CHAPTER VI

CONTROL STRUCTURES AND DYNAMIC SIMULATION

The essential task of plantwide control for a complex plant consists of recycle streams and energy integration is maintaining the plant energy and mass balances. As the operating condition changes, the control system is needed to reject loads and regulate an entire process into a design condition to achieve its objectives. Therefore, our purpose of this chapter is to present the new control structures of HDA process with energy integration (Alternative 6). In addition, the four new designed control structures are also compared with the prior work based on rigorous dynamic simulation using the commercial software HYSYS.

6.1 Design of plantwide Control for HDA Process with minimum Auxiliary Reboiler

The plantwide control systems for the HDA process is developed based on the HPH. However, the designed control systems must achieve certain control objectives within prescribed operational constraints. The control objectives for this process are typical for a chemical processes and listed below:

1. Maintain process variables at desired values
2. Keep process operating conditions within equipment constraints.
3. Minimize variability of the product rate and the product quality during Disturbances
4. Minimize the disturbance propagation

For the HDA process, several constraints are given by Douglas (1988). These include:

1. The reactor feed ratio of hydrogen to aromatic feed must be greater than 5:1

to prevent coking

2. The reactor outlet temperature must be less than 704°C to prevent hydro – cracking
3. The reactor effluent must be quenched to 621.1°C with liquid from separator to prevent fouling in the process-to-process heat exchanger
4. The conversion must be less than 0.97 for the product distribution Correlation

The four new control structures are designed for HDA process alternative 6 with minimum auxiliary utility unit that is propose in this research

6.1.1 Control Structure 1 (CS1) for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units.

This control structure is shown in Figure 6.1.In this control structure, the all bypass of 3 feed effluent heat exchangers (FEHE) is on cold side. A selector controller with low selector switch (LSS) for FEHE1 is employed to select an appropriate heat pathway. This control system involves one manipulated variable (bypass valve of FEHE1) and two controlled variable (hot and cold outlet temperature of FEHE1). The appropriate controlled variable is selected by LSS in order to achieve maximum energy recover.

Since the hot reactor product is used to drive reboiler in the three columns, part of this stream is bypassed and manipulated to control the tray temperatures in the three columns. In odder to prevent the propagation of thermal disturbance to separation section, the hot outlet temperatures of FEHE2 (the temperature at the entrance of the reboilers at stabilizer column) are controlled by manipulating the bypass valves and the hot outlet temperatures of FEHE3 (the temperature at the entrance of the reboilers at recycle column) are controlled by manipulating the bypass valves of FEHE3.

Since the four auxiliary utility units consist of three auxiliary reboilers at stabilizer column, product column and recycle column and one auxiliary condenser at recycle column. There are employed next to process to process heat exchanger as reboiler or condenser unit as show in figure 6.1. The optimum operation would be to minimize the heat load of auxiliary utility units. One way to do this is the using split range control. This control system involves two manipulated variable (the bypass valve of process to process heat exchanger and heat load of auxiliary utility unit) and one controlled variables (temperature or pressure) and works as for example: if the decreasing disturbance loads of hot stream occurs at reboiler and then the percent opening of bypass valve at reboiler will decrease in order to increase heat transfer at reboiler unit until the target tray temperature achieves. The heat load of the auxiliary utility units will be used when the bypass valve is full close but the target tray temperature still doesn't achieves the target tray temperature. The split range control is used for the tray temperature control in stabilizer column, product column and recycle column by manipulating the bypass valve of reboiler and the heat load of the auxiliary reboiler. For recycle column, the split control is also applied to control column pressure by manipulating the bypass valve of condenser and the heat load of the auxiliary condenser.

Since the temperature profile in the recycle column is very sharp because of temperature changes from tray to tray. This means that the process gain is very large when a single tray temperature is controlled. The standard solution for this problem is to use an average (AVG) temperature of several trays instead of a single tray (Luyben, 2002).

A heat exchanger (i.e. as a heat source or a heat sink) is artificially installed in the hot-side stream in order to make the disturbance loads of the hot stream (i.e. the hot reactor product). Note that, this exchanger is not used in the real plant. The control structure and controller parameter are given in table 6.1. P controllers are employed for level loops, PI controllers for the pressure and flow loops and PID controllers for temperature loop.

