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Heat Recovery from Process to Process Exchanger by Using Bypass Control

Woranee Paengjuntuek, Chotirat Kiatpiriya, Harnpon Phungrassami and Phanida Saikhwan

Department of Chemical Engineering, Faculty of Engineering, Thammasat University,
Khlong Luang, Pathumthani, Thailand, 12120

Abstract: Energy integration in real and large process is considered important because a large amount of energy can be conserved with the use of energy integration. Hence, it is a common practice to install Feed-Effluent Heat Exchangers (FEHEs) around reactors and distillation columns to recover energy. The bypass control for process to process exchanger is common used for heat recovery within a process and it is essential to design a control strategy for process associate with energy integration. However, the control performance will be degraded in real applications as the existence of external disturbances. Thus, the dynamic responses of the bypass location and control point under disturbances should be considered. In this work, Hydrodealkylation (HDA) process of toluene to benzene simulated by HYSYS simulator is chosen as a case study. The four alternatives of the bypass location and control point are introduced to the FEHE.

Key words: Bypass control . Feed-effluent heat exchanger . Hydrodealkylation process

INTRODUCTION

Chemical process composed of many interconnected units can be divided into two main sections: reaction and separation. In the reaction section, the interconnected units are composed of several units such as reactors, heaters, coolers, heat exchanger and furnaces. In the separation section, units such as separators, extractions, evaporations and distillations are used. Although chemical process is complex, significant efforts have been made to reduce the amount of energy used in processes [1]; the great improvement in the thermal efficiency of the process can be made by recycling much of the energy needed for heating and cooling process streams [2].

Most industrial processes contain a complex flowsheet with several recycle streams, energy integration and many different unit operations. By introducing recycle streams and energy integration into the process, the economic of the process can be improved. However, the recycle streams and energy integration introduce a feedback of material and energy among units upstream and downstream. Therefore, strategies for plantwide control are required to operate an entire plant safely and achieve its design objectives. Among chemical plants, hydrodealkylation (HDA) process of toluene to benzene is widely used as a case study to analyze the dynamic behavior of proposed control design structures. In addition, the HDA process is a complex chemical process that creates disturbance propagation and the complicated system dynamic behavior. Many researches have developed a heat exchanger network for HDA process [4]. For example, Terrill and Douglas [5] developed a heat exchanger network for HDA process. The temperature-enthalpy (T-H) diagram was considered and obtained six alternative heat exchanger networks, all of which had close to maximum energy recovery. Quin *et al*. [6] presented a rigorous model for the HDA process, which is developed by the commercial software, HYSYS.PLANT. Control Configuration Design (CCD) method was selected for application to the process. The results shown that the CCD method successfully yields workable base-level regulatory control structures. Polypaisansang [7] designed resilient network for the HDA process. Six alternatives were redesigned to be the resiliency networks for maintain target temperature and also reduced maximum energy recovery.

Because energy conservation has always been important in process design and a number of streams must be heated and other streams must be cooled in any process flowsheets, it is common practice to install feed-effluent heat exchangers (FEHEs) around reactors and distillation columns. For instance, the controllability of a complex heat-integrated reactor has been studied by Yih and Yu [8]. The ultimate effectiveness parameter was defined to indicate the amount of heat that can be recovered via a Feed-Effluent Heat Exchanger (FEHE) before the overall open-loop system becomes unstable. First, a systematic

Corresponding Author: Dr. Woranee Paengjuntuek, Department of Chemical Engineering, Faculty of Engineering, Thammasat University, Khlong Luang, Pathumthani, Thailand, 12120

