Chinese J. of Chem. Eng., 8 (4) 339—346 (2000)

Assessment of Control Configurations for a General Heat Integrated Distillation Column*

HUANG Kejin(黄克谨) and QIAN Jixin (钱积新)**
Institute of Industrial Process Control of Zhejiang University, Hangzhou 310027, China

NAKAIWA Masaru(中岩勝) and NAKANE Takashi(中根尧)
National Institute of Materials and Chemical Research, Tsukuba 305-8565, Japan

TAKAMATSU Takeichiro(高松武一郎)
Institute of Industrial Technology, Kansai University, Suita 564-8680, Japan

Abstract The assessment of control configurations for an ideal heat integrated distillation column incorporated with an overhead condenser and a bottom reboiler (general HIDiC) is addressed in this work. It is found that double ratio control configuration, $(L/D,\ V/B)$, is still the best one among all the possibilities. The control configuration, $(p_r - p_s,\ q)$, appears to be a feasible one for the general HIDiC and the pressure difference between the rectifying and the stripping sections and feed thermal condition are expected to be consistent manipulative variables for the process. The performance of the general HIDiC can be substantially improved by employing effective multivariable control algorithms.

Keywords distillation, control configuration, interaction, disturbance rejection, closed-loop simulation

1 INTRODUCTION

The synthesis and analysis of control configurations for conventional distillation columns have attracted much attention since 1960s, which have been well reflected by a large amount of work being conducted on these problems[1]. However, for heat integrated distillation columns, although various kinds of processes have been developed and studied, very little work has been done so far on the synthesis and analysis of their control configurations. This might be one of the reasons that heat integrated distillation columns have not found widespread applications in chemical process industry yet.

In our previous work we finished examining the operation feasibility of an ideal heat integrated distillation column (ideal HIDiC), without reboiler and/or condenser[2,3]. Although it has been found feasible to operate the process with manipulation of the pressure difference between its rectifying and stripping sections, $p_r - p_s$, and feed thermal condition, q, it is often argued that it might be better to manipulate reflux flow and reboil rate as in conventional distillation columns by adding a condenser and a reboiler to the ideal HIDiC. During the stage of process start-up, a reboiler-condenser structure is also needed for the ideal HIDiC. To guarantee the process with high energy efficiency in a wide operation region, a trim condenser and reboiler structure looks also necessary. In view of these aspects, it appears to be needed to evaluate the operation of the ideal HIDiC when it is incorporated with the structure. In this paper the ideal HIDiC incorporated with an overhead condenser and a bottom reboiler will be named general HIDiC in the sequel, as shown in Fig. 1.

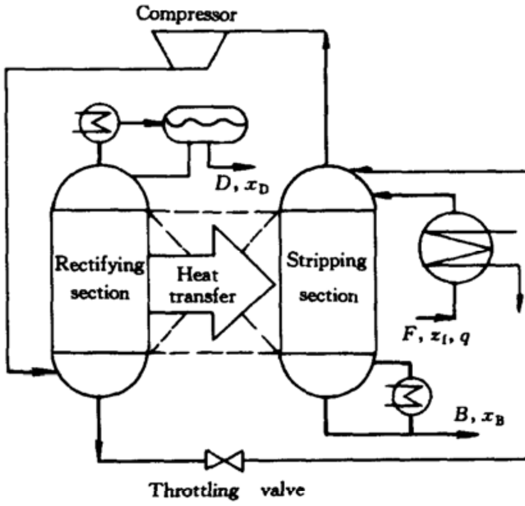

Figure 1 Schematic representation of a general HIDiC

Because of the addition of a total condenser and

Received 1999-04-28, accepted 2000-04-08.
* Supported by the New-Energy and Industry Technology Development Organization (NEDO), through the Energy Conservation Center of Japan.
** To whom correspondence should be addressed.

a reboiler, the alternatives for the control configurations increase dramatically and the selection of appropriate control configurations becomes much more complicated and time-consuming. Because of the diverse characteristics among these control configurations, such as the degree of interactions among control loops and disturbance rejection abilities, it is necessary to explore better control schemes. Therefore, the objective of this paper is to investigate all the possible control configurations and provide a general guideline for the effective control system design for a general HIDiC. Special emphasis is placed on the control scheme ($p_r - p_s$, q), which is the designated control system for the operation of an ideal HIDiC. Simulations are also conducted to evaluate and compare the potential control configurations.