6.1.2 Control Structure 2 (CS2) for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Unit

This control structure is shown in Figure 6.2. The major loops in this control structure are the same as CS1 except for control loop for FEHE .We apply the CS1 by changing the manipulated variable of the column C2 base level control from the feed flowrate of recycle column to the cold inlet flowrate of R2 and the feed flowrate of recycle column is flow-controlled for to reduce the material and flow fluctuation before propagate to the recycle column when the disturbance occurs. The controller parameter is given in table 6.2.

6.1.3 Control Structure 3 (CS3) for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Unit

This control structure is shown in Figure 6.3 and the control configuration is given in table 6.3. The major loops in this control structure are the same as CS1 except for temperature control in product distillation column. The temperature control in product distillation column is two point controls as the tray 12 and tray 17 temperatures.

6.1.4 Control Structure 4 (CS4) for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Unit

This control structure is shown in Figure 6.4 and the control configuration is given in table 6.4. The major loops in this control structure are the same as CS1 except for control loop for FEHE. The all bypass of 3 FEHEs will be on hot side.

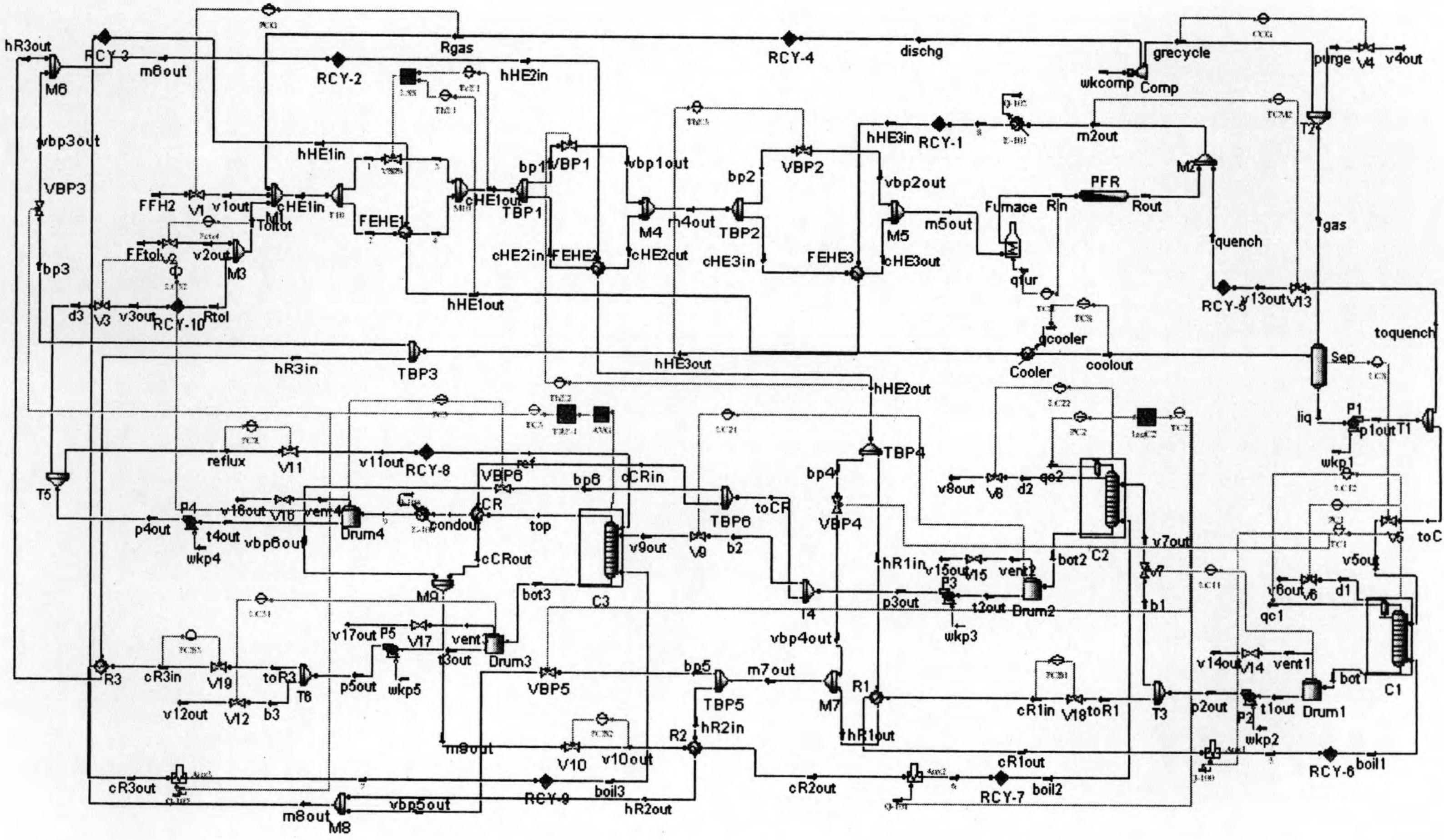


Figure 6.1 Control Structure 1 (CS1) for HDA Process Alternative 6(Basecase) with Three Auxiliary Utility Unit

Table 6.1 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: Control Structure 1

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.300	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.970	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.40	1.360	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3) and auxiliary reboiler 1 (AR1) duty	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCC3	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5) and auxiliary condenser(ACR) duty	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4) and auxiliary reboiler 3 (AR3) duty	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