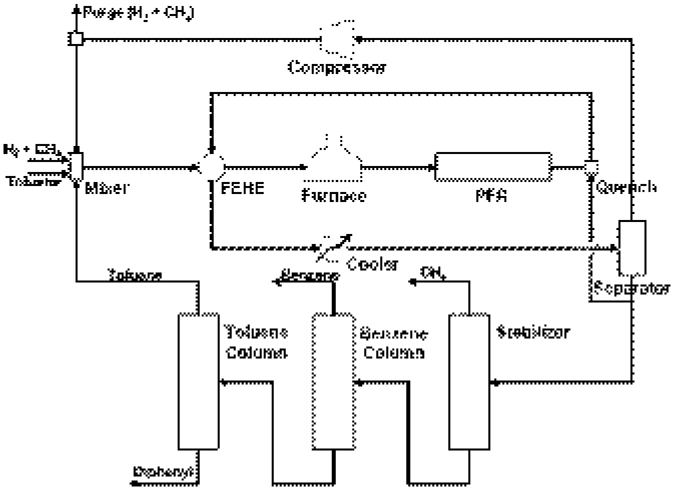


Fig. 1: Hydrodealkylation of toluene process flowsheet

approach is proposed to model the reactor. Then the controllability of a particular flowsheet can be evaluated on the basis of the stability margin of design. With the evaluated controllability, implications for design are further explored. Since the loss of controllability comes from the positive feedback loop, several design parameters are studied and design heuristics are proposed to improve the controllability of heat-integration schemes. Two examples, a simple two-FEHE example and HDA example, were used to assess the controllability of different designs. The results shown that, some of the complex heat-integrated reactor design alternatives were indeed more controllable than the simpler schemes. Shih and Cheng [9] analyzed the tradeoff between steady-state economics and dynamic controllability for heat-integrated recycle plants. Results are shown that the steady-state controllability deteriorated gradually as the degree of heat integration increases. However, if the recycle plant is optimally designed, acceptable turndown ratio is observed and little tradeoff between steady-state economics and dynamic operability may result. The results revealed that improved control can be achieved for well-designed heat-integrated recycle plants. More importantly, better performance is achieved with up to 40% energy saving and close to 20% saving in total annual cost.

In this work, the hydrodealkylation of tolune (HDA) process proposed by Douglas [3] is chosen as a case study. A bypass control of process-to-process (P/P) exchangers is proposed for heat recovery within the process. The two exit temperatures can be controlled by manipulating the two inlet flow rates. As the existence of external disturbances, the robust bypass control strategy has been studied. The process dynamic behavior is studied by using HYSYS simulator.

HYDRODEALKYLATION PROCESS

The flowsheet of HDA process is shown in Fig. 1. According to the figure, this process can be separated into two parts: (i) the reaction part containing reactor, separator, heat exchanger (FEHE) and gas recycle and (ii) the separation part that includes the three distillation columns. The reaction part is only considered in this work. Raw materials, toluene and hydrogen, are converted into the benzene product, with methane and diphenyl produced as by-product. The reactions are:

$$\text{Toluene} + H_2 \rightarrow \text{Benzene} + CH_4$$
$$2\ \text{Benzene} \leftrightarrow \text{Diphenyl} + H_2$$

The kinetic rate expressions (lbmol/(min.ft^3)) are functions of the partial pressure of toluene (p_T), hydrogen (p_H), benzene (p_B) and diphenyl (p_D).

$$r_1 = 3.6858\times10^6 \exp(-25616/T)\, p_T\, p_H^{1/2}$$
$$r_2 = 5.987\times10^4 \exp(-25616/T) - 2.553 \times10^5 \exp(-25616/T)\, p_D\, p_H$$

The heats of reaction for r_1 and r_2 are -21500 Btu/lbmol of toluene and 0 Btu/lbmol of toluene, respectively [3].

The reaction section of the HDA process is simulated by HYSYS simulator as shown in Fig. 2. The effluent from the adiabatic reactor is quenched with liquid from the separator. This quenched stream is the hot-side feed to the process-to-process heat exchanger, where the cold stream is the reactor feed stream prior to the furnace. The reactor effluent is then cooled with cooling water and the vapor (hydrogen, methane) and liquid (benzene, toluene, diphenyl) are separated. The vapor stream from the separator is split and the

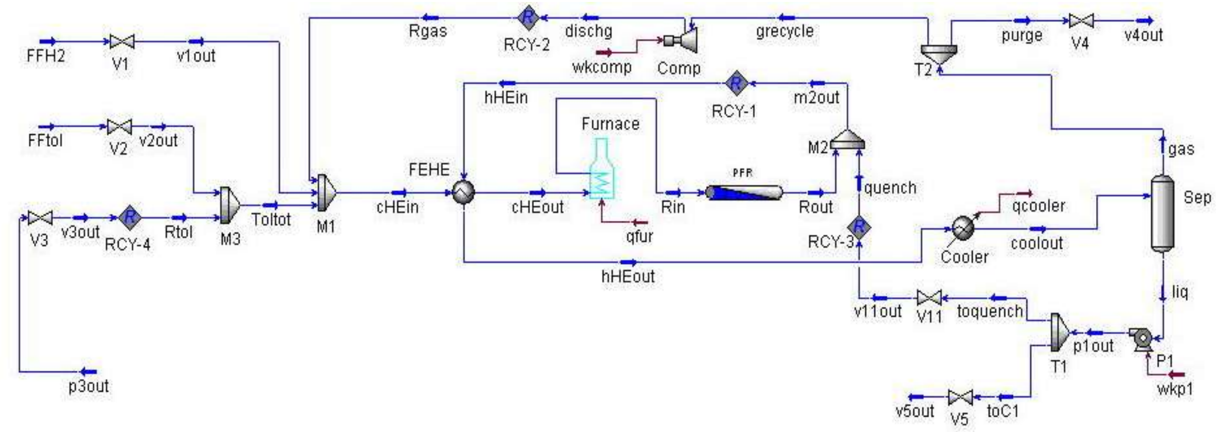
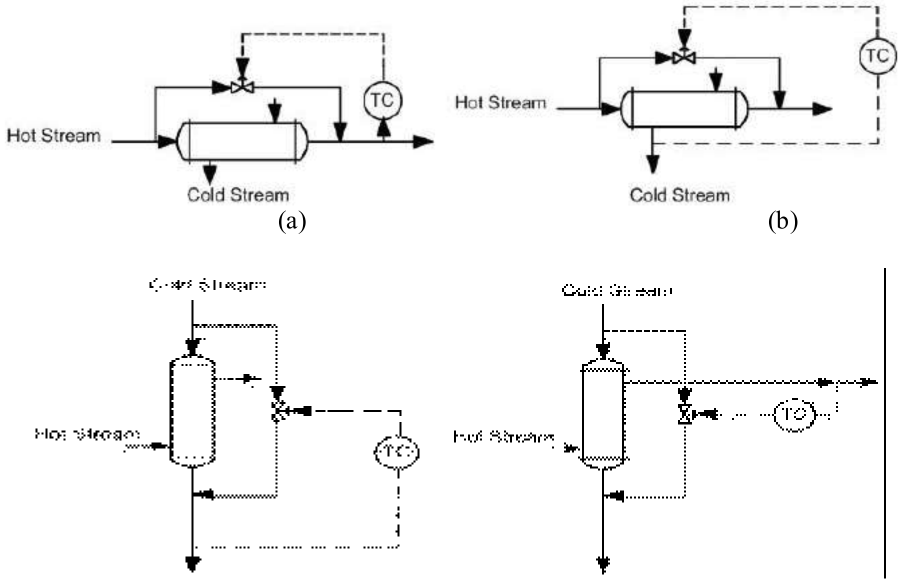