2 PROCESS MODELING AND PROCESS DYNAMICS

A first-principle dynamic model of the general HIDiC is developed and regarded as a substitute of a real process. Francis formula is used to describe the stage liquid hydraulics with the time constant around 0.15 min. The stage liquid hydraulics adds further complexity to the process dynamics and causes the process operation a more challenging one. The dynamics of control systems for the levels of reflux drum and reboiler are also included in the model and the level controllers are proportional ones tuned by the Ziegler-Nichols rule. The nominal operating conditiion of the process is illustrated in Table 1. To speed up the control system analysis and comparisons we found that using reduced-order models is apparently an efficient alternative. Process transfer function models, mainly first-order plus time-delay ones, were developed here for each control configuration by simple step tests. For some control configurations there may exist non-minimum-phase behaviors, such as the response of the overhead product to the changes in the pressure difference between the rectifying and the stripping sections, $p_r - p_s$. When the inventory was controlled by the overhead and the bottom product flows, a zero on the right-half plane had to be included in the transfer function models. Furthermore, higher convergent accuracy ($\leqslant 10^{-6}$) had to be adopted in the dynamic calculations to assure the reduced-order model to represent the dynamics of the general HIDiC accurately enough for the followed synthesis and analysis. Transformation relations of the control system configurations were used to check the consistency among the obtained reduced-order models[4-5]. Logarithmic transforms for the overhead and the bottom products were made to reduce the effects of process nonlinearities.

Table 1 Steady state operating conditions of the general HIDiC

Items	Values
No. of stages	20
feed stage	11
condenser holdup	5 kmol
reboiler holdup	5 kmol
stage holdup	0.1—0.6 kmol
reflux flow rate	32.645 kmol·h^{-1}
reboil-up rate	32.645 kmol·h^{-1}
overhead product flow rate	50 kmol·h^{-1}
bottom product flow rate	50 kmol·h^{-1}
pressure of rectifying section	0.25325 MPa
pressure of stripping section	0.1013 MPa
feed flow rate	100 kmol·h^{-1}
feed composition (benzene)	0.5
(toluene)	0.5
feed thermal condition	0.5
relative volatility	2.4
latent heat of vaporization	30001.1 kJ·kmol^{-1}
heat transfer rate	9800 W·K^{-1}
overhead product specification	0.995
bottom product specification	0.005

3 CONTROL SYSTEM CONFIGURATION

The general HIDiC has more alternatives for the control system configurations than the ideal HIDiC. For the general HIDiC, there exist four variables to be controlled, *i.e.*, overhead product composition x_1, bottom product composition x_n, levels of reflux drum and reboiler, H_c and H_R. There exist eight possible manipulative variables, *i.e.*, flow rate of the overhead product D, flow rate of the bottom product B, reflux flow rate L, reboil-up rate V_n, ratio of the reflux flow rate to the overhead product flow rate (L/D), ratio of the reboil-up rate to the bottom product flow rate (V/B), pressure difference between the rectifying and the stripping sections ($p_r - p_s$), and feed thermal condition q. Although a number of flow rate ratio variables can be formed, we consider only the above mentioned two, L/D and V/B, here. It should be reminded that the two extra degrees of freedom could be used in the optimum design of the general HIDiC. Apparently there exist $\begin{pmatrix} 8 \\ 4 \end{pmatrix} = 70$ possible control schemes. Deleting those apparently unfeasible ones leaves 32 control schemes as listed in Tables 2 to 4. Some control configurations, such as (D, B), although might be feasible from the dynamic point of view, are not included in these tables, because the corresponding control systems become more complicated in design than those listed in the tables in order to deal with their integrity drawbacks.

4 CONTROL STRUCTURE ANALYSIS

To find the best control system for the general HIDiC, analyses and comparisons have to be made in both steady state and dynamic state for all the possible control configurations.

4.1 Steady state analysis

Various kinds of steady-state criteria have been proposed for evaluation and comparison of control systems. The following performance indices are used in this work to examine all the control configurations.

(1) The Niederlinski index (*NI*) It must be positive for stable control systems.

(2) The Morari resiliency index (*MRI*) The magnitude of this index is a measure of the process inherent ability to handle disturbance, model-plant mismatch and changes in the operating conditions. The larger the value of *MRI* is, the more resilient the control configuration is.

