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RESEARCH ARTICLE

Investigation of controllability of systems with recycle – a case-study

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Abstract

In this case-study the effects of the recycles in an ethylbenzene producing system are investigated, simulated and analysed. The studied steady-state technology contains of two recycle streams, hence serves as a good model system for our study. Recirculation is often used in chemical technologies, especially in separating techniques. Being a positive feedback, it is expected that the application of recycle streams may result in controllability problems. In this study composition control is dealt with, exclusively. Based on our simulation calculations, it is shown that applying recirculation in the studied technology can effectively lead to instability if no appropriate process control system is installed. A method is shown that enables the selection of the appropriate process control structure, which ensures constant product purity. The example systems behaviour is studied with and without recirculation in both steady-state and dynamic domains. All the reasonable composition control structures are simulated and compared. Based on the steady-state results, controllability indices are calculated for the distillation columns and the best control structures are predicted. The steady-state investigations are confirmed later by dynamic simulations, and finally the best composition control scheme is selected for the entire system – based on the controllability indices.

Keywords

Recycle · control · feedback · ethylbenzene · case-study · snowball effect · separation process

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1 Introduction

Nowadays, the cost-side approach and the tendency to increase the efficiency of production processes have become the most important viewpoints, especially in cases where chemicals are produced on a large scale. Separation of reactor effluents is most commonly followed by recirculation of the unreacted raw materials; in fact most steady-state synthesis or separation technologies contain recycle streams.

Recirculation in general as a process-design element is worth investigating from several points of view, especially from controllability aspects, because every recycle stream generates a positive feedback in the system, which may escalate the effect of disturbances or may lead to instability (Fig. 1).

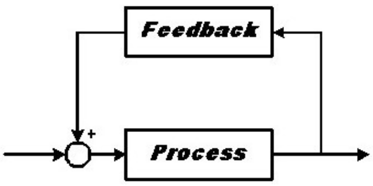

Fig. 1. Scheme of the recycle

Recycle streams are usually essential parts of the technologies, therefore cannot be removed. The harmful effects of recirculations are to be handled using process control loops that keep the process variables at their prescribed steady-state values, even if disturbances are present.

In this paper a case-study is presented. The effects of the recycle in an ethylbenzene producing system are investigated, simulated and analysed. The studied steady-state technology contains two recycle streams, hence serves as a good model system for our study. In this study composition control is dealt with, exclusively. The general aim of our work is to find the best composition control scheme for the selected industrial process.

2 Investigated Process

An ethylbenzene producing process is selected as a model system for our controllability investigations related with recycle. The scheme of the steady-state system can be seen in Fig. 2. The technology is taken from Ullmann's Encyclopedia of Industrial Chemistry [3]. This is the most widespread technology for the production of high purity ethylbenzene. As shown in Fig. 2, the technology consists of a continuously stirred tank reactor and of a separation system.

Ethylbenzene is produced starting from ethylene and benzene as raw materials. Liquid benzene and gaseous ethylene are fed into an isotherm, continuously stirred tank reactor (CSTR) where liquid phase reactions take place at 180 ^{0}C and at 10 bar pressure. $AlCl_3$ (aluminium-trichloride) is used as catalyst. Reactions that take place in the reactor block, are shown in Fig. 3. All of the alkylation reactions are reversible. Reaction rate equations and Arrhenius constants for the second order alkylation reactions and for the first order decompositions can also be found in Ullmann's Encyclopedia of Industrial Chemistry [3]. During the simulations ideal mixing can be assumed in the reactor.