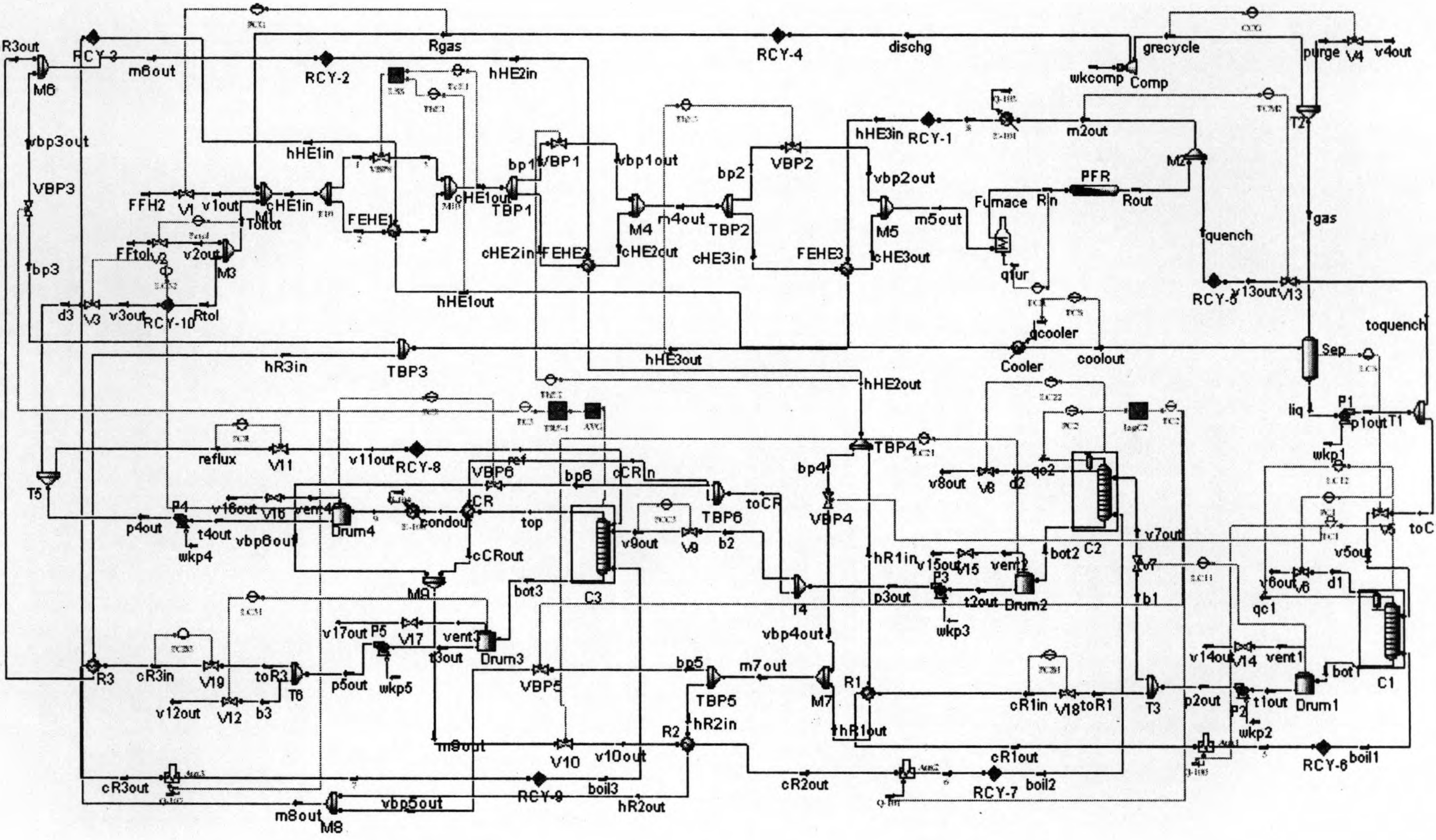


Figure 6.2 Control Structure 1 (CS2) for HDA Process Alternative 6(Basecase) with Three Auxiliary Utility Units

Table 6.2 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: Control Structure 2

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.300	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.970	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.40	1.360	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3) and auxiliary reboiler 1 (AR1) duty	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCC3	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5) and auxiliary condenser(ACR) duty	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4) and auxiliary reboiler 3 (AR3) duty	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