(3) The condition number (*CN*) It indicates the degree of directionality within the system. The smaller the number, the less difficult the control.

(4) The relative gain array (*RGA*) *RGA* is a useful tool for addressing the issue of input uncertainty. Configurations with large values of *RGA* should be avoided[6]. In addition, it is also a good indicator for interactions among control loops.

The steady-state performance indices for various control configurations are shown in Tables 2—4. According to the structure of control configurations it is reasonable to arrange them into three generalized subgroups as follows.

Table 2 Control system configurations with $p_r - p_s$ as one manipulative variable*

No.	Config.	H_C	H_R	*NI*	*MRI*	*CN*	$RGA(\lambda_{11})$
1	$(p_r - p_s, q)$	D	B	1.9527	2.9303	1	0.51211
2	$(p_r - p_s, q)$	L	B	-6.1993×10^{-3}	6.4900×10^{-3}	647.23	−161.31
3	$(p_r - p_s, q)$	D	V	8.0963×10^{-3}	8.5703×10^{-3}	492.05	123.51
4	$(p_r - p_s, q)$	L	V	8.2775×10^{-3}	8.7622×10^{-3}	481.24	120.81
5	$(p_r - p_s, V)$	D	B	1.8393	2.8440	1	0.54370
6	$(p_r - p_s, V)$	L	B	-5.9442×10^{-3}	6.2234×10^{-3}	674.92	−168.23
7	$(p_r - p_s, B)$	D	V	1.8000	2.8346	1	0.55558
8	$(L, p_r - p_s)$	D	B	2.0386	2.9941	1	0.50946
9	$(p_r - p_s, L)$	D	V	8.2471×10^{-3}	8.7303×10^{-3}	483.02	121.26
10	$(p_r - p_s, D)$	L	B	2.0715	3.0182	1	0.48273
11	$(p_r - p_s, V/B)$	D	B	1.9275	2.9178	1	0.51881
12	$(p_r - p_s, V/B)$	L	B	-6.0891×10^{-3}	6.3743×10^{-3}	658.91	−164.23
13	$(L/D, p_r - p_s)$	D	B	2.0742	85.542	1	0.48213
14	$(L/D, p_r - p_s)$	D	V	-8.549×10^{-3}	5.0034×10^{-3}	469.88	−116.97

* Throughout this work the optimal scaling that minimizes the condition number has been adopted, *i.e.*, $\gamma[G] = \min_{S_1,S_2} \gamma[S_1 G S_2]$

where $S_1 = \begin{pmatrix} s_{11} & 0 \\ 0 & s_{11}\sqrt{|g_{11}g_{12}/g_{21}g_{22}|} \end{pmatrix}$ $S_2 = \begin{pmatrix} s_{21} & 0 \\ 0 & s_{21}\sqrt{|g_{11}g_{21}/g_{12}g_{22}|} \end{pmatrix}$

s_{11} and s_{21} are any nonzero real number.

Table 3 Control system configurations with q as manipulative variable*

No.	Config.	H_C	H_R	*NI*	*MRI*	*CN*	$RGA(\lambda_{11})$
15	(q, V)	D	B	0.11911	11.599	31.551	8.3957
16	(q, V)	L	B	-1.1965×10^{-4}	6.2441×10^{-5}	2138.9	−8357.8
17	(q, B)	D	V	1.8065	1.7488	1	0.55357
18	(L, q)	D	B	8.2648×10^{-2}	8.5973×10^{-2}	46.377	12.100
19	(L, q)	D	V	1.5204×10^{-4}	1.7834×10^{-6}	26310	−6577.43
20	(D, q)	L	B	1.9387	2.7740	1	0.51582
21	$(L/D, q)$	D	B	-2.3381×10^{-2}	0.69034	173.08	−42.771
22	$(L/D, q)$	D	V	1.1807×10^{-4}	6.9247×10^{-5}	33879	−8469.5
23	$(q, V/B)$	D	B	0.087294	5.5343	43.780	11.456
24	$(q, V/B)$	L	B	-1.1342×10^{-4}	5.9191×10^{-5}	35269	−8816.7

* See the note in Table 1

Table 4 Control configurations without $p_r - p_s$, or q as manipulative variables*

No.	Config.	H_C	H_R	*NI*	*MRI*	*CN*	$RGA(\lambda_{11})$
25	(L, V)	D	B	0.19190	0.20581	18.791	5.211
26	(L, B)	D	V	1.8066	3.1532×10^{-2}	1	0.55354
27	(D, V)	L	B	2.3686	3.0662	1	0.42220
28	$(L, V/B)$	D	B	−0.11483	3.3131	36.8062	−8.7084
29	$(D, V/B)$	L	B	1.9388	2.7741	1	0.51579
30	$(L/D, V)$	D	B	9.8512×10^{-2}	3.00145	38.578	10.151
31	$(L/D, B)$	D	V	1.8065	1.5766	1	0.55354
32	$(L/D, V/B)$	D	B	0.14862	3.4233	24.873	6.7284

* See the note in Table 1.