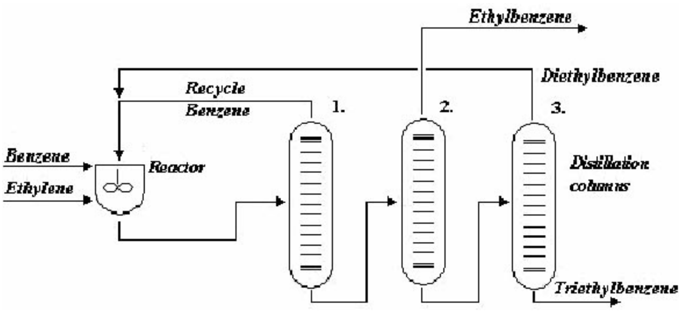

Fig. 2. The investigated process

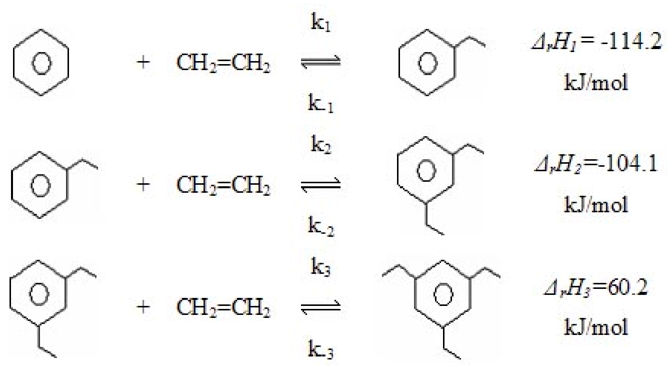

Fig. 3. Reactions in the continuously stirred tank reactor

The reactor effluent consists of unreacted benzene, ethylbenzene, diethylbenzene and triethylbenzene that are to be separated in the separation system. The desired main product of the reaction is ethylbenzene. From the point of view of vapour-liquid equilibrium, the reactor effluent is an ideal mixture, therefore, the four components above are separated in three distillation columns connected in direct sequence. As shown in Fig. 2, the unreacted benzene is recovered in the top of the first column and ethylbenzene (the main product) is withdrawn from the top of the second column. The second distillation column is called "ethylbenzene column", and produces 99.9 mole % pure ethylbenzene in the top, which is often used for polystyrene production. The third column separates the diethylbenzenes from the tri- and polyethylbenzenes. Tri- and polyethylbenzenes are byproducts that cannot be utilized any further.

As Fig. 2 shows, the process contains two recycle streams. Untreated benzene from the top of column 1 is recycled to the reactor – this is the first recycle stream. To maximize ethylbenzene formation, also the diethylbenzene from the top of the third column is recycled to the reactor, because from diethylbenzene and from benzene ethylbenzene can be produced again in a transalkylation reaction - this is the reason for the second recycle [3].

3 Control Structures and Problems

In order to guarantee the prescribed steady-state value of the compositions of the key components composition control loops are to be installed. The structure of the control loops are to be designed in a way that no interaction among them should occur if possible. In our case this can be achieved. Selection of the appropriate composition control loops for the distillation columns can be carried out separately. Setting up of a single control loop requires the pairing of a controlled and a manipulated variable. The applicable manipulated variables in case of distillation columns are shown in Table 1.

Tab. 1. Possible manipulated variables in case of the distillation columns

Manipulated variable	Name
D (in the top)	Flow rate of the distillate
L (in the top)	Flow rate of the reflux
R (in the top)	Reflux ratio
Q (in the bottom)	Heat duty of the reboiler
B (in the bottom)	Flow rate of the bottom
BR (in the bottom)	Boil-up ratio

Selection of the controlled variables of the distillation columns is straightforward. Composition control loops are to be set up, and in each column the two key-components (between which the current separation is to make a cut) are known. The controlled variables of the distillation columns are the concentrations of the key components in the head and in the bottom, as shown in Table 2.

Tab. 2. Controlled composition variables of the distillation columns

	Controlled variable
First column	x(B) - Composition of benzene (in the head) x(EB) - Composition of ethylbenzene (in the bottom)
Second column	x(EB) - Composition of ethylbenzene (in the head) x(DEB) - Composition of diethylbenzene (in the bottom)
Third column	x(DEB) - Composition of diethylbenzene (in the head) x(TEB) - Composition of triethylbenzene (in the bottom)

Control loops are to be set up because different disturbances may offset the values of the prescribed steady state compositions. When a pump does not work properly, or the pressure changes in the pipes, it can cause a feed flow rate disturbance – and/or feed composition disturbance, if just one of the feed streams changes. This disturbance can change both the composition and the flow rate of the distillate and the bottom product, hence the feed flow rate and composition of the next column is also changed. Resulting from this, both the feed flow rate disturbance and the composition disturbance are to be investigated. Table 3 shows the disturbances that are taken into consideration throughout this study.

Tab. 3. Disturbances

Disturbance
Feed flow rate
Feed composition

In this article composition control is dealt with, exclusively. It is assumed that appropriate level and pressure control loops are installed. If there is no control in the head of the column 1 and, as a consequence, the flow rate of the benzene recycle stream is not stable then the so-called snowball-effect occurs [2] and the system becomes unstable. This means that the effect of a feed-disturbance results in an auto-amplifying change in the flow rate of the distillate stream of column 1; and at the same time, a big decrease in the purity of the bottom-product appears (Fig. 4). Resulting from this, benzene appears both in the bottom of the first column and in the top of the second column, hence separation of ethylbenzene in the second column cannot be carried out as it is required (99.9 mole % purity). The snowball-effect can be eliminated by installing a proper flow rate-, or composition control onto column 1, throughout our simulation calculations such a controller has been applied.