Fig. 2: Flowsheet of HDA reaction section by HYSYS.PLANT



(a) (b)

(c) (d)

Fig. 3: Bypass controls of process-to-process heat exchanger. (a) Controlling and bypassing hot stream; (b) controlling cold stream and bypassing hot stream; (c) controlling and bypassing cold stream; (d) controlling hot stream and bypassing cold stream

remainder is sent to the compressor for recycle back to the reactor. The component physical data for the HDA process were obtained from Lyuben *et al*. [2].

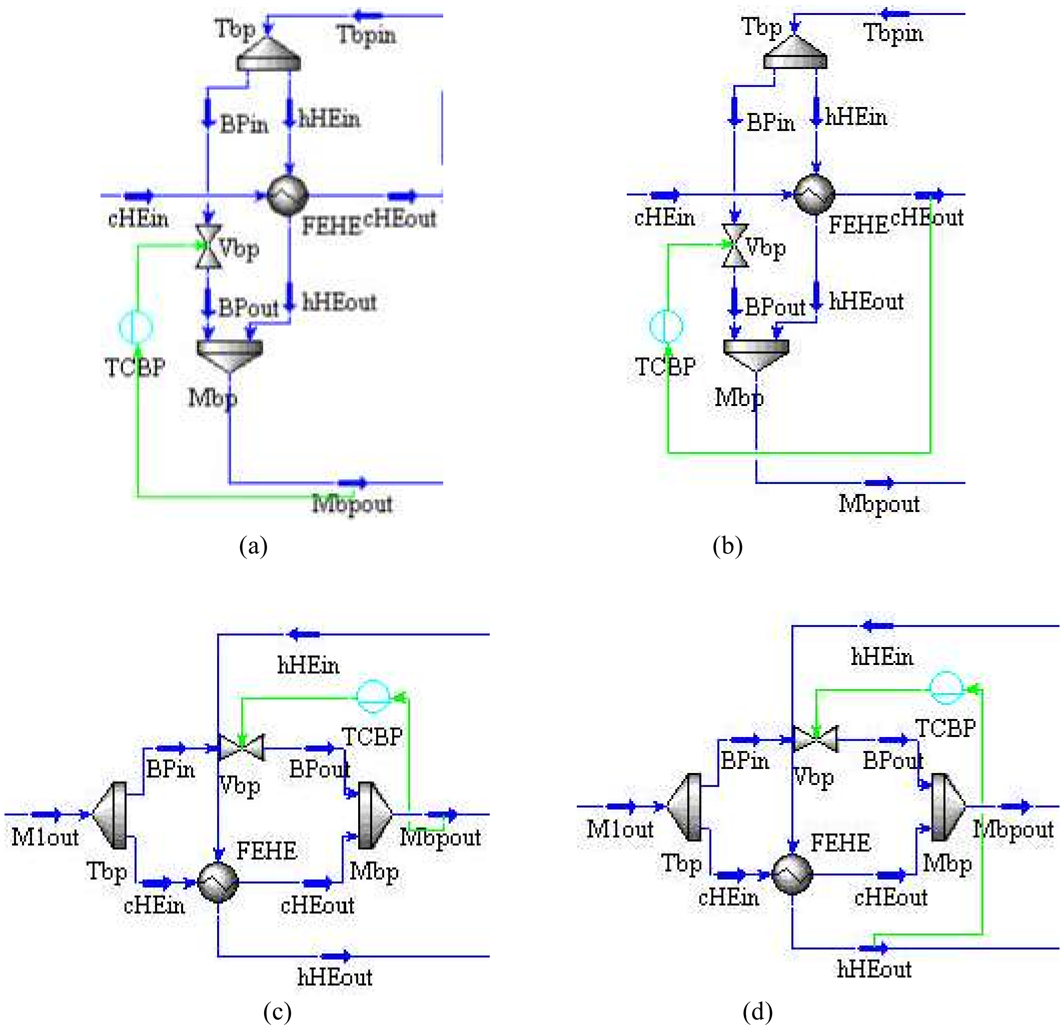
BYPASS CONTROL

Among a number of techniques for heat recovery within a process, the use of bypass control for process-to-process exchanger is common. There are several choices of the bypass location and the control point as shown in Fig. 3. However, in real applications the control performance may be degraded due to the existence of disturbances. For this reason, the dynamic responses of four alternatives of the bypass location and control point under external disturbances have been studied.

SIMULATION RESULTS

In order to evaluate the dynamic behaviors of the bypass control of process-to-process heat exchangers in HDA process, disturbance loads of cold stream (reactor feed stream) and hot stream (reactor product stream) have been studied. Figure 4 shows the simulated FEHE of HDA process by HYSYS.PLANT.

The disturbance load of cold stream (reactor feed stream): When the load of cold stream in terms of the



(a) (b)

(c) (d)

Fig. 4: Bypass controls of process-to-process heat exchanger (a) Controlling and bypassing hot stream (BP1); (b) controlling cold stream and bypassing hot stream (BP2); (c) controlling and bypassing cold stream (BP3); (d) controlling hot stream and bypassing cold stream (BP4)

temperature of fresh feed toluene (T_{cHEin}) is changed, the reactor inlet and outlet temperatures are slightly oscillated (Fig. 5). Compare all the bypass locations and control points, the cold stream outlet FEHE (T_{cHEout}) oscillates widely in case of bypassing and controlling at hot stream. The response affects the reactor inlet temperature ($T_{Reactor,in}$), reactor outlet temperature ($T_{Reactor,out}$) and hot inlet temperature of FEHE (T_{hHEin}). Moreover, the results are shown that controlling and bypassing cold stream (BP3) and bypassing hot stream and controlling cold stream (BP2) are more robust than other structures.

The disturbance load of hot stream (reactor product stream): The simulation results are shown in Fig. 6. When the hot inlet temperature of FEHE (T_{hHEin}) is changed, the hot and cold outlet temperatures are widely oscillated resulted in the swing of reactor inlet and outlet temperatures ($T_{Reactor,in}$ and $T_{Reactor,out}$) and separator temperature ($T_{separator}$). In addition, the response from controlling hot stream (BP1 and BP4) oscillates widely when compared with other alternatives.

The dynamic performance of four alternatives of the bypass location and control point are evaluated by using the integral absolute error (IAE) method. The results are shown in Table 1 and 2; when hot stream load is changed, the bypassing and controlling at cold stream (BP3) gives the small summation of IAE value, hence is more robust. In addition, when the cold stream load is changed, this case of bypassing at hot stream and controlling at cold stream gives the small summation of IAE value.