(1) The first subgroup refers to the control configurations of No. (1) to (14), all of which involve using pressure difference, $p_r - p_s$, as one of the manipulative variables. The *NI* indices for control configurations No. (2), (6), (12) and (14) are negative, indicating possible instabilities might occur with those control configurations. For control configurations No. (3), (4) and (9), although the *NI* indices are positive, they have substantially small *MRI* and high *CN* values, showing the potential of great difficulties in process operation. The control configurations No. (1), (5), (7), (8), (10) and (11) possess almost the same performance indices. For example, the *RGA* elements are all very close to 0.5, indicating the high potential of strong interactions between the overhead and the bottom composition control loops. Particularly, all the configurations appear to be properly formed with all the condition numbers equaling 1 and all *MRI* of similar magnitudes, ranging from 2.8 to 3.02. It is believed that they have quite similar system performances, though certain difference may exist among them. The control configuration No. (13), with the largest *MRI* value and quite similar other indices to those just mentioned above, appears to be the best one for the operation of the general HIDiC in this subgroup. In the sequel we will adopt it and the control configuration No. (1), $(p_r - p_s, q)$, as the representatives of the subgroup. Here $(p_r - p_s, q)$ denotes that the pressure difference, $p_r - p_s$, and the feed thermal condition, q, are used for the overhead and the bottom composition control, respectively. It is worth reminding that $(p_r - p_s, q)$ is also the control structure that has been used for the operation of the ideal HIDiC, hence the study is also expected to give further insight into the operation of this process.

(2) The second subgroup is composed of control configurations from No. (15) to (24), which is featured with the feed thermal condition, q, as one of the manipulative variables. The *NI* indices point out that the control configurations No. (16), (21) and (24) might have instability problems. The *MRI* and *CN* indices indicate that the control configurations No. (18), (19), and (22) may not be effective to counteract external disturbances. The rest control configurations, *i.e.*, No. (15), (17), (20) and (23), look feasible for the operation of the general HIDiC. The control configurations No. (15) and (20), *i.e.*, (q, V) and (D, q), appear to be the better ones in this subgroup because they have much better performance indices and will be selected as representatives of the subgroup for the further investigations.

(3)The third subgroup contains the rest of the control configurations, *i.e.*, No. (25) to (32), which represents the general operation methods for conventional distillation columns. The *NI* indices point out that the control configuration No. (28) may have instability problems. The *MRI* and *CN* indices indicate that the control configurations No. (25) and (26) are not effective to counteract external disturbances. The rest control configurations, *i.e.*, No. (27), (29), (30), (31) and (32), seem to be feasible for the operation of the general HIDiC. Among them the control configuration No. (27), (D, V), and the double ratio control configuration No. (32), $(L/D, V/B)$, are the possible better ones for the operation of the general HIDiC and will be adopted for the further analysis and comparison.