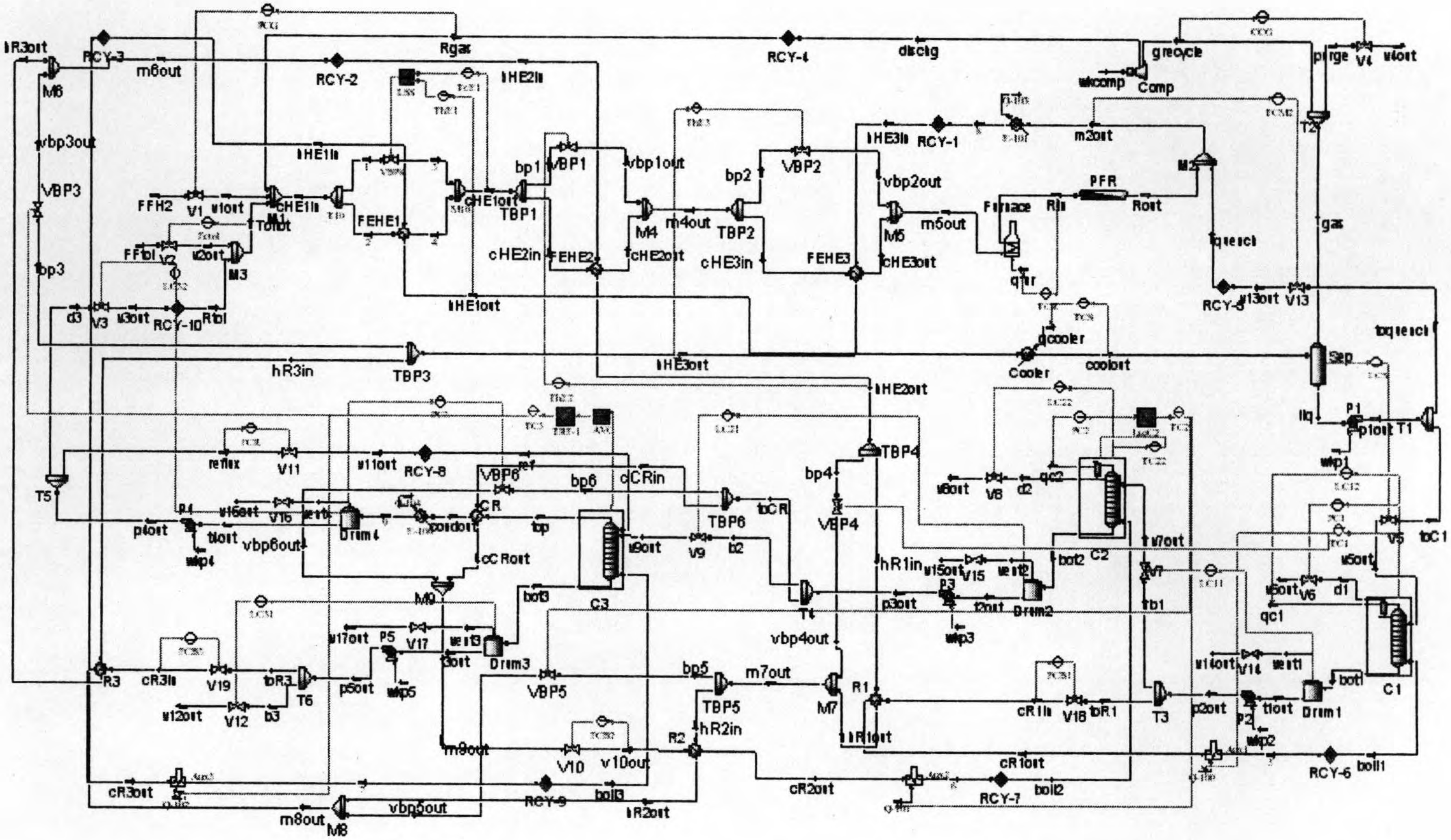


Figure 6.3 Control Structure 3 (CS3) for HDA Process Alternative 6(Basecase) with Three Auxiliary Utility Units

Table 6.3 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: Control Structure 3

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.30	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.97	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3) and auxiliary reboiler 1 (AR1) duty	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC21	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.9	6.9	0.325
TC22	column C2 tray-17 temperature	column 2 reflux flow rate	PID	6.87	7.34	1.63
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5) and auxiliary condenser(ACR) duty	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4) and auxiliary reboiler 3 (AR3) duty	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

