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DESIGN AND TESTING OF CONTROL SCHEMES WITH DYNAMIC SIMULATOR

NÁVRH ŘÍZENÍ V PROSTŘEDÍ UNIVERZÁLNÍHO SIMULAČNÍHO PROGRAMU

Abstract

The standard approach to the control systems design is based on "black box" models – first or second order systems, parameters of them are determined experimentally. The increasing performance of computers allows us to use rigorous dynamic models of unit operations that can perform material, energy and composition balances including an additional "accumulation" term which is differentiated with respect to time. In our contribution we intended to try an alternative approach to the control systems design that uses dynamic simulation in HYSYS. We appreciate the advantages of this procedure at teaching in particular, for the students giving preference to the illustrative control of a concrete apparatus or plant over the control of an abstract model. With the help of dynamic simulation, we have designed and test control strategy of heat exchanger network. HYSYS enable us to examine the dynamic response to system disturbances and optimize the tuning of controllers without difficulties.

Abstrakt

Obvyklý postup návrhu řídicích systémů je založen na modelech typu „černá skříňka" – soustavách prvního nebo druhého řádu, jejichž parametry se určí experimentálně. Rostoucí výkon počítačů usnadňuje používání rigorózních dynamických modelů, založených na bilancích hmoty, složek, energie a hybnosti včetně dodatečných akumulačních členů, které jsou diferencovány vzhledem k času. V našem příspěvku jsme se pokusili ukázat alternativní přístup k návrhu řídicích obvodů založený na použití dynamického simulátoru HYSYS. Tento postup má své přednosti zejména při výuce, neboť pro studenty je názornější řízení konkrétního zařízení než řízení abstraktního matematického modelu. Byl navržen a testován řídicí systém sítě výměníků tepla. HYSYS umožňuje snadné zkoumání odezvy systému na změny poruchových veličin a optimalizaci nastavení konstant regulátoru.

1 INTRODUCTION

One of the most important tasks in the analysis and design of control systems is the mathematical modeling of the controlled process. The two most common methods of this are the transfer-function approach and the state-equation approach [Kuo 1991]. These models are not based on material substance of the process, but, most frequently, parameters of the model are determined experimentally, we can classify these models as "black box" models. The increasing performance of computers allows us to use rigorous dynamic models of unit operations that can perform material, energy and composition balances including an additional "accumulation" term which is differentiated with respect to time. Numerical integration is used to determine the process behavior at distinct time

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steps. These models can be more accurate and need not expensive experiments. In our work we have used simulator HYSYS 3.2 Build 5029 [HYSYS 2004]. With dynamic simulation, we can design and test a variety of control strategies before choosing one that is suitable for implementation. We can examine the dynamic response to system disturbances and optimize the tuning of controllers. Particularly, the performance of difficult control loops, such as processes with large deadtime, variable gains, or highly interactive elements, can be improved significantly by first modeling them and then analyzing them.

2 PROBLEM STATEMENT

The heat exchanger network is shown in Figure 1 [Seider 1999]. Temperatures and heat capacity flow rates of input streams H1 (n-octane) and C1 and C4 (n-decane) are given (see Table 1). The goal of operation is to cool the hot stream H1 from 500 to 300 °F using cold streams C1 and C4 having feed temperatures of 300 and 200 °F. The corresponding target temperature of stream C4 is 400°F, the target temperature of stream C1 is 371.4 °F. Furthermore, the feed rate and temperature of the hot stream are considered to be disturbances. The aim of this work is to propose the control loops that secure achievement of target temperatures 400, resp. 300 °F of output streams H4, resp. C3.

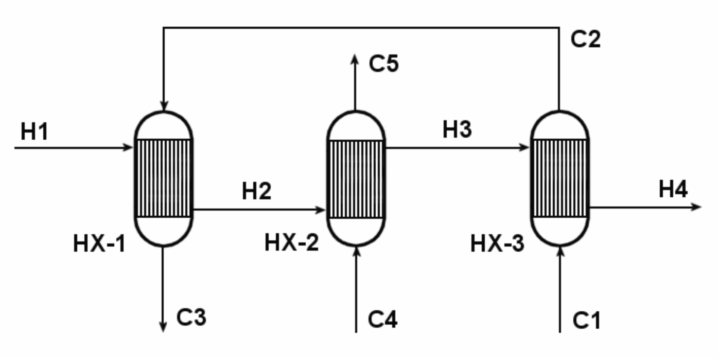

Fig. 1 Heat exchanger network

Tab. 1 Input data for heat exchanger network

Input streams		**H1**	**C1**	**C4**
temperature	[°F]	500	200	300
heat capacity flow rate	[10^6 BTU /hr/°F]	0.2	0.28	0.1
Output streams		**H4**	**C3**	**C5**
temperature	[°F]	300	400	371.4