4.2 Dynamic analysis

The above control system analyses and comparisons provide only steady state information on control configurations. Dynamic behavior should be further checked for the general HIDiC. Figs. 2 and 3 depict the relations of *MRI* and the 1, 1 element of *RGA* with the frequency ω for the six candidate control configurations, *i.e.*, $(p_r - p_s, q)$, $(L/D, p_r - p_s)$, (q, V), (D, q), (D, V) and $(L/D, V/B)$. It is well-known that the lower the frequency when λ_{11} approaches 1, the better the system performances might be. In Fig. 2, it can be easily seen that the double ratio control configuration $(L/D, V/B)$ presents the largest *MRI* value within the indicated frequency region. Particularly, the value of *MRI* increases monotonously with the increase of the frequency, indicating even stronger capability of subduing external disturbances in the dynamic state than in the steady state. The control configuration $(L/D, p_r - p_s)$ shows the second largest *MRI* value in a large frequency range, followed by the control configuration (q, V). The control configuration $(p_r - p_s, q)$ gives much larger *MRI* value than the control configurations (D, V) and (D, q). In Fig. 3, λ_{11} of the double ratio control configuration $(L/D, V/B)$ reaches 1 at around $10\,\mathrm{rad \cdot h^{-1}}$, which is the smallest value among the six control candidates. For the control configuration $(L/D, p_r - p_s)$, λ_{11} approaches 1 at about $80\,\mathrm{rad \cdot h^{-1}}$, the second smallest value, showing the potential of better performances than the other control configurations. For the control configuration (q, V), λ_{11} approaches 1 at extremely high frequency, which is far beyond the indicated frequency range, demonstrating strong interactions with this configuration and high sensitivity to input uncertainties. As to the control configuration $(p_r - p_s, q)$, λ_{11} takes a value of 1 at a frequency larger than $1000\,\mathrm{rad \cdot h^{-1}}$. Moreover, it lies around 0.5 within a wide frequency region, indicating much stronger interactions with this configuration. As far as the control configurations (D, q) and (D, V) are concerned, λ_{11} suggests different control configurations in the dynamic state rather than those based on the steady state analysis. It is readily anticipated that such changes would certainly introduce much stronger interaction in these control schemes.

Summary: The control configurations $(L/D, V/B)$ and $(L/D, p_r - p_s)$ are expected to be much better than the rest ones. However, sensitivity to input uncertainties might be a potential problem for $(L/D, V/B)$ because the steady-state *RGA* value is of considerable magnitude. The control configuration $(p_r - p_s, q)$ appears to be a feasible one for the operation of the general HIDiC. However, the strong interaction should be carefully taken into account in the control system design. Similar comments should be applied to the other three control configurations. In a word, the strong interaction among control loops is a salient character of the general HIDiC.

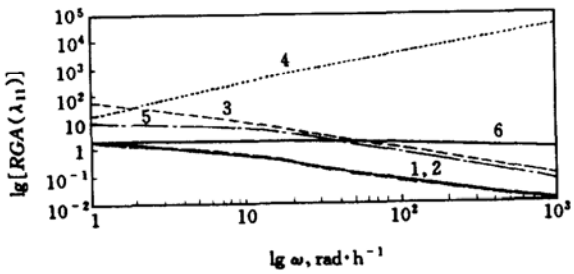

Figure 2 Frequency-dependent *MRI*
1—(D, q); 2—(D, V); 3—$(L/D, p_r - p_s)$; 4—$(L/D, V/B)$; 5—(q, V); 6—$(p_r - p_s, q)$

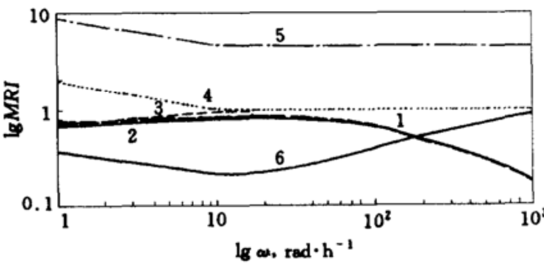

Figure 3 Frequency-dependent *RGA*
1—(D, q); 2—(D, V); 3—$(L/D, p_r - p_s)$; 4—$(L/D, V/B)$; 5—(q, V); 6—$(p_r - p_s, q)$

5 SIMULATION EXAMINATION

Open-loop and closed-loop simulations have been conducted to check the summarized conclusions. The open-loop is defined as the open composition control loops with only the two inventory control loops closed. The above six control configurations, $(p_r - p_s, q)$, $(L/D, p_r - p_s)$, (q, V), (D, q), (D,V) and $(L/D, V/B)$, are to be studied here.

5.1 Open-loop simulation

Both feed flow rate and composition disturbances are introduced into the general HIDiC and their effects are examined respectively. Fig. 4 compares the system open-loop responses for the case of feed flow disturbance. The double ratio control configuration $(L/D, V/B)$ produces the smallest deviations. The next comes from the control configurations $(p_r - p_s, q)$ and (q, V), which give exactly the same responses. The control configuration $(L/D, p_r - p_s)$ ranks the fourth place. The control configurations (D, V) and (D, q) demonstrate the strongest sensitivity to flow rate disturbances. Although the control configurations $(L/D, p_r - p_s)$, (D, q) and (D, V) are very sensitive to external flow rate disturbances, the resulted changes can lead to less degree of symmetry in the process and, to a certain degree, alleviate the difficulties in process operation. For the feed composition disturbance, although not shown here, all the control configurations demonstrate the same responses. It is interesting to note that although the heat integration between the rectifying and the stripping sections holds close relations with the internal composition profile, the feed composition exhibits the same influences on the six control configurations studied.