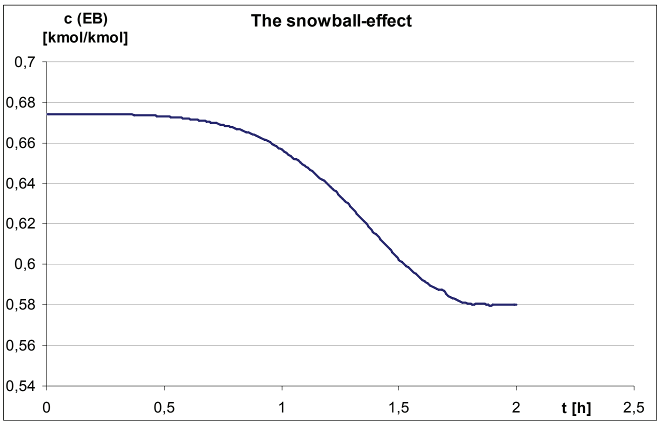

Fig. 4. Concentration change due to the "snow ball" effect. Drastic ethylbenzene composition change in the bottom of the first column occurs when there is not any controller installed at the top of column 1.

4 Aims of the work

The main goal of the work is to find the best composition control scheme for the entire ethylbenzene producing system. This goal is equivalent to finding the best composition control scheme for each distillation column, since the control loops of the columns do not interact.

To reach this goal, the responses of the recycle-free and full systems to feed flow rate and composition disturbances are studied first using simulation tools. Using the simulation results, controllability indices can be calculated for each distillation column and the best control structures (appropriate pairings of manipulated and controlled variables) can be predicted based on the calculated indices. The performance of the obtained control structures must be confirmed later by dynamic simulations. Tuning of the control loops is carried out, based on the open-loop dynamic investigations.

Based on the obtained results, it is possible to compare systems with and without recycles, and it is expected, that general conclusions can be drawn regarding the effects of the recycles on the performance of the control structures.

5 Calculation methods

Our work is based on computer simulations. The Aspen Plus^{TM} [16] software package is used for steady-state simulations and Aspen Dynamics^{TM} [17] is used for dynamic simulations. Both Matlab^{TM} [18] and a self-developed VisualBasic^{TM} [19] routine are used to calculate the controllability indices from the results of the step-responses [9] obtained by AspenPlus^{TM}. Matlab^{TM} is also used to order and store the dataset and to plot the necessary diagrams from them.

In case of steady-state simulations, step disturbances in the feed flow rate and feed composition are applied, and the product composition changes are registered, i.e. the transfer functions of the system are measured out. Time-dependency in this case is irrelevant. We worked with 2×2 systems, what means that on each column two controlled variables and two manipulated variables are considered. The extent of the changes of the controlled variables due to unit-change of the manipulated variables can be used to calculate the steady-state gains as shown in Eq. 1.

$$\mathbf{A}_{ij} = \left[\frac{\Delta x_c^i}{\Delta x_m^j} \right] \quad (1)$$

Using the steady-state gains that are calculated using Aspen Plus^{TM}, steady-state controllability indices can be calculated for all the possible control structures [4]. The values of the Niederlinski-index (NI), the Condition Number (CN), the Morari Resiliency Index (MRI), and the Relative Gain Array (RGA) allow us to compare the different control structures in case of each column. Based on the values of the steady-state controllability indices, the well performing control structures can be selected.

Designing of control structures based on steady-state controllability indices [4] is a well functioning empirical method, still the dynamic behaviour of the well performing control systems are to be verified afterwards, in order to find the optimal control structure. It is not worth investigating the dynamic behaviour of control structures that are not performing well based on the steady-state controllability predictions. Investigations in the dynamic domain focus on time-functions. Dynamic responses with and without composition-controls (closed loop and open loop) can be simulated. Simulating the dynamic response functions to the disturbances, control loop tuning becomes possible (open loop) and the maximum overshoot of the controlled variables, stability and control time can be exactly monitored (closed loop). Based on the closed loop investigations, the best control structure can be selected finally. This way, dynamic effects of the recycle can be clearly observed, too.

6 Results of the Steady-state Investigations

Transfer functions were measured out in a way that 1% high step disturbances were applied to the feed flow rates and to the feed compositions and changes in product mole-fractions were measured (see Eq. 1). This 1% disturbances seem to be small, but after linearity-studies we found it the best. By these linearity-studies we investigated the correlation between the controlled and the manipulated variables, and obtained a range, in which this correlation is linear and we worked in this. By bigger disturbances the systems remained stable, but the controllability indices below could not have been calculated so accurately. Two concentration-control loops were set up onto every column, one in the head, the other in the bottom. Hence at the steady-state investigations two manipulated variables per columns could be set up. In the top, one variable had to be chosen from among D, L and R, in the bottom one variable from among Q, B and BR (see Table 1). The controlled variables were the compositions of the key components in the head and in the bottom.

Based on the transfer functions, the matrices of the steady-state gains could be constructed. Starting from the matrices of the steady-state gains, the Relative Gain Array (RGA), the Condition Number (CN), the Morari Resiliency Index (MRI), and the Niederlinski Index (NI) could be calculated using matrix operations [9].