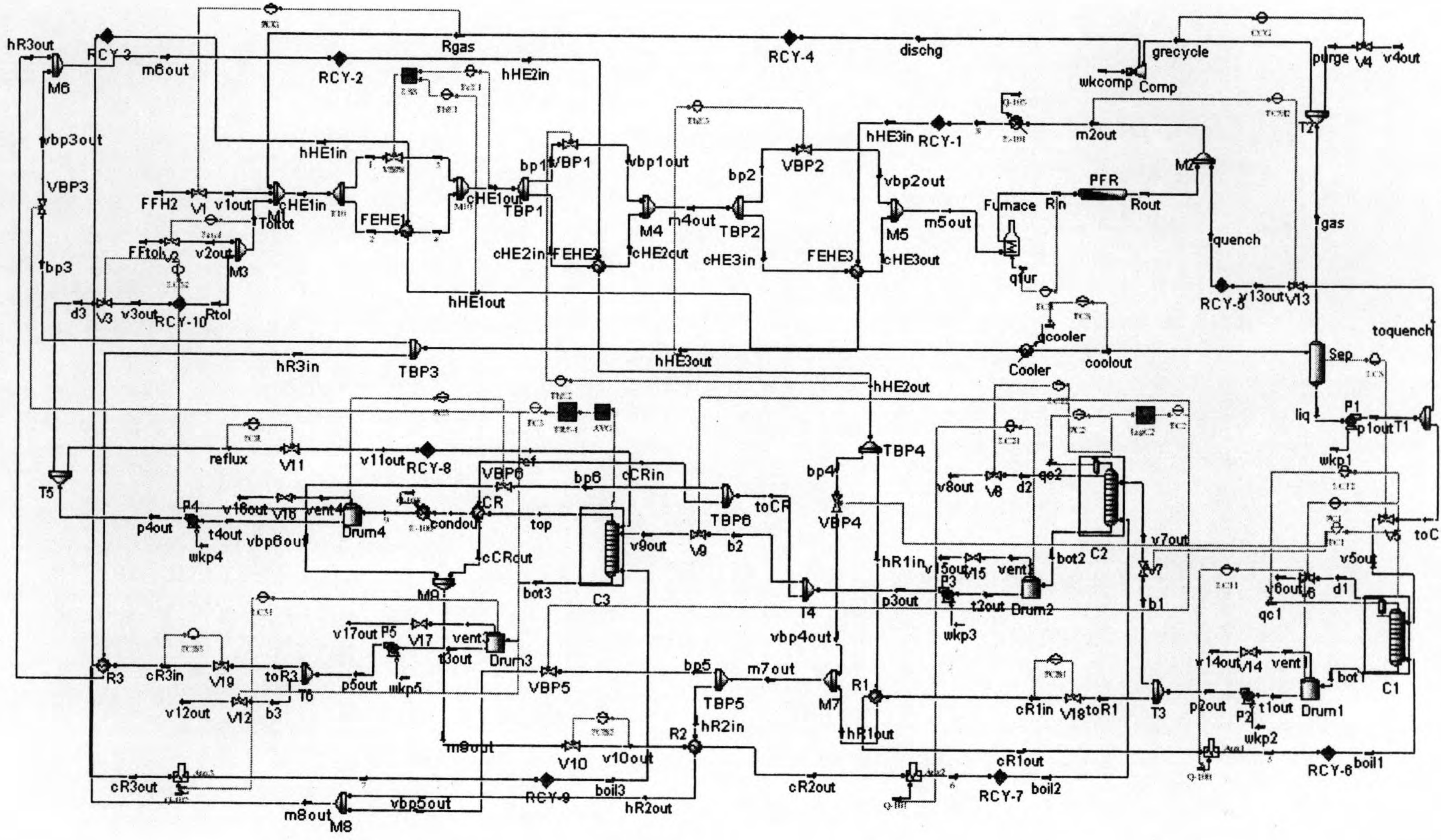


Figure 6.4 Control Structure 4 (CS4) for HDA Process Alternative 6(Basecase) with Three Auxiliary Utility Units

Table 6.4 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: Control Structure 4

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.300	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.970	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.40	1.360	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3) and auxiliary reboiler 1 (AR1) duty	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCC3	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5) and auxiliary condenser(ACR) duty	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4) and auxiliary reboiler 3 (AR3) duty	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

6.1.5 Control Structure 1 (CS1) for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary utility unit

The same control structure 1 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.5). Since the number of minimum auxiliary utility unit for HDA process alternative 6 is only one unit therefore the split range control will employ only one for product column to control the tray temperature. The control structure and controller parameter are given in table 6.5.

6.1.6 Control Structure 2 (CS2) for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary utility unit

The same control structure 2 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.6). We apply the CS1 by changing the manipulated variable of the column C2 base level control from the feed flowrate of recycle column to the cold inlet flowrate of R2 and the feed flowrate of recycle column is flow-controlled for to reduce the material and flow fluctuation before propagate to the recycle column when the disturbance occurs. The control structure and controller parameter are given in table 6.6.

6.1.7 Control Structure 3 (CS3) for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.7 and the control configuration is given in table 6.7. The major loops in this control structure are the same as CS1 except for temperature control in product distillation column. The temperature control in product distillation column is two point controls as the tray 12 and tray 17 temperatures.

6.1.8 Control Structure 4 (CS4) for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.8 and the control configuration is given in table 6.8. The major loops in this control structure are the same as CS1 except for control loop for FEHE. The all bypass of 3 FEHEs will be on hot side.

6.1.9 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN1 with Minimum Auxiliary utility unit