5.2 Closed-loop simulation

Controller parameters found through the procedure of Luyben[7] are tabulated in Table 5. Input uncertainties (±20%) have been included in the overhead and the bottom composition control loops respectively, according to the characteristics of process gain directionality. Both servo and regulatory experiments are carried out and the corresponding integral square error (ISE) is listed in Table 6.

Fig. 5 shows servo responses of the general HIDiC after the setpoint of overhead product has been disturbed by +0.001. It can be readily seen that the six control systems produce sharply different responses. The double ratio control configuration $(L/D,\ V/B)$ appears to be the best one, which can effectively realize setpoint transitions and keep the bottom product from being upset. The multivariable operation nature is believed to offer this advantage. The control configuration $(L/D,\ p_r - p_s)$ ranks the second place and gives much better performances than the other four schemes. In fact, it can be viewed as a special case of $(L/D,\ V/B)$ because the variation of pressure difference, $p_r - p_s$, actually leads to ratio changes between vapor and liquid flows. The control configurations $(p_r - p_s,\ q)$, $(q,\ V)$, $(D,\ q)$ and $(D,\ V)$ demonstrate much stronger interactions between the overhead and the bottom control loops. Although the system responses appear to be different from one to another, it is believed that the strong interaction is a common factor that degrades the system performance and prohibits the process from achieving the performances as $(L/D,\ V/B)$ or $(L/D,\ p_r - p_s)$.

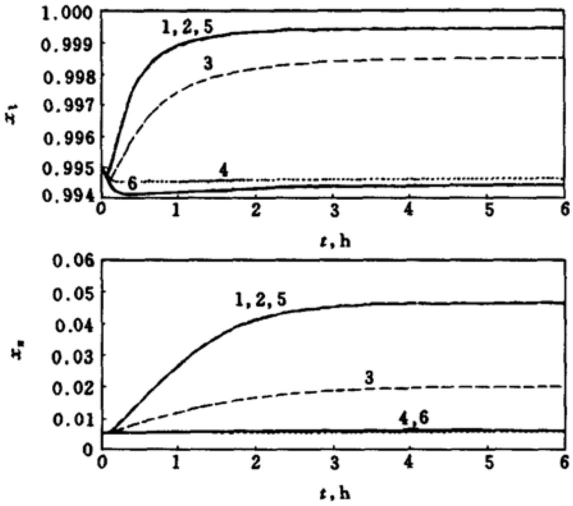

Figure 4 Open-loop responses to a feed flow rate disturbance
1—$(D,\ q)$; 2—$(D,\ V)$; 3—$(L/D,\ p_r - p_s)$; 4—$(L/D,\ V/B)$; 5—$(q,\ V)$; 6—$(p_r - p_s,\ q)$

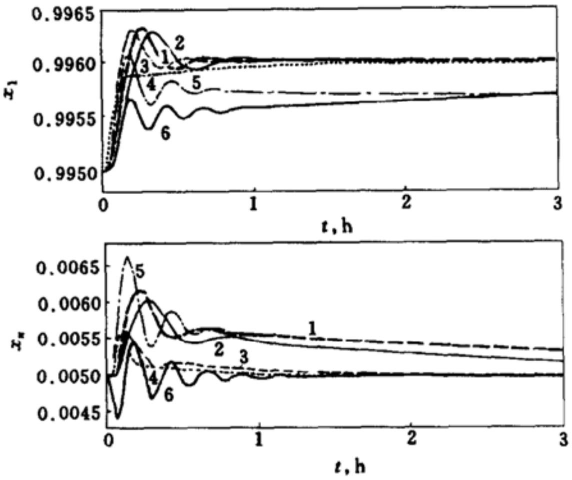

Figure 5 Servo responses of the general HIDiC
1—$(D,\ q)$; 2—$(D,\ V)$; 3—$(L/D,\ p_r - p_s)$; 4—$(L/D,\ V/B)$; 5—$(q,\ V)$; 6—$(p_r - p_s,\ q)$

