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Teaching Classical and Advanced Control of Binary Distillation Column

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Abstract: This paper deals with education of graduate and undergraduate students in the field of classical and advanced controllers. A pilot scale binary distillation column is utilized to serve the teaching purposes. The emphasis of the paper is to practically teach identification, and widely used classical and advanced control schemes, such as Proportional-Integral-Derivative (PID) and Model Predictive Control (MPC), over a plant. MATLAB/Simulink-based Human Machine Interface (HMI) is used by students to implement these control strategies. Performance results of both controllers subject to reference tracking, constraints and disturbance handling are presented. Developed directives and control schemes can be used for effective process control education of chemical/process engineers.

Keywords: Laboratory education, distillation column, process control, PID and MPC.

1. INTRODUCTION

The concept of teaching students with the objective of stuffing theoretical knowledge and practical experience, is the need of the hour. The concept helps familiarizing the students with the advances in using computer and information technology, along with the theoretical aspects of control engineering.

For many years and till date, Proportional-Integral-Derivative (PID) controller has been providing the backbone for most of the control applications, as inscribed in O'Dwyer (2000), and Åström and Hägglund (2006). PID controllers are easy to derive, implement and tune, but at the same time they lack the efficient handling of constraints, moreover they show poor performance for integrating processes and processes with large time delay. The reasons above induced the development of advanced controllers, such as Model Predictive Controller (MPC) (Morari and Lee, 1999). As mentioned in (Balaji and Rajaji, 2013), MPC unlike PID could be used for handling Multiple-Input Multiple-Output (MIMO) systems. The primary advantage of MPC is its ability to explicitly deal with the constraints. The better performance guaranteed by advanced controllers like MPC, makes it essential to get students acquainted to the modern control techniques besides the classical ones, in order to develop them into excellent future process/control engineers. The MPC based control in educational framework as discussed in (Canale and Casale-Brunet, 2014) marks the theoretical and practical aspects of it.

Distillation process as studied from Perry and Green (2008) and Andrzej Gorak (2014) is the separation of the components with the aid of evaporation and condensation, where the components are separated on the basis of their relative boiling points. Distillation is widely used in partial fractionation of crude oil, separation of noble gases, and production of distilled alcoholic beverages, etc. The control of temperature is hence the basic necessity for the process to run efficiently. This could be achieved by students using various parameters as control inputs, i.e. *reflux ratio* between the cooled condensate taken out and returned back to the process, the *heater* and the *reboiler* powers and more. H. Gorecki and Byrski (1997) discusses this implementation of process control over a distillation column, in order to aid education. Similarly in Jishuai Wang (2008), virtual control of distillation column is presented. It describes the education of students by virtual engineering environment, over a distillation column.

In this paper, we present the application of a well-equipped binary distillation plant, from the learning perspective of students. The communication with the plant, its hardware considerations, and control using classical and advanced controllers are taught to the students. This paper will also serve as a tutorial for the students to understand the process and design of control algorithms for binary distillation column.

2. DISTILLATION PLANT

In this paper, a separation of the methanol-water mixture based on their boiling points is discussed. The process unit of the laboratory distillation column used by the students, is depicted in Fig. 1, with corresponding Process and Instrumentation Diagram in Fig. 2. It consists of eight 50 mm diameter sieve plate trays, divided into two sections, each containing four sieve plates. The cylindrical shell encloses the trays which are stacked one above the other, forming 2 meter tall insulated column. The operation of the plant begins in the reboiler, having storage tank capacity of 20l. Here, the mixture is being heated to the boiling point by