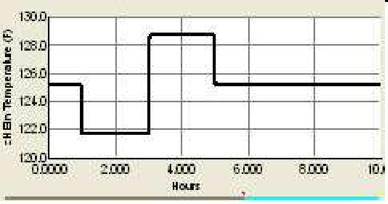
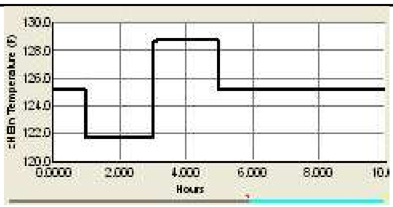
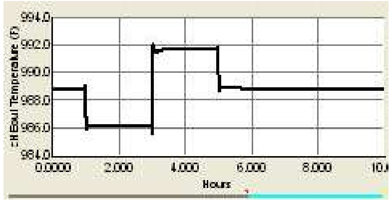
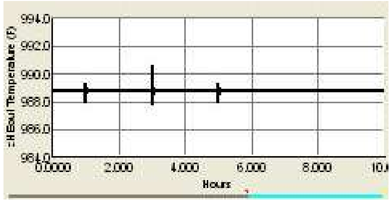
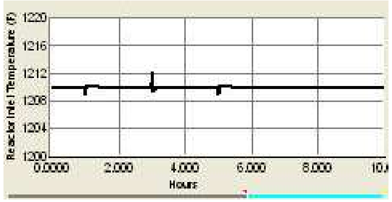
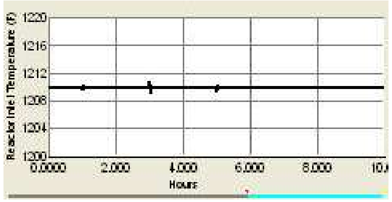
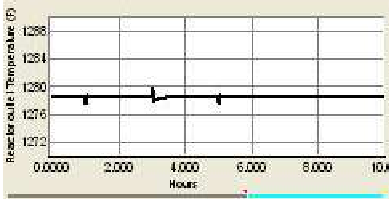
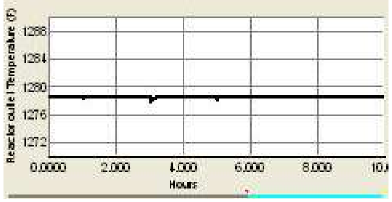
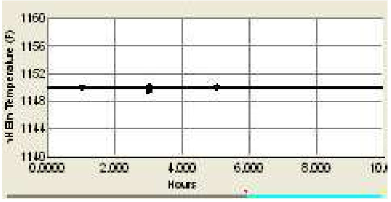
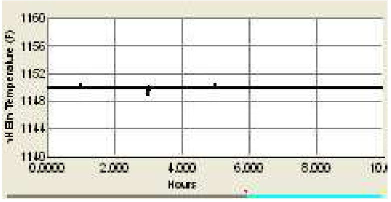
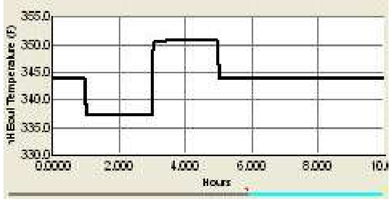
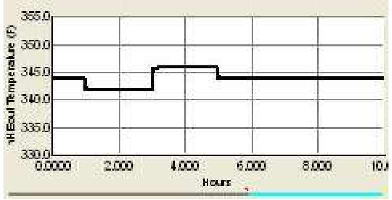
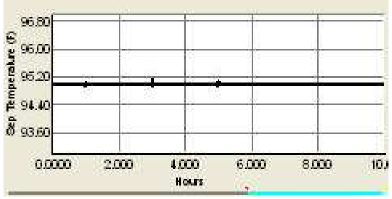
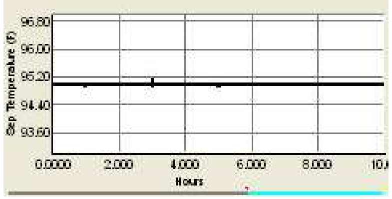
	Bypassing hot stream	
	Controlling hot stream (BP1)	Controlling cold stream (BP2)
T_{cHEin}		
T_{cHEout}		
$T_{reactor, in}$		
$T_{reactor, out}$		
T_{hHEin}		
T_{hHEout}		
$T_{separator}$		