Table 5 Controller settings for various control configurations

No.	Configuration	Overhead		Bottom	
		K_C	T_I	K_C	T_I
1	$(p_r - p_s,\ q)$	0.18	2.6	0.3	2.2
13	$(L/D,\ p_r - p_s)$	0.7	0.4	0.8	0.6
15	$(q,\ V)$	0.2	2.8	9.8	0.8
20	$(D,\ q)$	20.8	0.8	0.5	2.0
27	$(D,\ V)$	10.8	1.2	21.8	1.1
32	$(L/D,\ V/B)$	0.9	0.3	1.2	0.32

Fig. 6 shows the responses of general HIDiC after it has been subjected to a ±5% step change in feed flow rate. The simulation results indicate again that the double ratio control configuration $(L/D,\ V/B)$ is the best control scheme for the general HIDiC, producing the smallest deviations and possessing the shortest setting time. As predicted in the open-loop simulation the control configuration $(L/D,\ p_r - p_s,)$ exhibits the second best responses. Other control configurations are generally not able to compete with the above two schemes although they can finally circumvent feed flow rate disturbance. In peculiar, they present deteriorated responses with substantially large deviations in either the overhead or the bottom products. The

Table 6 Performance indices of control systems

Control structure	Servo responses		Regulatory responses(z_f)	
	Overhead	Bottom	Overhead	Bottom
$(p_r - p_s,\ q)$	5.3949×10^{-7}	3.6592×10^{-8}	6.6663×10^{-8}	3.5241×10^{-7}
$(L/D,\ p_r - p_s)$	6.2741×10^{-8}	6.2006×10^{-8}	1.9306×10^{-7}	4.2893×10^{-8}
$(q,\ V)$	2.9321×10^{-7}	1.0192×10^{-6}	6.7097×10^{-7}	3.1952×10^{-7}
$(D,\ q)$	9.5903×10^{-8}	8.7457×10^{-7}	3.4749×10^{-7}	3.8509×10^{-7}
$(D,\ V)$	1.1933×10^{-7}	5.8846×10^{-7}	1.4972×10^{-6}	1.0135×10^{-6}
$(L/D,\ V/B)$	5.5669×10^{-8}	2.5648×10^{-8}	1.4263×10^{-8}	9.2883×10^{-9}

strong interactions in these control schemes are considered the main reasons that give rise to the sluggish responses.

Fig. 7 illustrates the responses of general HIDiC after it has been subjected to a +5% step change in feed composition. The double ratio control configuration (L/D, V/B) appears to be the best one again in this case for the process operation, followed by the control configuration (L/D, $p_r - p_s$), which is also quite effective in rejecting feed composition disturbances. The rest control schemes, although capable of overcoming feed composition disturbances, produce much more degraded responses compared with (L/D, V/B) and (L/D, $p_r - p_s$). Their drawbacks are apparently the strong interactions which introduce not only large deviations but also oscillations in the system responses.

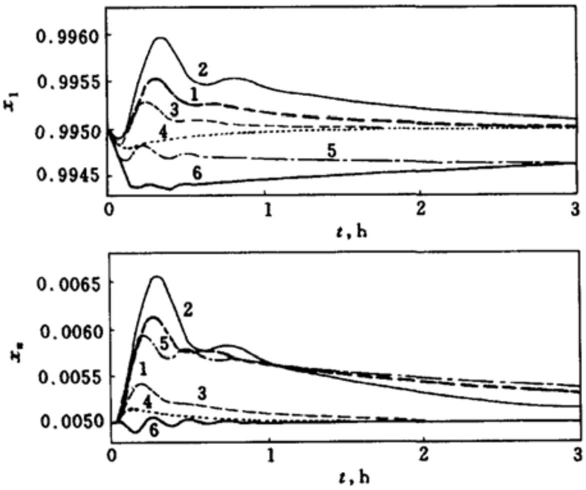

Figure 6 Regulatory responses to a feed flow rate disturbance

1—(D, q); 2—(D, V); 3—(L/D, $p_r - p_s$); 4—(L/D, V/B); 5—(q, V); 6—($p_r - p_s$, q)

