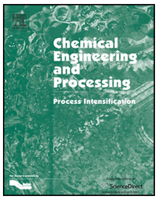
Chemical Engineering and Processing xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep



A control strategy for extractive and reactive dividing wall columns

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ARTICLE INFO

Article history:
Received 7 March 2016
Received in revised form 22 September 2016
Accepted 7 October 2016
Available online xxx

Keywords:
Distillation
Dividing wall column
Extractive dividing wall column
Model predictive control

ABSTRACT

Dividing wall Columns (DWC) are being an important breakthrough in distillation technology due to the energy consumption and capital cost reduction they provide. There is an increasing amount of research papers devoted to DWCs although most of them present different applications and DWC setups like extractive DWC, azeotropic DWC or reactive DWC. These units have strong interactions in their operation and to achieve a good control is of great importance to guarantee a smooth and stable performance. Although control of standard DWCs has been presented somewhere else, in this work we present the control of an extractive and a reactive DWC. We establish the decentralized structure as well as a model predictive control and compare both approaches.

1. Introduction

As a thermal separation method, distillation is one of the most used and therefor important separation technologies in the chemical industry. Basically, in every production process some of the chemicals go through at least one distillation column on their way from raw species to final product. Distillation is and will remain the separation method of choice in the chemical industry (about 95% of all industrial separation processes involve distillation, [17]. Despite its flexibility and widespread use, this unit operation is very energy demanding, which constitutes one important drawback. The US Dpt. of energy estimated in 2001 [15] that there are more than 40000 distillation columns in North America and that they consume about 40% of the total energy used to operate plants in the refining and bulk chemical industries, around 4.8 quadrillion BTUs and it is the responsible of 3% of the energy usage in the US [14]. Distillation resembles a heat engine producing a separation work with a rather low efficiency. Lost work (energy) in separation systems is due to irreversible processes of heat, mass transfer, and mixing, and is directly related to entropy production according to the Gouy-Stodola principle [2]. The thermodynamic efficiency of a distillation column is around 10% [8]. In order to reduce this drawback, which is important to achieve overall plant energy savings, new approaches and configurations have appeared.

Conventional ternary separations progressed via thermally coupled columns such as Petlyuk configuration to a novel design that integrates two distillation columns into one shell setup known today as dividing-wall column (DWC). DWC can separate three or more components in one vessel using a single condenser and reboiler. The DWC concept is a major breakthrough in distillation technology, as both energy consumption and capital cost can be reduced. In fact, using dividing wall columns can save up to 30% in the capital invested and up to 40% in the energy costs particularly for close boiling species [3,9]. Several companies like Montz, BASF or AzkoNobel are actively researching in this area [1,6]. However, the control of a dividing wall column is more difficult than the control of a conventional schema with two columns for the separation of ternary mixtures because there is more interaction among control loops. The distrust on DWC controllability and flexibility is mainly due to the complex design of the control strategy. Part of the complexity comes from DWCs having more degrees of freedom (DOF) compared to conventional distillation columns. This entails a complex design, but also presents extended optimization capabilities. If three product specifications are taken into account, DWC has 7 DOF: distillate and bottoms flowrate, reflux ratio, reboiler duty, sidestream flowrate and vapour and liquid internal split ratios. 5 DOF are used to stabilize 2 levels and 3 compositions while the remaining 2 DOF are used for optimization purposes. Traditionally, liquid split ratio ($\alpha L = LP/LM$) and vapour split ratio ($\alpha V = VP/VM$) are optimization variables. Vapour split ratio is usually fixed during the design stage because it is given by the pressure drop across both sides of the wall, which in turn depends on the stages type and geometry. The liquid split ratio is used as a control variable during operation by manipulating the flowrates leaving the bottom tray of the rectifying section. The optimal de-sign is given by the number of stages in the different sections of the DWC. The number of stages at both sides of the wall

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http://dx.doi.org/10.1016/j.cep.2016.10.004
0255-2701/

Please cite this article in press as: M. Rodríguez, et al., A control strategy for extractive and reactive dividing wall columns, Chem. Eng. Process. (2016), http://dx.doi.org/10.1016/j.cep.2016.10.004