3 STEADY STATE MODEL

It is possible to create a dynamic model directly in Dynamics mode. But it is also possible to build a dynamics case by first creating the case in Steady State mode. We are sure it is the best way for less experienced users. The transition to Dynamics mode is then made with some modifications to the flowsheet topology and stream specifications.

We built steady state model according to technological scheme in Fig. 1 and input data from Tab. 1. We used property package SRK (Soave-Redlich-Kwong). In the steady state mode pressure drop of all heat exchangers was assumed to be zero. For modeling of heat exchangers „Steady Stated Rating“ type of model was used that is suitable for a transition from steady state to Dynamics mode.

At standard simulators the inlet streams and the equipment parameters are specified, along with selected variables of the outlet streams (e.g. temperatures and pressures), and the unknown variables of the outlet streams (typically, the flow rates and compositions) are computed. When it is necessary to provide specifications for variables of outlet streams, control subroutines are provided to iteratively adjust the manipulated variables so as to achieve the desired specifications. In the HYSYS, this is accomplished by the ADJUST operation.

HYSYS differs from many of the alternative simulators in two main respects. First, it has facility for interactively interpreting commands, as they are entered one at a time, whereas most of the other flowsheet simulators require that a RUN button be pressed after new entries are completed. Whenever a stream variable is altered, the adjacent process unit is resimulated. Second, it has the unique feature that information propagates in both forward and reverse direction. This bidirectionality often makes iterative calculations and the use of ADJUST operation unnecessary. Bidirectional information flow in HYSYS makes possible to enter temperature of output stream and without any other disposal (e.g. use of ADJUST operation) molar flow of input stream is at once calculated so as to achieve the desired output temperature. When we entered three output temperatures, calculation after a few iterations unsuccessfully ended (crossing of temperatures). So we used combination of both approaches (see Fig.2). Simulation results are given in Table 2.

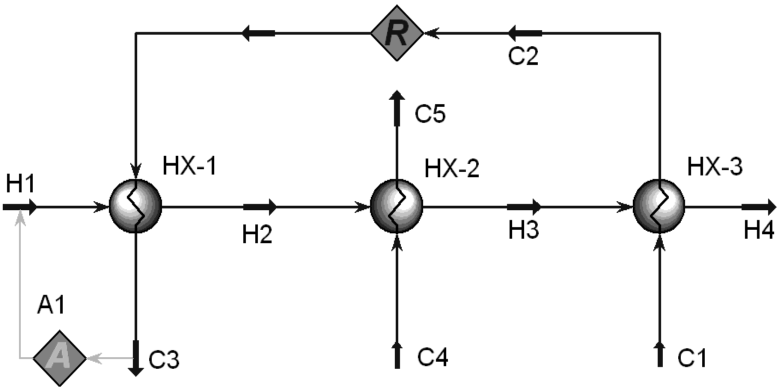

Fig. 2 Process flow diagram in Steady-State Mode

Tab. 2 Results of steady state simulation

Input streams in:		H1	C1	C4
$\mathbf{F_i}$ (desired)	[lbmol/hr]	1840	1210	3070
$\mathbf{F_i}$ (calculated)	[lbmol/hr]	1857	981	2169

4 CONTROL LOOP DESIGN

Remind us of the objective of the control system – to regulate three output temperatures $T_{H4,}$ $T_{C3},$ T_{C5}. The number of manipulated variables cannot exceed the number of degrees of freedom, which are two. The two manipulated variables are clearly the flow rates of the two cold streams F_{C1} and F_{C4}. Now it is necessary to select which two of three target temperatures $T_{H4},$ $T_{C3},$ T_{C5} to regulate. At the same time it is necessary to consider the controllability and resiliency of a process. Controllability analysis of our multiple-input, multiple output (MIMO) system is based on the method RGA (Relative Gain Array) [Bristol 1966, McAvoy 1983]. The RGA indicates that the diagonal pairings T_{C3}-F_{C1}, T_{C5}-F_{C4}, which appear in Figure 3, are recommended [Štýs 2004], while off-diagonal pairings have stability problems.