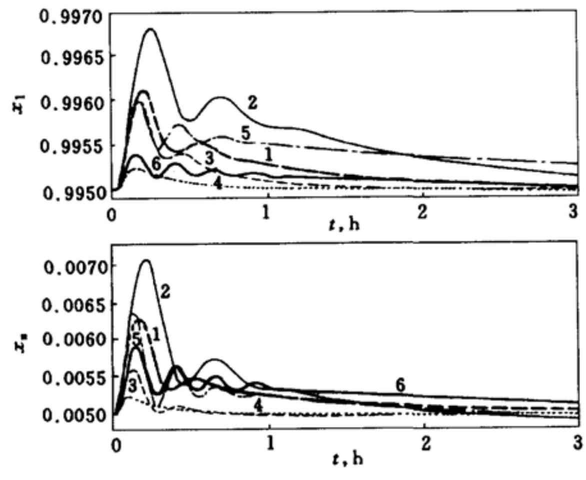

Figure 7 Regulatory responses to a feed composition disturbances

1—(D, q); 2—(D, V); 3—(L/D, $p_r - p_s$); 4—(L/D, V/B); 5—(q, V); 6—($p_r - p_s$, q)

6 CONCLUSIONS

Several conclusions were obtained for a general HIDiC and summarized as follows:

(1) The double ratio control configuration (L/D, V/B) appears to be the best one for the process operation. In addition, it is worthy to mention that it is much easier to tune the control system than any other control configurations. This, on the other hand, reflects its high robustness. However, care should be taken towards the possible sensitivity to input uncertainties.

(2) The pressure difference between the rectifying and the stripping sections, $p_r - p_s$, and the feed thermal condition, q, are consistent manipulative variables for the process operation. The control configuration ($p_r - p_s$, q) was proved to be a feasible one although it is not a high-ranking alternative. The major concern with this scheme is the strong interaction among control loops.

(3) The conventional control schemes, such as (D, V), can be used for the operation of the general HIDiC. However, the strong interaction in these schemes might be a potential problem that can cause degraded system performances or even instability.

(4) The performances of the general HIDiC can be improved substantially by adopting effective multivariable control methods, especially for those control configurations without ratio manipulative variables. The implications from the control configurations (L/D, V/B) and (L/D, $p_r - p_s$) justify this conclusion.

NOMENCLATURE

B	bottom product flow rate, kmol·s^{-1}
CN	condition number
D	overhead product rate, kmol·s^{-1}
F	feed flow rate, kmol·s^{-1}
G	process model
H	level, m
ISE	integral square error
L	liquid flow rate, kmol·s^{-1}
MRI	Morari resilience index
NI	Niederlinski index
n	number of total stages
$p_r - p_s$	pressure difference between rectifying and stripping sections, kPa
q	thermal condition of feed
RGA	relative gain array
t	time, s
V	vapor flow rate, kmol·s^{-1}
x	mole fraction of liquid
z_f	feed composition
y	mole fraction of vapor

r condition number

λ element of RGA

ω frequency, $rad \cdot s^{-1}$

Subscripts

B bottom

C reflux drum

D overhead

R reboiler

REFERENCES

1 Takamatsu, T., Hashimoto, I., Hashimoto, Y., "Selection of manipulated variables to minimize interaction in multivariate control of a distillation column", *Int. Chem. Eng.*, **27** (4), 669 (1987).

2 Takamatsu, T., Nakaiwa, M., Huang, K., Akiya, T., Aso K., "Simulation oriented development of a new heat integrated distillation column and its characteristics for energy saving", *Comput. and Chem. Eng.*, **S21**, 243 (1997).

3 Nakaiwa, M, Huang, K., Owa, M., Akiya, T., Nakane, T., Takamatsu, T., "Operating an ideal heat integrated distillation column with different control algorithms", *Comput. and Chem. Eng.*, **S22**, 389 (1998).

4 Haggblom, K. E., Waller, K. V., "Transformation and consistency relations of distillation control structures", *AIChE J.*, **34** (10), 1634 (1988).

5 Yang, D. R., Waller, K. V., Seborg, D. E., Mellichamp, D. A., "Dynamic structural transformations for distillation control configurations", *AIChE J.*, **36** (9), 1391 (1990).

6 Skogestad, S., Lundstrom, P., Jacobsen, E. W., "Selecting the best distillation control configuration", *AIChE J.*, **36** (5), 753 (1990).

7 Finco, M., Luyben, W. L., Polleck, R. E., "Control of distillation columns with low relative volatilities", *Ind. Eng. Chem. Res.*, **28** (1), 75 (1989).