The same control structure 1 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.9). Since the number of minimum auxiliary utility unit for HDA process alternative 6 is only one unit therefore the split range control will employ only one for product column to control the tray temperature. The control structure and controller parameter are given in table 6.9.

6.1.10 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN1 with Minimum Auxiliary utility unit

The same control structure 2 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.10). We apply the CS1 by changing the manipulated variable of the column C2 base level control from the feed flowrate of recycle column to the cold inlet flowrate of R2 and the feed flowrate of recycle column is flow-controlled for to reduce the material and flow fluctuation before propagate to the recycle column when the disturbance occurs. The control structure and controller parameter are given in table 6.10.

6.1.11 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN1 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.11 and the control configuration is given in table 6.11. The major loops in this control structure are the same as CS1 except for temperature control in product distillation column. The temperature control in product distillation column is two point controls as the tray 12 and tray 17 temperatures.

6.1.12 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN1 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.12 and the control configuration is given in table 6.12. The major loops in this control structure are the same as CS1 except for control loop for FEHE. The all bypass of 2 FEHEs will be on hot side.

6.1.13 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

The same control structure 1 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.13). Since the number of minimum auxiliary utility unit for HDA process alternative 6 is only one unit therefore the split range control will employ only one for product column to control the tray temperature. The control structure and controller parameter are given in table 6.13.

6.1.14 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

The same control structure 2 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.14). We apply the CS1 by changing the manipulated variable of the column C2 base level control from the feed flowrate of recycle column to the cold inlet flowrate of R2 and the feed flowrate of recycle column is flow-controlled for to reduce the material and flow fluctuation before propagate to the recycle column when the disturbance occurs. The control structure and controller parameter are given in table 6.14.