Fig. 5: Continued

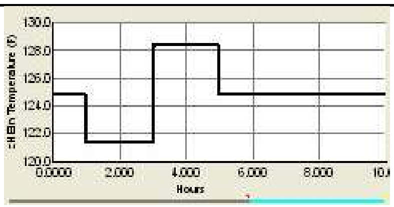
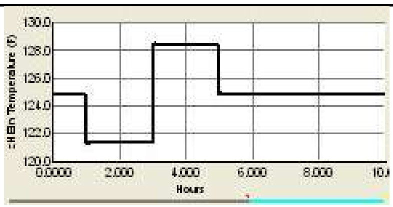
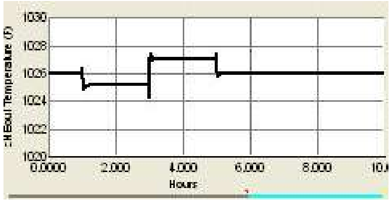
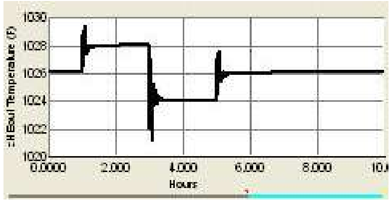
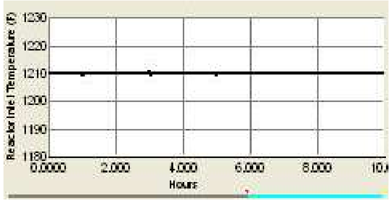
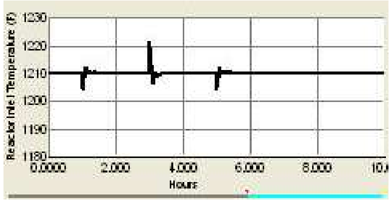
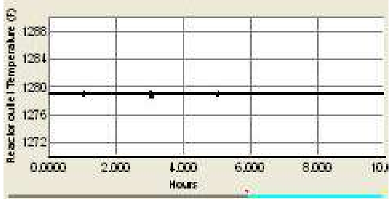
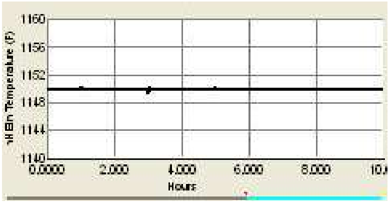
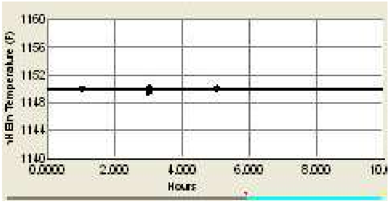
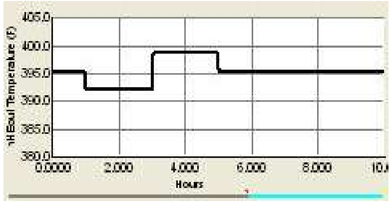
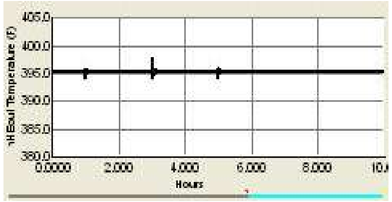
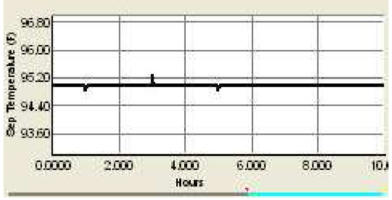
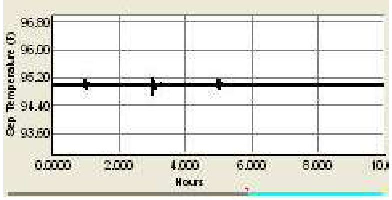
	Bypassing cold stream	
	Controlling cold stream (BP3)	Controlling hot stream (BP4)
T_{cHEin}		
T_{cHEout}		
$T_{reactor, in}$		
$T_{reactor, out}$		
T_{hHEin}		
T_{hHEout}		
$T_{separator}$		

Fig. 5: Dynamic responses of four alternatives of bypass control under changing the load of cold stream

