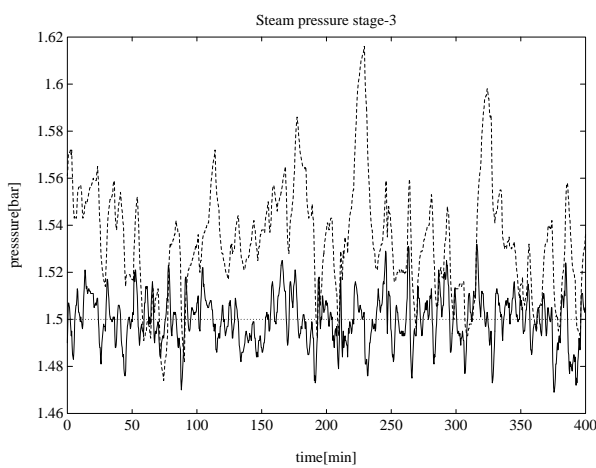Figure 3: The control sceme for the multiple effect evaporator.

Figure 4: The effect 3 juice steam pressure variations using constant(dashed line) and controlled signal.
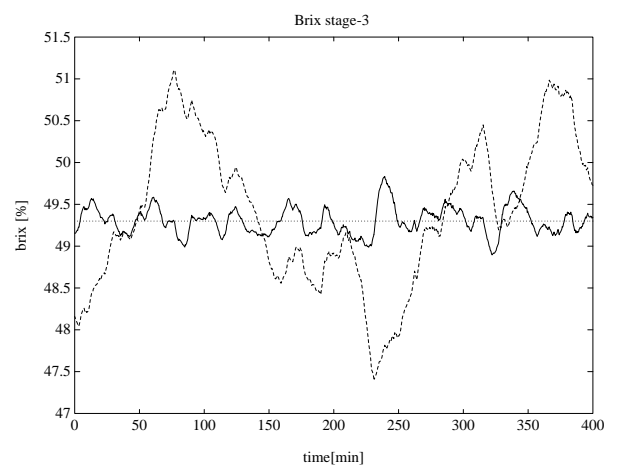

Figure 5: The brix-3 variations using constant (dashed line) and controlled input signal.
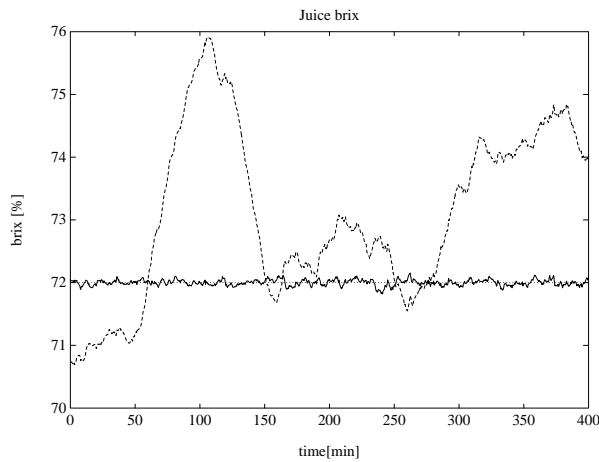
Figure 6: The brix-5 variations using constant (dashed line) and controlled input signal.

According to economical considerations a simplified version of the control concept has been implemented at a Danish sugar plant. In the plant only the steam to the turbo-compressor can be controlled, consequently the described effect 1 to effect 3 control concept must be simplified. It is chosen to use turbo-compressor steam flow as input for the brix-3 control and to insert a reference control from the effect 3 juice steam pressure to the heating steam, this system is only activated when the pressure exceeds specified limits.

To evaluate the control system the brix-5 variations have been measured at the sugar plant . Figure 7 shows typical brix-5 variations using manual control and figure 8 shows brix-5 variations using automatic control. As seen the control decreases the brix fluctuations causing considerable energy savings. The measurements are not quite comparable due to different operating conditions e.g. input signals and disturbances in the production are varying.

CONCLUSION

The purpose of this paper has been to describe a strategic design of a control system for the evaporator process in a sugar plant. The control system is based on the idiomatic control concept. The idea is to separate the system into a number of independent sub-systems each controllable using well known control methods (idioms).
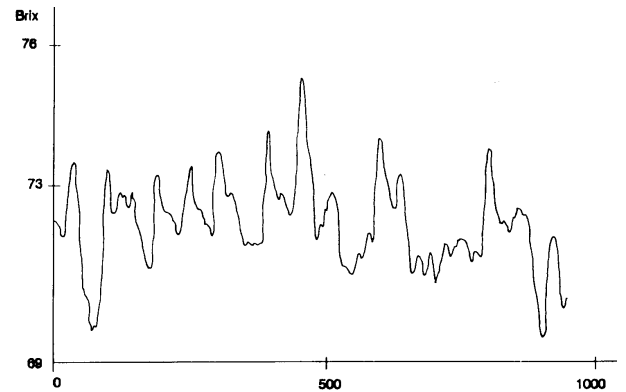

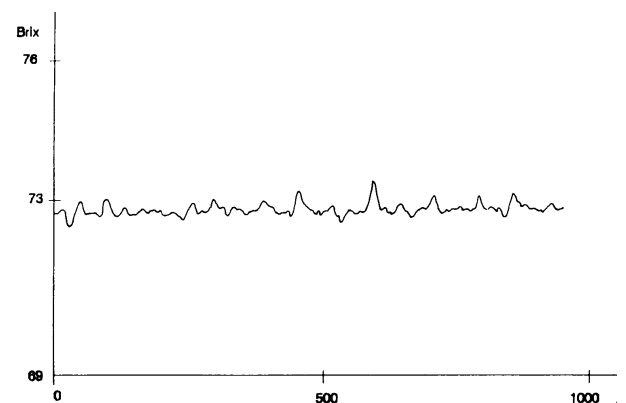Figure 7: Typical brix-5 variations using manual control measured at the sugar plant.

Figure 8: Typical brix-5 variations using the automatic control system measured at the sugar plant.

The control system for the evaporation process must ensure robustness to juice flow variations, the quality of the outlet syrup and the juice steam pressure to the crystallization process. The quality control is carried out stabilizing the brix-3 and the brix-5 separately. Control of the effect 3 juice steam pressure is obtained by feedback adjustment of the heating steam. The non-linear evaporator process necessitates a separate control system performing controller set point transformations corresponding to the inlet juice flow, these set point adjustments are tabulated.

The control concept is implemented on a real time evaporator simulator developed at Aalborg University. The simulator handles the normal working conditions, it consists of a non-linear dynamic model based on mass and energy balances. The model parameters have been adjusted to data measured on a sugar plant. Simulations show that the control system causes considerable reductions in the output signal variations. A simplified version of the control concept has been implemented at a Danish sugar plant causing considerable energy savings.

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