Table 4 shows the calculated values of these steady-state controllability indices for the several possible control structures. As for the notation, D-Q control e.g. means that the composition of the distillate is controlled by the flow rate of the distillate (D) and the composition of the bottom product is controlled by the heat duty of the reboiler (Q). The controllability indices are calculated for both the recycle-free and for the two-recycle containing systems.

7 Without recycles with recycles

The values shown in Table 4 inform us about the performance and applicability of the studied control structures. When evaluating the control structures, the following knowledge about the controllability indices are to be applied [4]:

- If the value of the Condition Number (CN) is close to 1 then the control structure is well conditioned, i.e. matching of controlled and modified variables is chosen well.
- Negative value of the Niederlinski Index (NI) predicts unstable integral control structure.

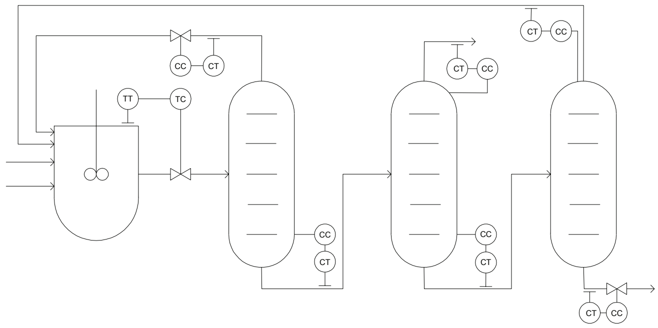

Fig. 5. Optimal control structure for the recycle containing process

- The higher the value of the Morari Resiliency Index (MRI) is, the better controllability can be expected.
- The quality of the control is good, when the values of the Relative Gain Array (RGA) are close to 1.

Considering these points, the possible control structures could be compared and the following two major conclusions could be drawn:

1 It can be clearly seen that in most cases the presence of the recirculation changes the values of the indices into an unfavourable direction. Usually higher condition numbers (it means worse conditioned control structures), higher negative NI numbers, and higher RGA-s (stronger interactions between the control loops) are obtained when recirculation is present.
For example, considering the D-BR control structure in the first column the followings can be concluded: The D-BR structure is applicable since the value of NI is positive for both the recycle-free and for the recycle containing system. The value of the CN without recycle is 3.7 while the presence of recycle increases it to 8.4, and the value of the MRI is 462 without recycle while the presence of recycle decreases it to 112. The values of the CN and the MRI indicate that recirculation causes worse controllability. Although the value of the RGA is better in the case of recycles (0.98) than in the case without recycles (0.78), it can be concluded that the presence of recirculation results in worse controllability. When comparing the structures, all the four indices have to be taken into consideration simultaneously.

2 The appearance of recirculation changes the optimal control structure on the second (ethylbenzene) column. The optimal control structure is different when recirculations are present. Based on the values shown in Table 4, the optimal control loops for the recycle-free and recirculation containing structures can be appointed. Optimal control structures are shown in Table 5.

The optimal control structure of the recycle containing technology cannot be designed based on recycle-free simulations or experiments. As Table 5 shows, the optimal control structure for the recycle-free system would become absolute instable when

Tab. 4. Steady-state controllability indices of the system with and without recycles

without recycles

Structure		1. column	2. column	3. column
D-Q	CN	1875,692	4383,487	5911,148
	NI	1,115016	0,989784	0,102597
	MRI	0,002343	0,000332	8,94E-05
	RGA	0,896848	1,010321	9,7469
D-BR	CN	3,732051	526,1842	48,05435
	NI	1,2665731	1,473303	2,217499
	MRI	462,3358	0,002686	0,011027
	RGA	0,789532	0,678747	0,450958
L-B	CN	1,000014	2,732569	1,040569
	NI	0,97558	0,556421	1,210542
	MRI	16,76004	3,68974	0,318621
	RGA	1,025031	0,796635	0,826076
L-Q	CN	1,000015	3,799358	5,552312
	NI	1,115698	5,16785	5,47412
	MRI	20,2569	0,45877	1,25124
	RGA	0,8962999	0,1935041	0,1826778
L-BR	CN	20,27574	2,562257	3,657668
	NI	20,36076	-3,65891	0,130618
	MRI	0,056896	0,796332	0,144932
	RGA	0,049114	1,569147	7,655906
R-Q	CN	25,04324	1,367159	2,955622
	NI	-1,62851	3,9654	0,044626
	MRI	0,010198	0,149875	0,275347
	RGA	-0,61406	1,025478	22,40861
R-B	CN	1,000014	1,720141	1,013072
	NI	0,974911	-18,795	2,298558
	MRI	16,6364	0,155277	0,329926
	RGA	1,025735	-0,05321	0,435055