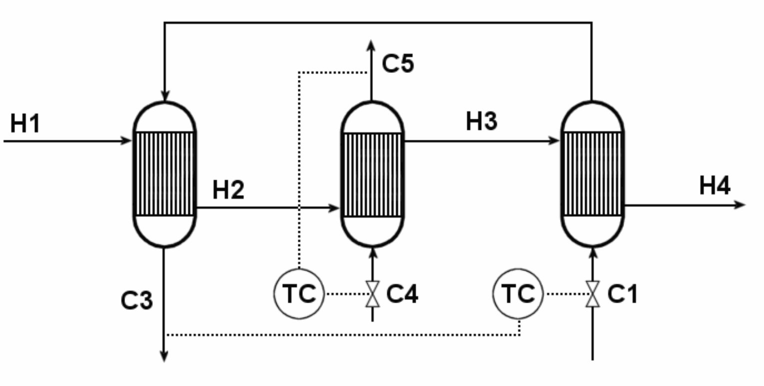

Fig. 3 Control system for the heat exchanger network

5 MOVING FROM STEADY STATE TO DYNAMICS

Before the transition from steady state to Dynamics mode occurs, the simulation flowsheet should be set up so that a realistic pressure difference is accounted for across the plant. It is necessary to specify one pressure-flow specification for each flowsheet boundary stream and for individual unit operations. Then all the unit operations in simulation are necessary to size; it means to define the vessel volumes and nominal liquid levels on the Dynamics page of each unit operation. The Adjust operation can be replaced by PID Controllers. The recycle operation is redundant in Dynamics mode. Resulting process flow diagram is shown in Figure 4. Before running dynamic simulation it is suitable to set parameters of integrator. Integrator allows us to control some of integration parameters that control mathematical solving of model such as the time step or the integration stop time.

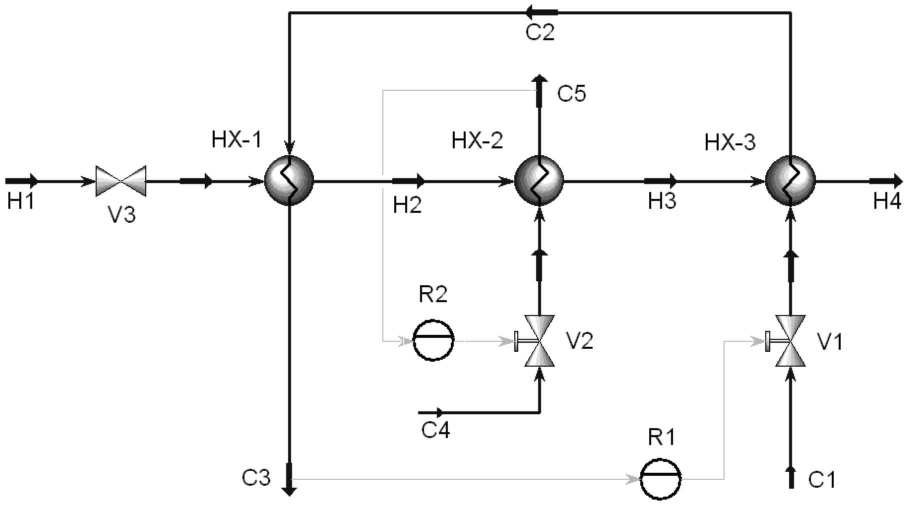

Fig. 4 Process flow diagram in Dynamic Mode

6 TUNING OF CONTROLLERS

The controller operation is the primary means of manipulating the model in dynamic mode. It adjusts a stream flow controller output to maintain a specific flowsheet variable process variable (*PV*) at a desired value set point (*SP*). The output is the percent opening of the control valve. The characteristic equation for a PID controller is given below:

$$OP(t) = OP_{ss} + K_c E(t) + \frac{K_c}{T_i} \int E(t)dt + K_c T_d \frac{dE(t)}{dt} \tag{1}$$

where:

OP(t) - controller output at time *t*,

OPss - steady state controller output (at zero error),

E(t) = SP(t) – PV(t) - error at time *t*.