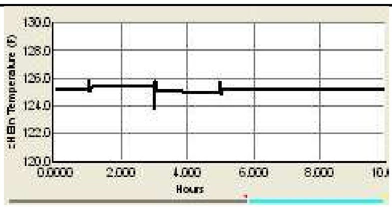
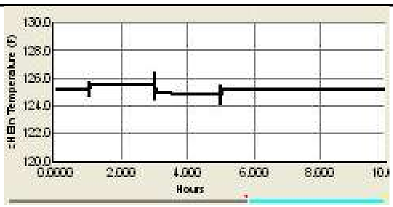
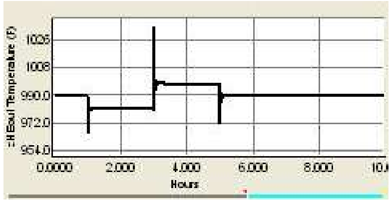
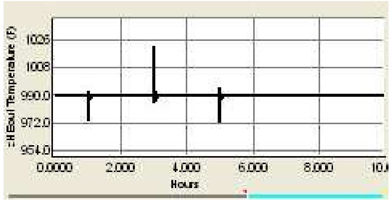
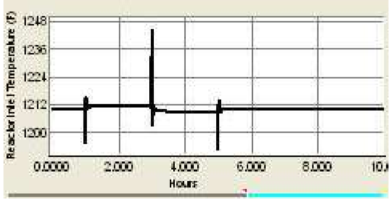
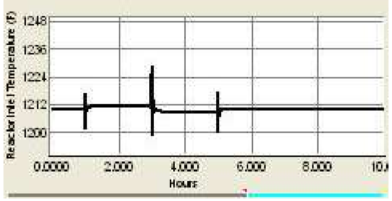
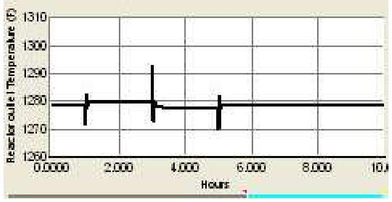
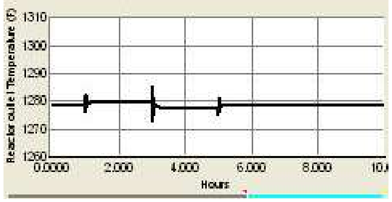
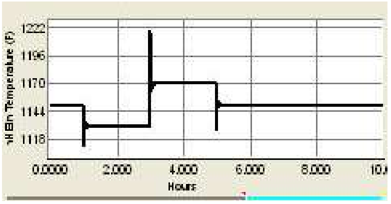
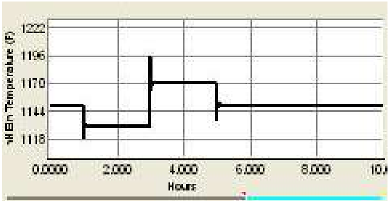
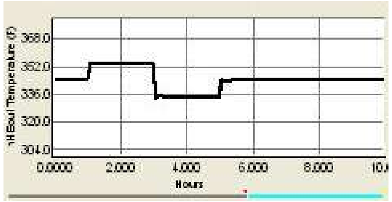
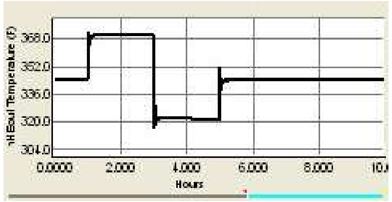
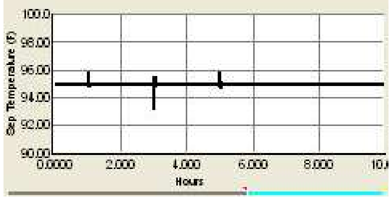
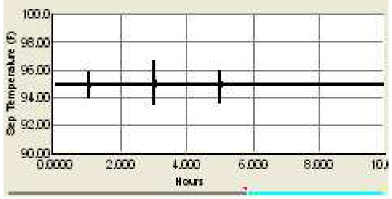
	Bypassing hot stream	
	Controlling hot stream (BP1)	Controlling cold stream (BP2)
T_{cHEin}		
T_{cHEout}		
$T_{reactor, in}$		
$T_{reactor, out}$		
T_{hHEin}		
T_{hHEout}		
$T_{separator}$		

