Chemical Engineering Research and Design xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

Chemical Engineering Research and Design

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

Modeling of a double effect evaporator: Bond graph approach

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ARTICLE INFO

Article history:
Received 25 April 2017
Received in revised form 3 November 2017
Accepted 4 July 2018
Available online xxx

Keywords:
Process
Double effect evaporator
Bond graph
Modeling
Simulation
Diagnosis

ABSTRACT

This paper deals with the modeling of a chemical engineering system, which is the double effect evaporator (DEE). The main physical phenomenon encountered in this system is the heat transfer during distillation and concentration process. The modeling of DEE is carried out using bond graph approach. It allows description of interdisciplinary systems involving energetic, thermodynamic, hydraulic and thermal phenomena. In this study a dynamical models for the different parts of the DEE system are established. Simulation data are presented and confronted to the experimental results. To supervise the DEE system, the bond graph model is used to obtain analytical redundancy relations (ARR). They allow detection and isolation of faults.

1. Introduction

Modeling and analysis of dynamic behavior of industrial processes needs acknowledgment of analytical expressions governing process physical laws. In literature, different modeling methods and tools are used such as software modeling tools for process engineering based on a stationary behaviors (Westerberg and Benjamin, 1985; Raman, 1986). Mathlab/Simulink libraries and Modelica modelling language are widely used in dynamic systems (Mathworks, 2004; Elmqvist et al., 1993; Wöllhaf et al., 1996). Object-oriented Dynamic Simulation Software Environment is used to model chemical processes for the simulation of their dynamic behavior, using fixed input/output causalities (Moyse et al., 1999). Aspen HYSYS software also allows modeling of chemical processes (Sunny et al., 2016; Lewis et al., 2010). Theses modeling softwares are based generally on a predefined model used just for simulation which means that the physical phenomena are not explicitly displayed to the user and derive symbolic state equations for non-linear systems (Ould Bouamama and Bouamama, 2003).

The bond graph approach has many advantages. The bond graph model is written with a unified representation language and obtained with a structure procedure. It conserves the physical meaning of parameters. Although with different physical domains, the model shows explicitly power flows and cause to effect relationships between all the elementary subsystems. The model leads to a graphical diagram allowing fast analyzing. Thus, to take into account a further phenomenon in an existing model, the latter is only extending without needing to rebuild the entire whole model. The model can also be rewritten to a Symantec language. A state space representation can easily be obtained and a reduced model can be deduced. The condition of the monitorability, observability and controllability can be graphically established and the configuration of sensors and actors can be discussed. Based on a state observer, a control low can designed even with non-measurable physical phenomena. The model can easily simulate a physical fault. The supervision and fault diagnosis and localization can be carried throw simple residues analyses. The bond graph approach was introduced for the first time in 1959 by Henry Paynter (Paynter, 1959, 1958). It

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https://doi.org/10.1016/j.cherd.2018.07.007

