Process Control Education using a Laboratory Separation Process

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Abstract: This paper deals with description of learning objectives and activities for topics in automatic control, on a laboratory scale membrane separation unit. Students learn theoretically and practically various process loops and configurations. These are crucial in order to attain desired operation of membrane aided separation. Moreover, students need to design and implement human machine interface, local and remote operation, and to evaluate performance of basic and advanced control tasks.

Keywords: laboratory education, remote control, human machine interface, process control, membrane separation.

1. INTRODUCTION

Methodology in control engineering education has evolved in the modern information era more than in its overall previous history. Due to the rise of various information technologies, new methods and approaches have been implemented to curricula and practical exercising was moved more towards the use of computer-aided learning.

The main goal of engineering educators is to prepare students for the real world outside academia, where they can apply their knowledge, experience, and practical skills to improve the progress in a particular field. Some of them will end up in industry, where the ability of solving practical problems is essential. This does not apply only for industrial practice, but also for other fields where young professionals can find their use. It is necessary not only to teach them what is the theory and where it came from, but also how this valuable knowledge can be applied to the real world situations.

In process control education, students need to come in contact with industrial plants to put the interconnecting pieces between theory and practice together, and to become skillful engineers. Different approaches or combination of them are used to achieve this goal. The methodology of educating students towards their practical professionalism depends on several factors. These are the number of students, availability of educational equipment, the standard of information technology of a particular institution, etc. Often, the demand is much higher than the number of actual training devices available, or the capacity of labs is the limiting factor. In these cases, educators usually opt for the use of virtual and remote laboratories. These two approaches became very popular in control education, and many educational institutions use them on a regular basis. The web-based approaches as discussed in Tzafestas (2009); Monroy et al. (2005); Sancristobal et al. (2014); Sumper et al. (2007) are being used nowadays

to help students experience the practical side of process control. Some of the approaches are directly focused on industrial control systems (Golob and Bratina, 2013; Carrasco et al., 2013; Marangé et al., 2007). In recent years several remote laboratories have been deployed at our institute, improving our educational methodology (Kalúz et al., 2014, 2015). However, there are some disadvantages of virtual and remote laboratories as well. Virtual labs provide only computer simulations, and it is very unlikely that students will face the problems of real industrial world. Remote labs provide an access to real physical equipment, but they are mostly limited to small-scale and naturally safe processes. As the educational practice and research have proven, it is not suitable to focus on strictly hands-on, or remote control approach (Lindsay and Good, 2005), but rather to find some balance between them, and thus to provide students with some kind of freedom in selection of methodology.

In this paper, a fully equipped medium-scale laboratory plant is presented along with all the features that allow student to practice real world control engineering situations. The presented plant is a membrane separation process with supplementary control hardware and software that allows students to perform experimentation in the lab as well as remotely.

2. LABORATORY MEMBRANE PLANT

Membrane separation process as described in Cheryan (1998) and Zeman (1996) separates two or more different molecules from a solution, or from each other in a solution, using semi-permeable membranes. Membranes have found numerous applications in water purification (Mallevialle et al., 1996), desalination, TOC (total organic carbon) minimization, juice clarification, product separation, and purification (Crespo et al., 1994). The various driving forces for separation in membrane processes are concentration gradient, pressure, and electric potential. Pressure

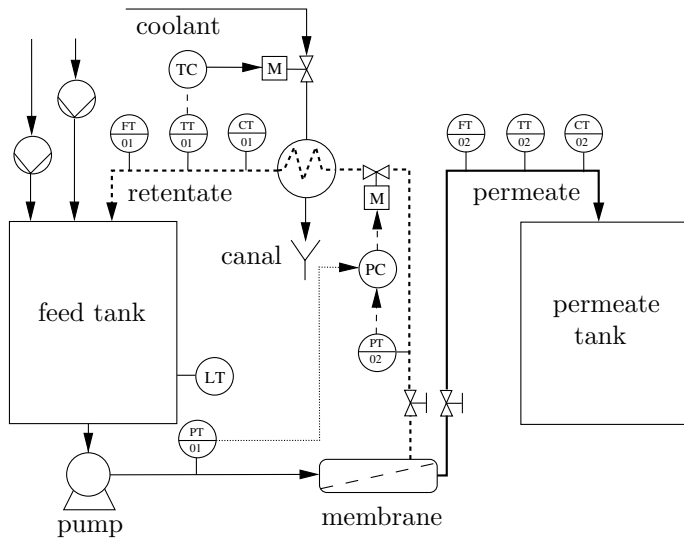Fig. 1. Membrane separation plant.

Fig. 2. Schematic diagram of membrane separation plant.

based membrane processes can be divided into micro-, ultra-, nano-filtration, and reverse osmosis. Every process has a range of pressure that can be defined by transmembrane pressure (TMP). The violation of these limits may damage the membrane and the plant, and hence negatively effect the process performance and product quality. Physical parameters i.e. temperature (Mänttäri et al., 2002) and pressure (Ahmad et al., 2013) play a big role in these membrane separation processes, and hence students must know to control them theoretically and practically.

The membrane separation plant (Fig. 1) installed at the Institute of Information Engineering, Automation and Mathematics (IAM), is represented in P&ID diagram in Fig. 2. The membrane separates the feed in two streams: retentate

stream (dashed line in figure), i.e. the concentrated stream, and permeate stream (bold black in figure). In this plant, the possible membranes that can be used are ultrafilter (UF), nanofilter (NF), and reverse osmosis (RO).

As mentioned, these processes are highly influenced by operating parameters, such as temperature and pressure. The high pressure pump on the membrane inlet generates heat and increases the temperature. The other reason for heat generation is due to the fluid dynamics resulting in molecular frictional heat, and viscous heat. Therefore, the temperature needs to be controlled and maintained in a safe zone. As shown in Fig. 2, the process is equipped with a heat exchanger in order to cool the retentate returning to the feed tank. The plant has temperature sensors on both retentate and permeate sides.

Along with temperature, pressure too must be maintained between specific ranges, and hence the identification and control of the pressure is a necessity. The pressure of the process can be influenced by two inputs, i.e. by the pump located upstream to the membrane, or by the retentate side valve downstream to the membrane. The retentate side valve is motorized, and hence with the aid of pressure sensors located upstream and downstream to the membrane, students can study the effect of each input, and control the processing pressure.

The objective of applying membranes is to separate solutes (for e.g. lactose and NaCl) from a solution, till the desired concentrations of these solutes are achieved. Concentrations can be inferred from conductivity sensors installed on both permeate and retentate sides. The concentrations during the membrane processing can be altered with the help of a diluent (diafiltration), or the feed solution itself. This possibility of external input is accomplished by two extra pumps installed at inlets to the feed tank (Fig. 2). Depending on the diluent or a solution being added to the system during the run, the following modes can be defined on the process:

- no addition of diluent, i.e. concentration mode (C);
- diluent flow rate equals the flow rate of permeate leaving the system, i.e. constant volume diafiltration mode (CVD);
- diluent flow rate is not equal to the flow rate of permeate leaving the system, i.e. variable volume diafiltration mode (VVD).

The switching between these modes can result in saving costs and time to achieve certain concentration of product and impurities as explained in Paulen et al. (2013).

3. LEARNING OBJECTIVES

In the education process at IAM, students enroll for several courses focused on system identification, control design, plant optimization, and overall automation of industrial systems. These courses are supplemented by laboratory exercises where students can test the theory in practice. To provide them with even higher freedom in practical experimentation, students enroll courses focused on individual or group practical projects that are held at our laboratories or even in the facilities of our industrial partners.