6.1.15 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.15 and the control configuration is given in table 6.15. The major loops in this control structure are the same as CS1 except for temperature control in product distillation column. The temperature control in product distillation column is two point controls as the tray 12 and tray 17 temperatures.

6.1.16 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.16 and the control configuration is given in table 6.16. The major loops in this control structure are the same as CS1 except for control loop for FEHE. The all bypass of 2 FEHEs will be on hot side.

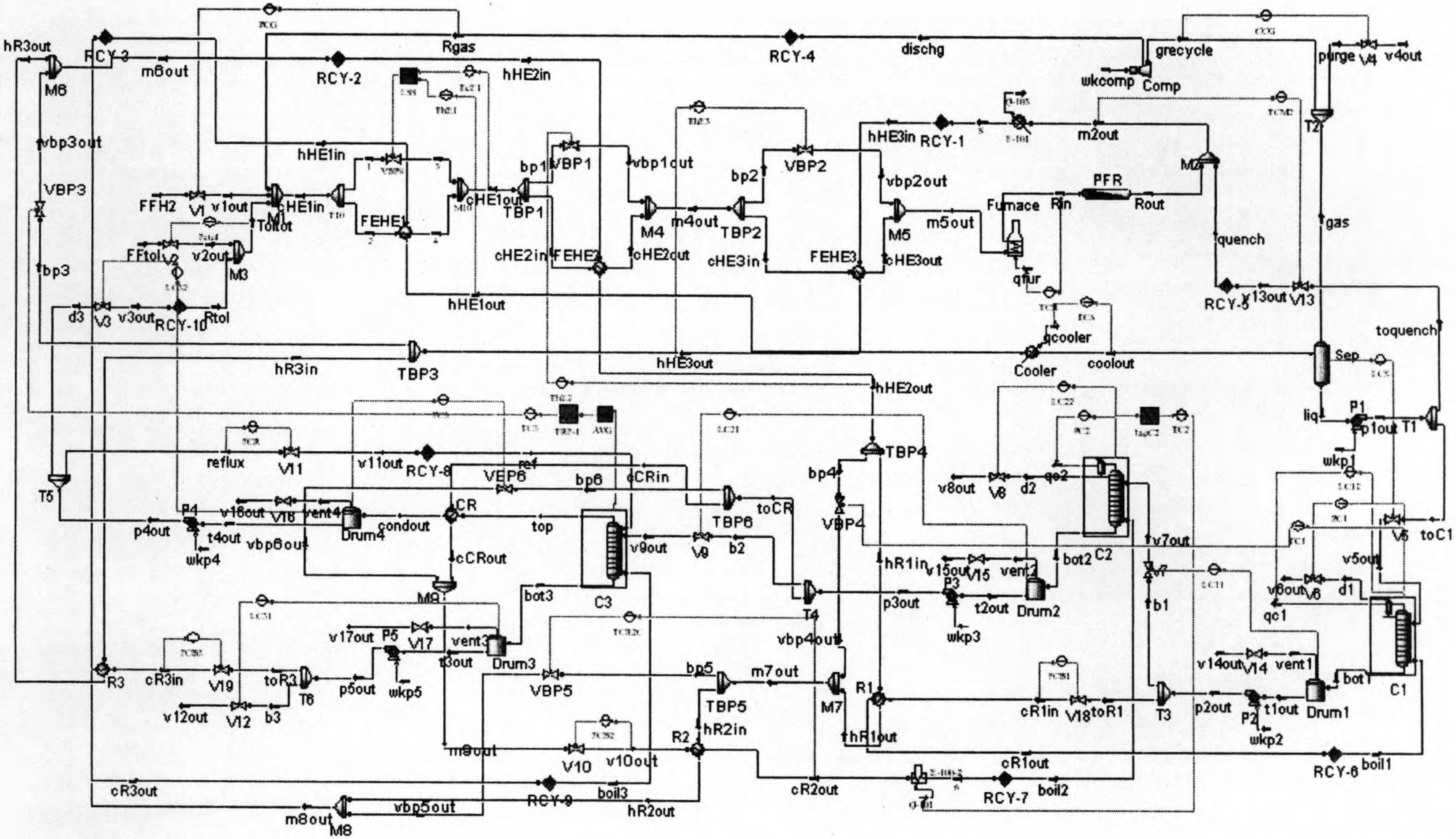


Figure 6.5 Control Structure 1 (CS1) for HDA Process Alternative 6(Basecase) with minimum Auxiliary Utility Unit