The PID controller parameters can be computed using the Tyreus-Luyben [Tyreus 1992] modification of Ziegler-Nichols tuning rules:

$$K_C = K_U / 3.2 \text{ [\%/\%]} \tag{2}$$

$$\tau_i = 2.2\, P_U \text{ [min]} \tag{3}$$

where: P_U - the ultimate period and K_U - the ultimate gain.

HYSYS includes an algorithm for setting of controller parameters based on the procedure described above under the name ATV (auto tune variation technique) [Aström 1984]. With its help we have got proportional and integral gains (see Tab. 3).

Tab. 3 Tuneable parameters of PID controller

Controller		R1	R2
K_C	-	9.6	11.5
τ_i	[s]	0.39	0.12
τ_d	[s]	-	-

HYSYS enables us to investigate controllability and resiliency by introducing set-point changes and disturbances to the process. As an example, we have set two disturbances: 100 lbmole/hr increase in feed flow rate and 5 °F decrease in feed temperature. The responses to them are demonstrated in Fig. 5.

ACKNOWLEDGEMENT

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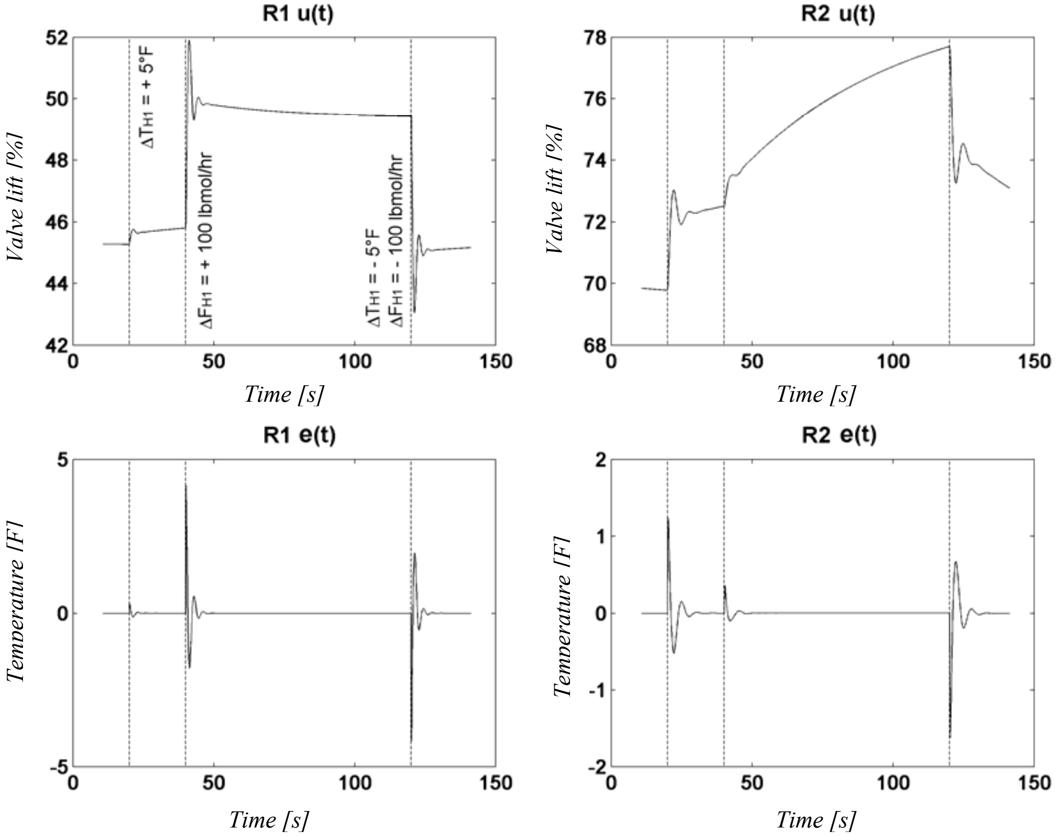

Fig. 5 Responses to 100 lbmole/hr increase in feed flow rate and 5 °F decrease in feed temperature

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