with recycles

Structure		1. column	2. column	3. column
D-Q	CN	732,518	502,2498	381,9348
	NI	1,033948	0,979852	1,298958
	MRI	0,000355	0,00194	0,002785
	RGA	0,967167	1,020562	0,769848
D-BR	CN	8,38796	502,1025	376,4233
	NI	1,01557	0,97989	1,237851
	MRI	112,4568	0,00194	0,002757
	RGA	0,984669	1,020523	0,807851
L-B	CN	1,000848	2,829359	1,002547
	NI	1,133378	0,414003	4,815612
	MRI	0,408968	0,000786	0,56321
	RGA	0,882318	2,415444	0,207658
L-Q	CN	1,000355	4,125345	4,89537
	NI	1,3056705	9,64153	3,98164
	MRI	18,87745	1,25341	0,98973
	RGA	0,76589	0,103718	0,251152791
L-BR	CN	25,3725	4,141974	2,505085
	NI	-2,31707	-3,39371	0,614762
	MRI	0,041695	0,094263	0,008948
	RGA	-0,43158	-0,29466	1,626645
R-Q	CN	30,8956	5,740454	3,428177
	NI	-29,93	-123,152	-0,77477
	MRI	0,0388561	0,626125	0,34246
	RGA	-0,03341	-0,00812	-1,29071
R-B	CN	1,000029	1,003448	1,0298573
	NI	1,039616	0,609407	10,78344
	MRI	0,409205	0,520649	0,321556
	RGA	0,961894	1,640938	0,092735

Tab. 5. Optimal control structures

	1^{st} column	2^{nd} column	3^{rd} column
Without recycles	L-Q	R-Q	L-B
With recycles	L-Q	R-B	L-B

recirculations are connected, because, in the second column the value of the NI is a high negative number in case of the R-Q pairing.

In accordance with Table 4, the optimal composition control structure for the entire recycle containing system is illustrated in Fig. 5. Fig. 5 shows the control loops (that were steadily present). Here we refer to the control loop of column 1 eliminating the snowball effect, to the control loops of the reactor.

As it was mentioned previously, the dynamic behaviour of the well performing control systems are to be investigated. These investigations are presented in the followings.

8 Investigations of the Dynamic Behaviour

Simulation calculations in the steady-state- and in the dynamic domains are different. Instead of solving sets of nonlinear equations, dynamic simulations require the solution of differential equations. Dynamic modelling in our case is carried out using Aspen Dynamics^{TM}. Dynamic behaviour of the well performing control systems (see Table 5) are investigated only. As a result of the dynamic investigations, the optimal control structure may be different from the optimal structure obtained from steady-state investigations.

In the dynamic domain 1% high square disturbances (1% jump upwards then later 1% jump downwards) were applied to the feed flow rates or to the feed compositions. Product molefractions were measured then as a function of time. Dynamic behaviour of the system was investigated in both open- and closed-loop. It is expected that the effects of recirculations will be much better perceptible in the dynamic domain.

9 Dynamic Investigations in Open Loop

In open loop simulations, composition control loops are switched off (still, level and pressure control exists on the columns), hence the disturbances cause definitive shifts in the compositions. Figs. 6, 7 and 8 show the responses of the compositions of the distillates of the three columns to feed flow rate and feed composition disturbances. Disturbances in this case are given at the column feeds. The curves marked with diamonds show the responses without recycles, the curves marked with + signs show the responses with recycles. Compositions of the key-components are shown only. The key components are: benzene in the first, ethylbenzene in the second and diethylbenzene

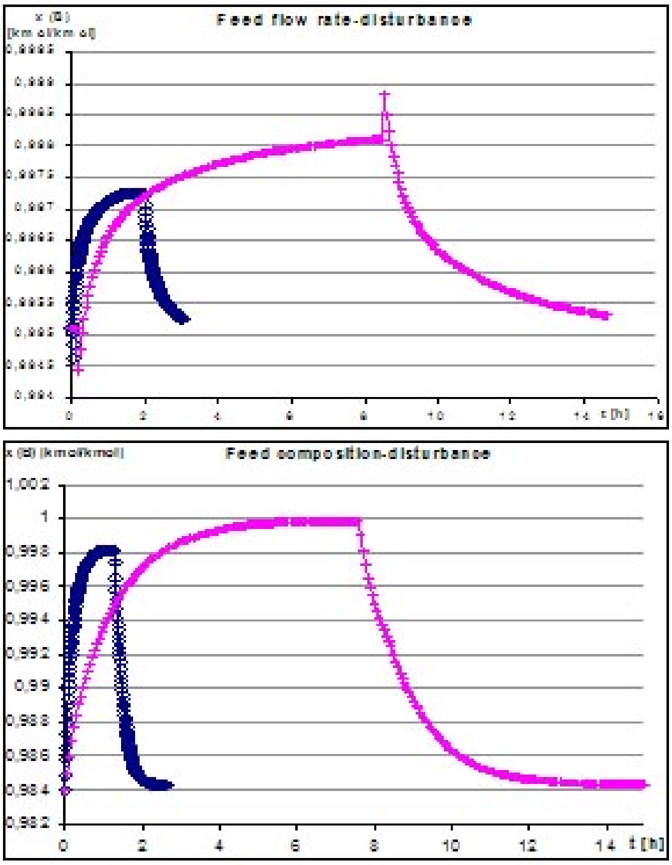

Fig. 6. Composition responses of column 1 in open-loop (the mole fraction of benzene in the head of the first column vs. time; diamond signs: without recycle, + signs: with recycles)