Fig. 6: Continued

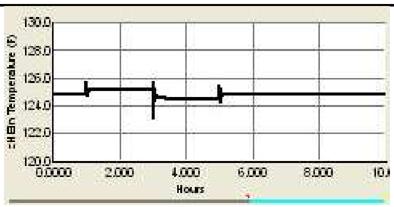
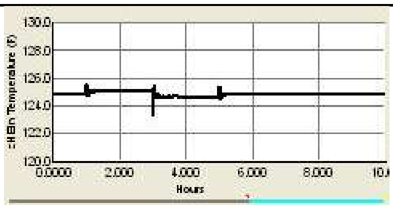
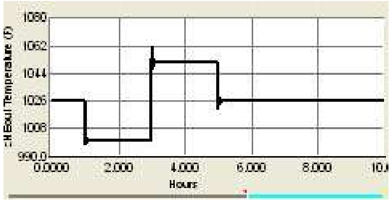
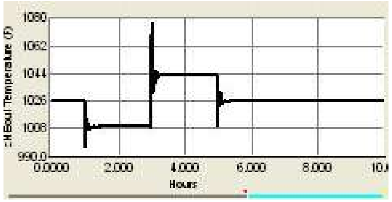
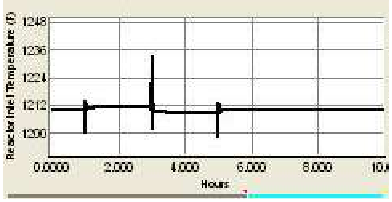
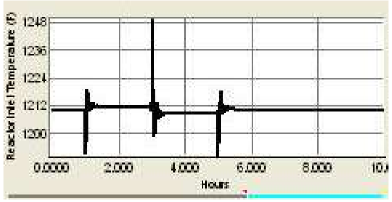
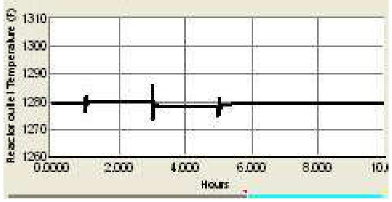
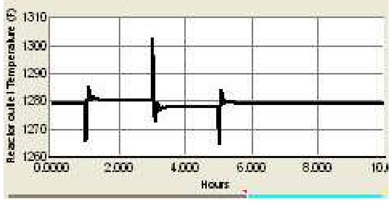
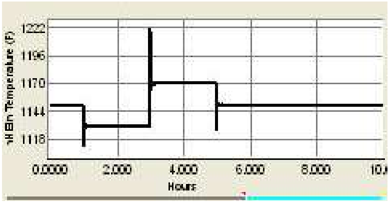
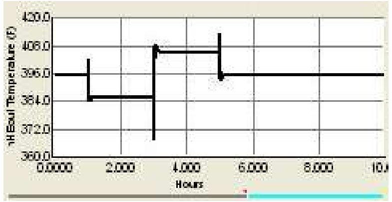
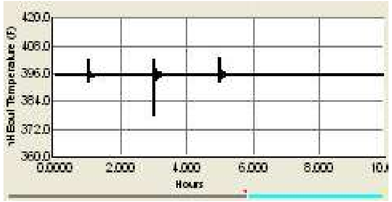
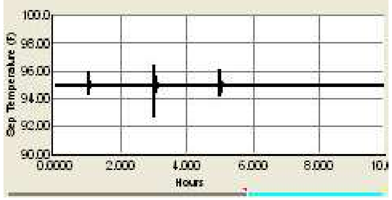
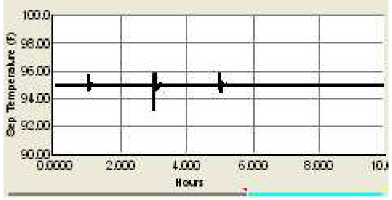
	Bypassing cold stream	
	Controlling cold stream (BP3)	Controlling hot stream (BP4)
T_{cHEin}		
T_{cHEout}		
$T_{reactor, in}$		
$T_{reactor, out}$		
T_{hHEin}		
T_{hHEout}		
$T_{separator}$		