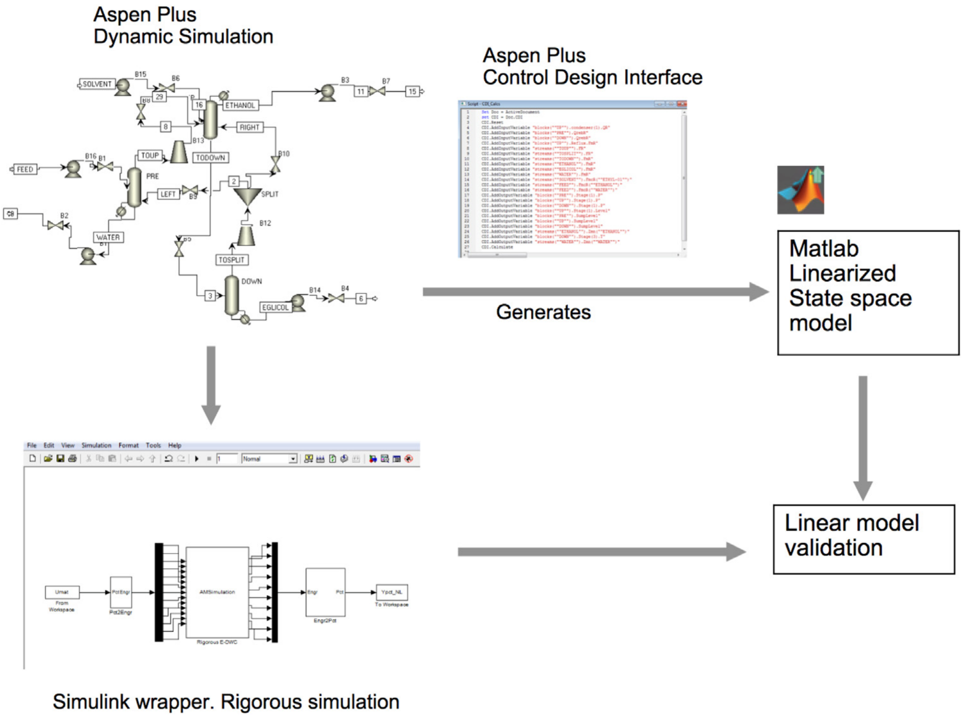

Fig. 1. Methodology to generate the model for the MPC.

is usually the same but approaches with different number of plates have been reported. Olujic et al. presents a review on the different design approaches of DWC [10]. Maintaining product specifications while rejecting disturbances and loop interaction are the key concerns together with achieving significant energy savings.

Some recent work has been presented extending DWC to other distillation setups, like extractive DWC and reactive DWC with important industrial applications like using extractive DWC for bioethanol dehydration [4,6,7]. Some work has been done related to have a good control structure for conventional DWC [5,16] or their control using multivariable predicive control [11,12] but there are very few works addressing the control of reactive and extractive DWC. In this work we present the control of extractive and reactive dividing wall columns using a decentralized approach as well as using the multivariable predictive controller approach.

The remaining of the paper is organised as follows. Section two describes the methodology used to generate a model for the model predictive controller (MPC). Section three simulates and designs the decentralized control structure and the MPC for an extractive DWC. Section four presents the reactive DWC case study along with its simulation and model predictive control. Finally, section five draws conclusions and discusses the obtained results.

2. Methodology

The methodology explained in this section has been applied to the extractive and reactive dividing wall columns case studies. The first step is to build a steady state simulation (in this case Aspen Plus was used for this purpose). The DWC column cannot be modelled as such using the commercial simulator so before constructing the model a thermodynamically equivalent system has to be developed. The steady state model of the thermodynamically equivalent configuration is used to size the equipments. The second step is to create the dynamic simulation (Aspen Dynamics have been used for this task). The dynamic model is automatically generated from the steady state model providing the necessary dynamic parameters for the different equipments.

Once the dynamic model is available the designed decentralized control is implemented in the dynamic simulator and its performance is recorded. The dynamic model as it is available in Aspen Dynamics is not suitable for MPC so a transformation is needed. In this case an existing API, called Control Design Interface, provided by Aspen, has been applied. In the Control Design Interface, the manipulated, controlled and disturbance variables are indicated, with that information the API generates the matrices of the linearized state space model using the rigorous dynamic model. This linearized model is the one to be used in Matlab for the MPC. The generated state space model has previously been scaled in order to avoid very different magnitudes and then implemented in Matlab. Before using the generated model for the MPC a validation has been performed. In order to validate the model, a Simulink wrapper (*AMSimulation block*) of the original dynamic model has been created. The linear model is validated against the rigorous model embedded in the Simulink environment (which means that the nonlinear dynamic model is being called from Simulink). Fig. 1 shows the followed procedure.

The final step is to design the MPC (in Simulink) using the state space model. Fig. 2 shows the final structure. To account for the performance of model predictive controller, it is connected to the rigorous model (through the Simulink wrapper *AMSimulation block*). The Pct2Eng and Eng2Pct blocks are unit converters from engineering to percentage, this is necessary as the MPC is scaled. The MPC parameters are tuned (control and prediction horizons, sampling time, weighting factors for the controlled variables) and the final MPC is used to evaluate its performance under different disturbances.

3. Extractive dividing wall columns case study

The case study is based on the paper by Kiss and Ignat [7] where they present the use of an extractive dividing-wall column for bioethanol dehydration. The ethanol dehydration and concentration is achieved using ethylene glycol as the extracting agent. The

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