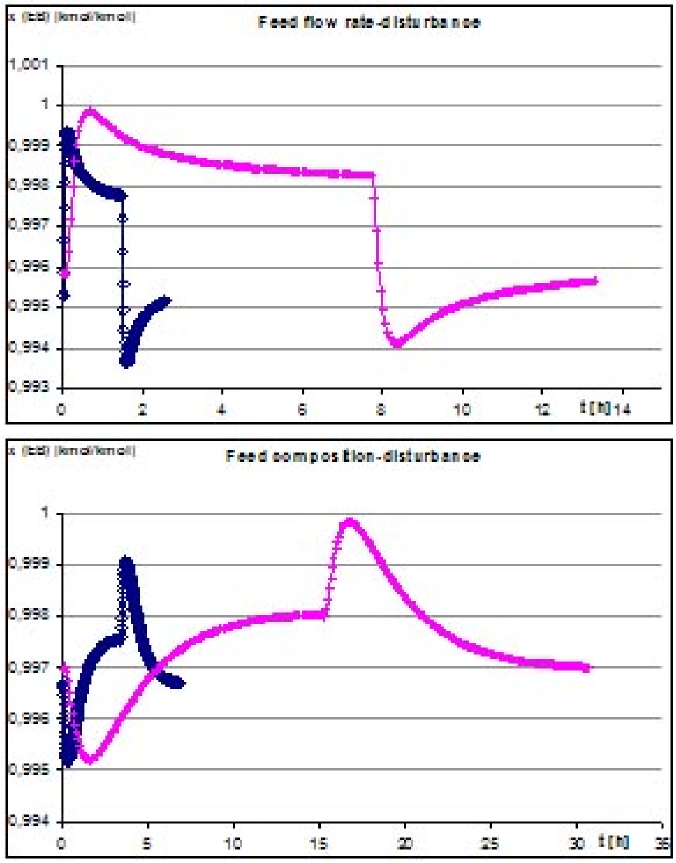

Fig. 7. Composition responses of column 2 in open-loop (the mole fraction of ethylbenzene in the head of the second column vs. time; diamond signs: without recycle, + signs: with recycles)

in the third column.

In Figs. 6, 7 and 8, concentrations begin to decrease at the end of the square disturbances, when the -1% step jump occurs. Without any calculations, one can see that the presence of recirculation results in much slower responses.

Two representative parameters can be obtained from the open loop curves: the gain and the time constant. These are needed for proper control loop tuning. In case of inverse responses (as in Figs. 6, 7), determination of gains and time constants is not straightforward, still can be carried out [9]: The gains are derived from the final and initial values of the step response functions, while the time constants are calculated from the slopes of the transient sections of the curves.

It can be seen that the appearance of the recycle increases the time constants; in the first column from 2 to 8 hours, in the second column from approx. 2-3 to 8-15 hours, and in the third column from 3 to 6 hours. The difference in the gains is not so apparent. Gains are very similar with or without recycles. One can conclude that the appearance of the recycle increases the time constants in a big compass, and makes the controllability of the columns more difficult.

Using the obtained gains and time constants, PID controllers of the composition control loops could be tuned. The Aspen Plus^{TM} software has its own automated tuning method. There was always installed at least one control loop at the top of the first column, so snowball effect never occurred. After tuning the composition control loops, investigation of the system in closed loop became possible.

10 Dynamic Investigations in Closed Loop

Investigation in closed loop means that the responses of the system are measured while the control loops are closed and properly tuned. To check the quality of the composition control loops in closed loop, disturbances were applied again, and the time dependence of the concentrations of the key components were registered. 1% high step disturbances were applied to the feed flow rates and to the feed compositions of the columns. Evaluation of the response functions gives rise again to the comparison of the recycle-free and recycle containing systems. The applied controls were stable in each of the cases; the product-compositions could be kept at their prescribed set points with a small integral absolute error.

Figs. 9, 10 and 11 show the closed-loop responses. The lighter curves marked with + signs belong to the system with recycles; the darker curves marked with diamonds show the responses of the system without recycles. The compositions of the key components of the columns are plotted again.