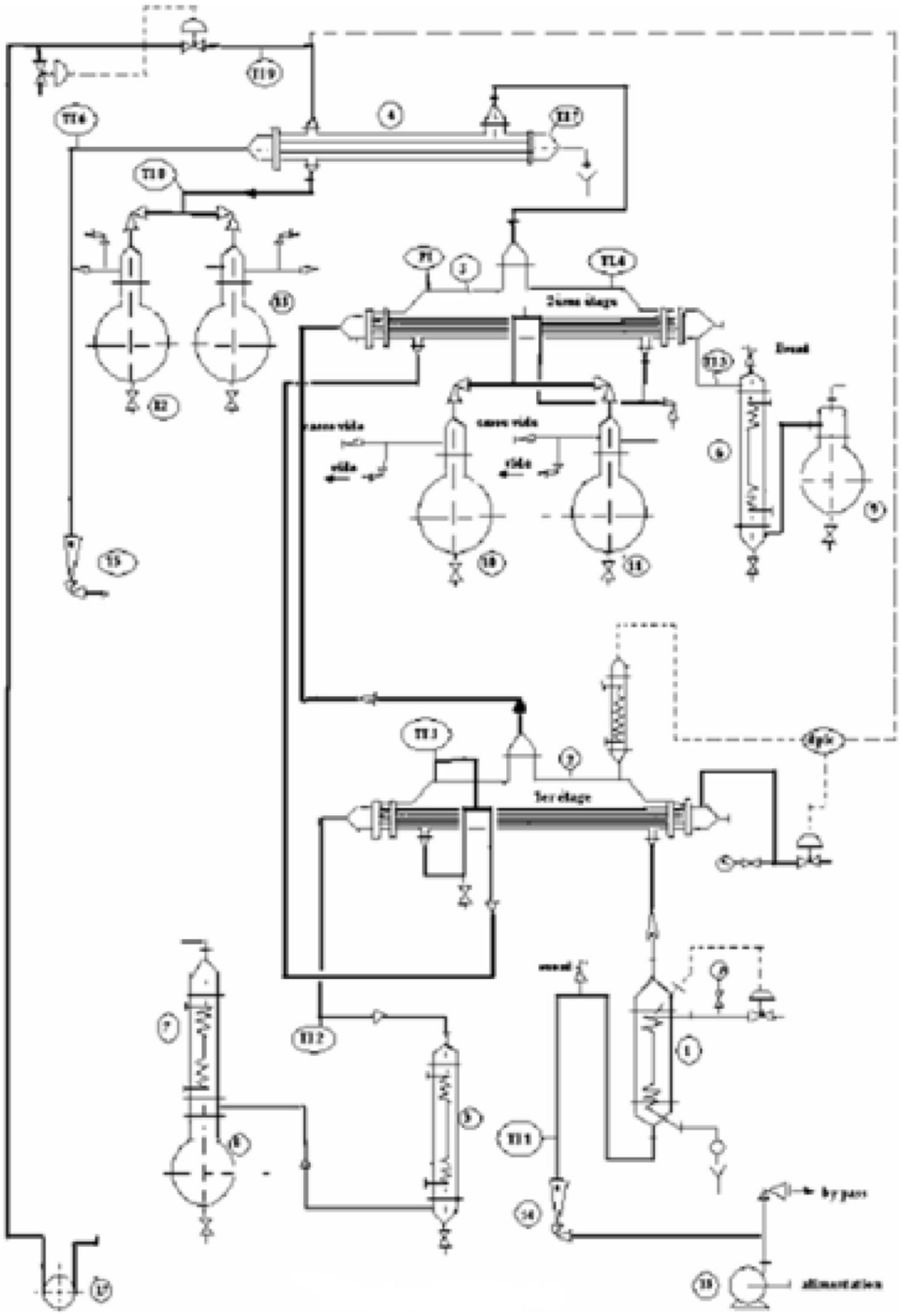

Fig. 1 – DEE pilot process.

was further more developed by Rosenberg, Thoma, Margolis and Karnopp (Karnopp, 1979; Margolis, 1977; Rosenberg and Karnopp, 1972; Thoma, 1975). Some other works deal with the definition of state variables, the representation, and equation formulation in bond graph language (Jr and Rosenberg, 1980; Breedveld, 1988; Karnopp, 1975, 1979). This approach was used to study linear systems in terms of energy variables and was expanded later to cover systems containing nonlinearities interconnection of different energetic fields (Ould Bouamama and Bouamama, 2003; Karnopp, 1981; Martens, 1973; Samanta and Mukherjee, 1985; Tagina et al., 1995). The complex interactions of many types of energy in thermodynamics, hydraulic, mechanic, electric and chemical systems can be represented by bond graph language (Balino et al., 2006; Ould-Bouamama et al., 2012; Couenne et al., 2006; Ould Bouamama et al., 2009; Mezghanni et al., 2007; Youping et al., 2011; Thoma and Bouamama, 2013; Cauffriez et al., 2016; Shekhar et al., 2017).

The purpose of this study is to model a double effect evaporator (DEE) using the bond graph approach. Then, physical analytical redundancy relations are established for fault detection and isolation.

2. Methods and materials

2.1. *Process description*

Evaporation is used to obtain a product with high added value such as distilled water or concentrated solution. The use of multiple effect evaporation is recommended to reduce energy consumption (Zhang et al., 2014). Only the energy used for the

Please cite this article in press as: Ben-Ali, S., Modeling of a double effect evaporator: Bond graph approach. Chem. Eng. Res. Des. (2018), https://doi.org/10.1016/j.cherd.2018.07.007