Fig. 6: Dynamic responses of four alternatives of bypass control under changing the load of hot stream

Table 1: The process performance in terms of integral absolute value (IAE) under disturbance load of cold stream

	Bypassing hot stream		Bypassing cold stream	
	Controlling hot stream (BP1)	Controlling cold stream (BP2)	Controlling hot stream (BP3)	Controlling cold stream (BP4)
T_{CBP}	4.2578	2.2493	2.6070	6.2963
T_{hHEin}	2.8075	1.1925	1.1570	12.9140
$T_{reactor,\ in}$	7.5950	1.7525	2.1260	53.7860
$T_{reactor,\ out}$	13.7080	2.8792	3.1880	75.6400
$T_{separator}$	0.3391	0.3683	0.8100	1.4215
$IAE_{sumation}$	28.7074	8.4418	9.8880	150.0578

Table 2: The process performance in terms of integral absolute value (IAE) under disturbance load of hot stream

	Bypassing hot stream		Bypassing cold stream	
	Controlling hot stream (BP1)	Controlling cold stream (BP2)	Controlling hot stream (BP3)	Controlling cold stream (BP4)
T_{CBP}	6.1947	42.0470	46.5800	22.1180
T_{hHEin}	79.0090	72.5630	70.5250	100.8600
$T_{reactor,\ in}$	44.9940	18.8350	23.4210	169.5100
$T_{reactor,\ out}$	302.4000	277.6400	265.5300	445.7900
$T_{separator}$	3.7984	4.0343	6.7750	6.5776
$IAE_{sumation}$	436.3961	415.1193	412.8310	744.8556

CONCLUSION

Since energy conservation has always been important in process design, the bypass control for process to process exchanger is developed for heat recovery. Four bypass locations and control points are investigated for HDA process. The simulation results show that under cold stream load disturbance the bypassing at hot stream and controlling at cold stream (BP2) and the bypassing and controlling at cold stream (BP3) are more robust than other alternatives as it gives the small summation of IAE value. The bypassing and controlling at cold stream (BP3) is also the most robust under hot stream load disturbance.

REFERENCES

1. Kim, J., J. Kim, J. Kim, C. Yoo and I. Moon, 2009. A Simultaneous Optimization Approach for the Design of Wastewater and Heat Exchanger Networks Based on Cost Estimation. Journal of Cleaner Production, 17: 162-171.
2. Luyben, W., B. Tyreus and M. Luyben, 1999. Plantwide Process Control. Singapore: McGraw Hill.
3. Douglas, J., 1988. Conceptual Design of Chemical Processes. New York: McGraw Hill.
4. Antonio, A., 2007. Study on Plantwide Control. Ph.D Thesis, Department of Chemical Engineering. Norwegian University of Science and Technology.
5. Terrill, L. and M. Douglas, 1987. Heat-exchanger Network Analysis. 1. Optimization, Industrial and Engineering Chemistry Research, 26: 685-691.
6. Qiu, F., P. Rangaiah and R. Krishnaswamy, 2003. Application of a Plant-wide Control Design to the HDA Process. Computer and Chemical Engineering Journal, 27: 73-94.
7. Ploypaisansang, A., 2003. Resilient heat exchanger network design of hydrodealkylation process. M. Eng. Thesis, Chemical Engineering, Chulalongkorn University.
8. Yih, H. and C. Cheng, 2003. Design and Control of Heat-integrated Reactors. Industrial and Engineering Chemistry Research, 42: 2791-2808.
9. Shih, W. and C. Cheng, 2004. Design and Control for Recycle Plants with Heat-integrated Separators. Chemical Engineering Science, 59: 53-70.