The consequences that can be drawn from the dynamic re-

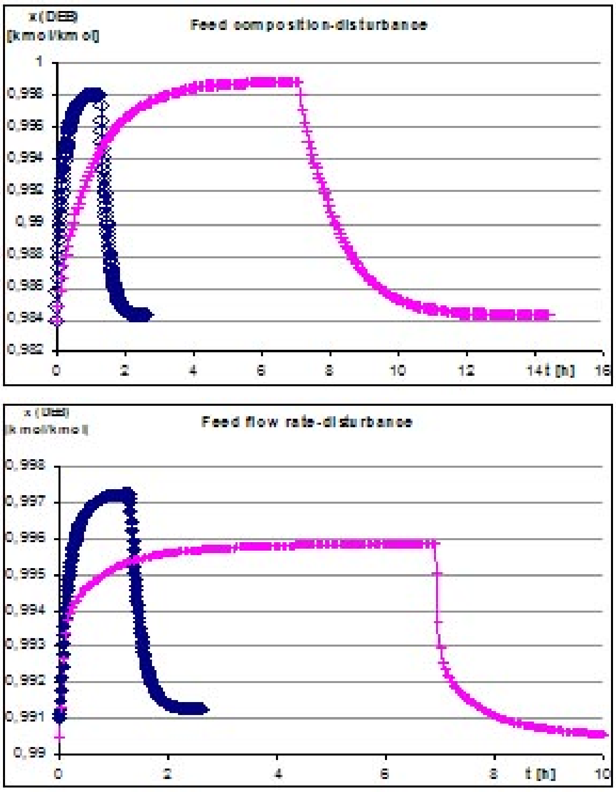

Fig. 8. Composition responses of column 3 in open-loop (the mole fraction of diethyl-benzene in the head of the third column vs. time; diamond signs: without recycle, + signs: with recycles)

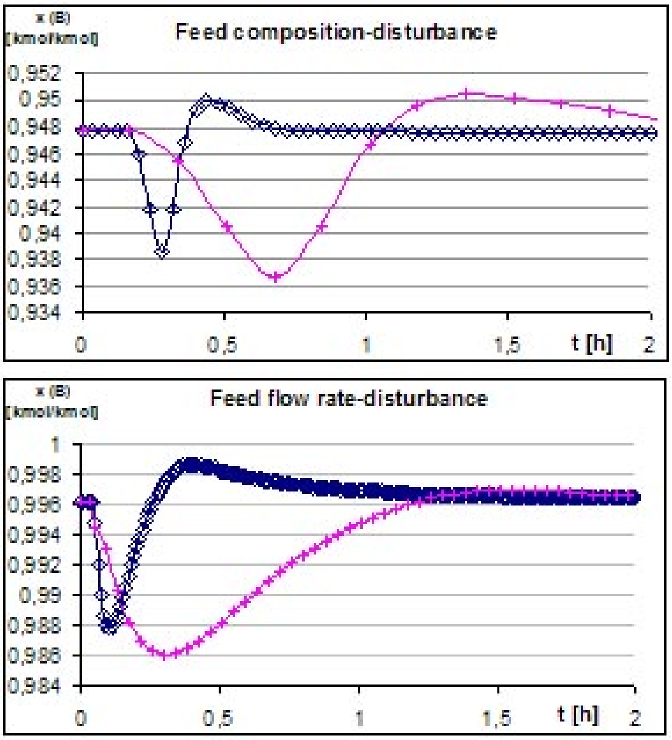

Fig. 9. Closed-loop responses to disturbances of column 1 (the mole fraction of benzene in the head of the first column vs. time; diamond signs: without recycle, + signs: with recycles)

sponses (Figs. 9, 10 and 11) are similar to the ones already concluded from the steady state investigations: The presence of the recycle streams makes the systems more difficult to control, because the recycle appears as a positive feedback.

The systems with recycles do not show significantly greater maximal overshoots, but the time constants of the systems do increase when recycles are present. Time constants of the recycle containing systems are usually at least three times bigger compared to the recycle-free cases. Higher time constants result in higher integral absolute errors. Higher time constants indicate the increased complexity of the recycle containing system.

The maximal overshoots do not differ so much: the differences between them is 15% at the first column, 14% at the second column, and under 5% at the third column.

The major result of the closed-loop investigations is that the control structures obtained based on the values of the steady-state controllability indices perform well in the dynamic domain, too. Instability does not occur, therefore, our control system design is successful. Dynamic investigations affirm that the optimal control structure is the one shown in Fig. 5.

By industrial circumstances these simulations and their results are reliable, it means the effects of the disturbances in the case of real columns are almost the same, the stability ranges also are the same, there is just one difference between columns in real and columns in Aspen Dynamics: if we model columns by this flowsheeting software, the responses to different disturbances show first order lags, but as we know a distillation column is typically higher than this. The typical column configurations (tray geometries, drums and vessels) in Aspen Dynamics and the applied residence times make the behaviour of the columns similar to a first order lag, therefore the responses are closer to this, than the responses of higher order lags.