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the immersion type heating element with maximum power of 2.5 kW. A semiconductor-controlled rectifier (SCR) controls this heating. The vapors resulting from heating subsequently rise through, and fill up the whole column. Once the vapors reach the top of the column, they travel to the condenser (C) and are condensed back to the liquid phase. The condensate is shortly stored in the reflux drum, from where it is either returned back to the column as *reflux*, or taken out as a top product and can be stored in the corresponding tank. The ratio between distillate returned back to the column and product is being called *reflux ratio*, with operation range spanning from 0 % to 100 %. The central feed section is where the feed mixture enters the column from the feed tank using a pump. The speed of the feed pump (P_1) is controlled in the range 0 RPM to 300 RPM by a Variable Frequency Drive (VFD). Feed separates the distillation column into the rectification and the stripping section. In the rectification section placed above the feed section, the rising vapors are being enriched by the more volatile substance. The stripping section is placed below the feed, here the more volatile substance is being stripped down from the rising vapors. The vertical arrangement of the trays ensures counter-current vapor/liquid flow. The feed mixture is being heated by pre-heater with maximum power 2 kW. In order to prevent flooding of the column, the bottom product is being continuously withdrawn from the reboiler.

Fig. 1. The binary distillation column plant at process control laboratory.

3. TEACHING OBJECTIVES

The bachelors level students at department of process control (IAM) are mostly taught identification techniques, design of classical controllers (PID, LQR), etc. The engineering students on the other hand learn the advanced (MPC) control techniques, and also the remote or virtual control of the processes (Kalúz et al., 2013). In order to implement such controllers, students need hands-on experience with the plant and its control. According to one of the master students:

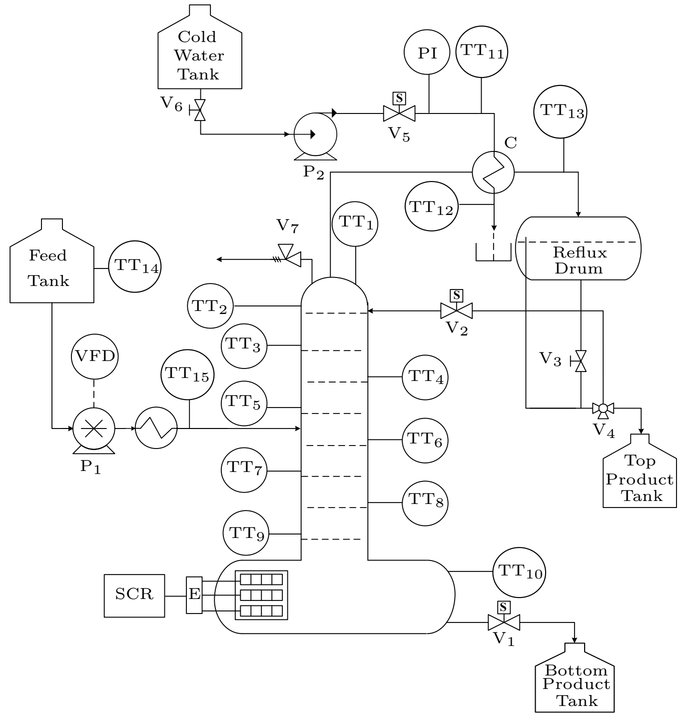

Fig. 2. Process and instrumentation diagram of the binary distillation plant.

"*I studied several techniques for identification and control theoretically, but learnt the procedure for their successful implementation on this distillation plant.*"

Simon Koniar

The complete procedure of communication, model identification and control, practiced by this and other students during projects is mentioned in further sections.

3.1 Communication and Data Acquisition

This section discusses the signal transfer between various sensors and operator. The students are taught to implement signal processing techniques, to filter or modulate raw data coming from the plant sensors. On top of that, the main task for the students is to design user-friendly Human Machine Interface (HMI) containing advanced data visualization features.

The distillation column is equipped with 15 thermocouples to measure temperatures in the individual parts of the process unit. The 10 most important signals are: $TT_2, \ldots, TT_9$, i.e. the signals representing the temperatures at each tray of the column, TT_{10} representing the temperature in the reboiler, and TT_1 for the temperature at top of the column. Further we measure the temperatures of the cooling water entering (TT_{11}), and leaving (TT_{12}) the condenser. Sensor TT_{13} indicates the temperature of the distillate. Finally, the last two signals are feed liquid temperature from the feed tank (TT_{14}), and pre-heated feed temperature (TT_{15}) entering the column. The sensor