11 Conclusions

In this case-study the effects of the recycle in an ethylbenzene producing system are investigated, simulated and analysed both in the steady-state and dynamic domains. Using the method of steady-state controllability indices, the optimal control structure for the entire two recycle containing system could be successfully designed. It is shown that the optimal control structure for the recycle-free system would become instable when recirculations were present, therefore, controllability of systems with recycles cannot be designed based on recycle-free data. The optimal control structure obtained by evaluating steady-state controllability indices proved to be optimal in the dynamic domain, too. It is shown that the presence of the recirculation always increases the time constants of the system resulting in slower responses and in increased integral absolute errors. On the other hand, the presence of recycles does not always result in higher maximum overshoots, in case of closed-loop dynamic investigations. It is proved again that controlling the flow rate of the distillate of the first column is a must, otherwise snowball-effect occurs making the system uncontrollable.

Nomenclature

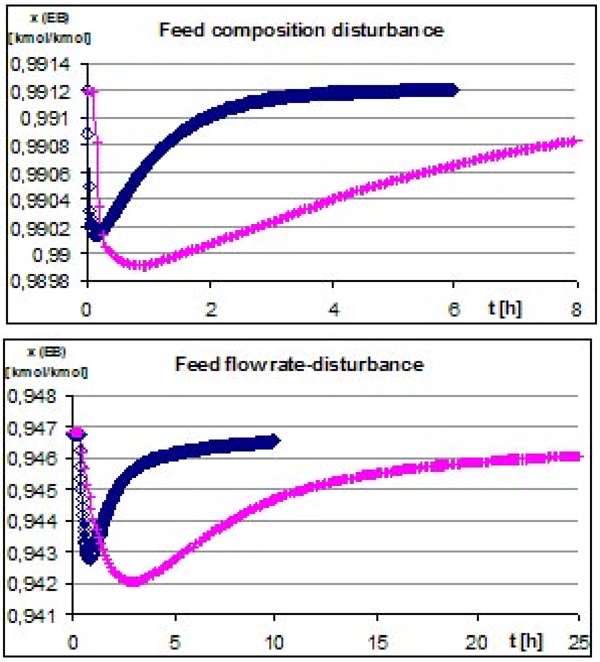

Fig. 10. Closed-loop responses to disturbances of column 2 (the mole fraction of ethylbenzene in the head of the second column vs. time; diamond signs: without recycle, + signs: with recycles)

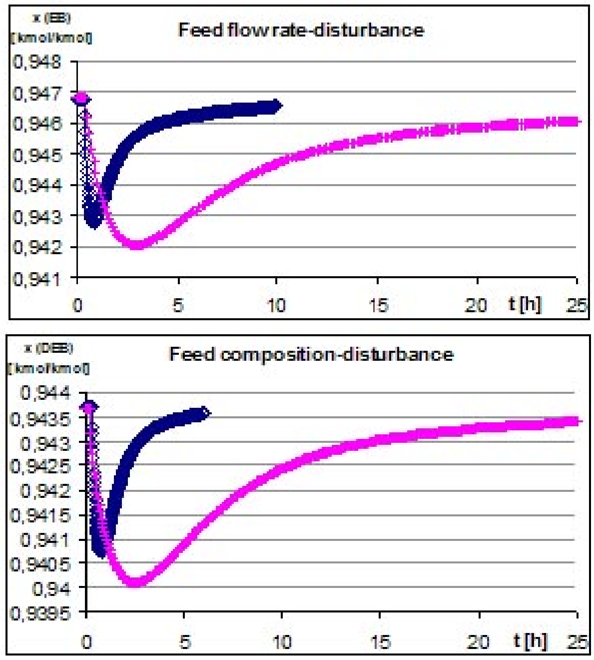

Fig. 11. Closed-loop responses to disturbances of column 3 (the mole fraction of diethyl-benzene in the head of the third column vs. time; diamond signs: without recycle, + signs: with recycles)

Indices

c	controlled variable
i, j	ordinal number
m	manipulated variable

Abbreviations

B	benzene or flow rate of the bottom product
BR	boil-up ratio
c	concentration
CC	composition control
CN	condition number
CSTR	continuously stirred tank reactor
D	flow rate of distillate
DEB	diethylbenzene
EB	ethylbenzene
H	heat of the reaction
IAE	integral absolute error
k	reaction rate constant
L	flow rate of the reflux
MRI	Morari-resiliency index
NI	Niederlinski-index
Q	heat duty of the reboiler
R	universal gas constant or reflux ratio
RGA	relative gain array
t	time
T	absolute temperature
TEB	triethylbenzene
x	mole fraction

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17 *Aspen Dynamics^{TM} from AspenTech.*

18 *Matlab^{TM} from MathWorks.*

19 *VisualBasic^{TM} from Microsoft*. a software used to the calculation.