Table 6.5 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Unit: Control Structure 1

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate .	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

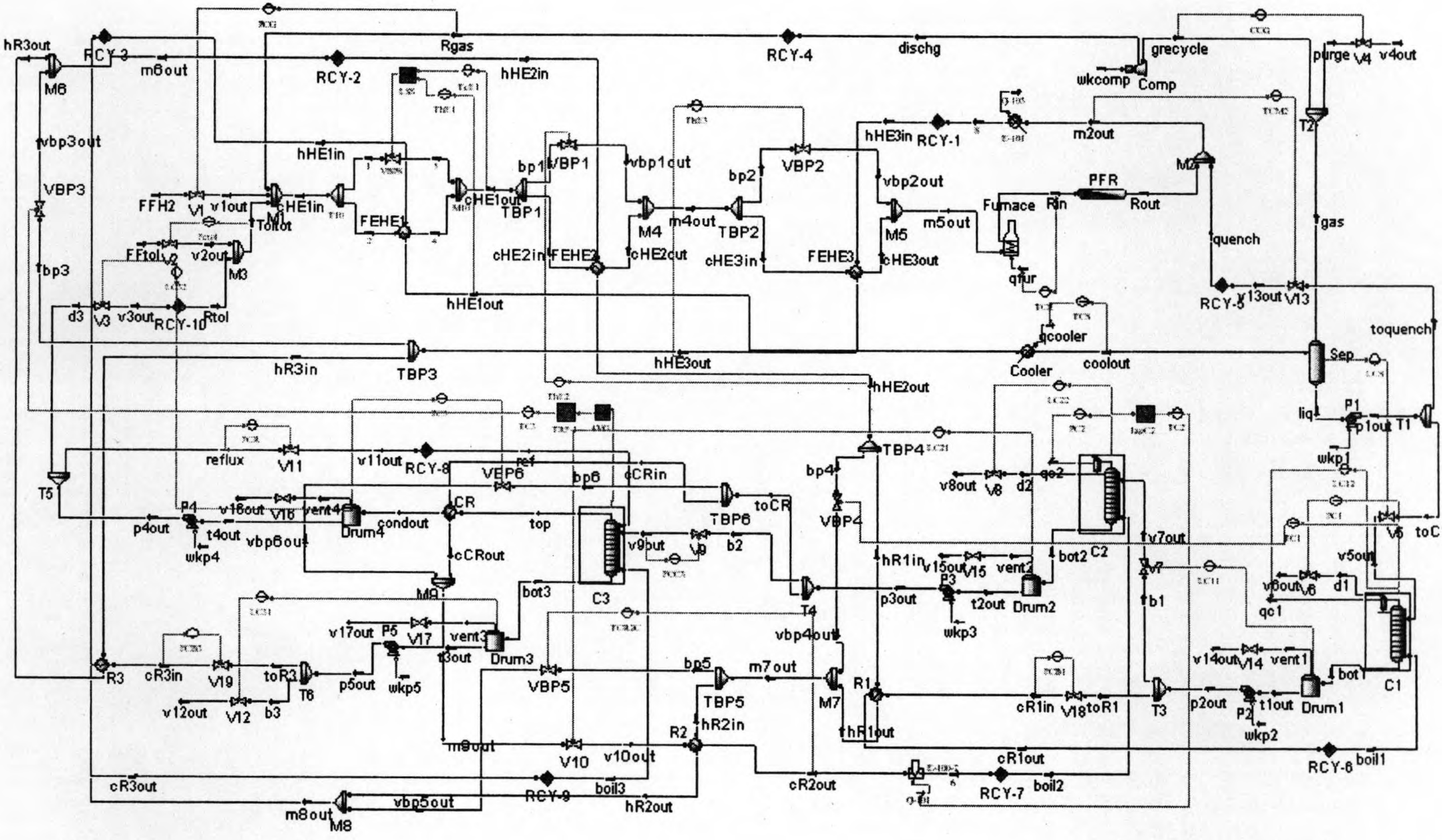


Figure 6.6 Control Structure 2 (CS2) for HDA Process Alternative 6(Basecase) with minimum Auxiliary Utility Unit

Table 6.6 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Unit: Control Structure 2

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

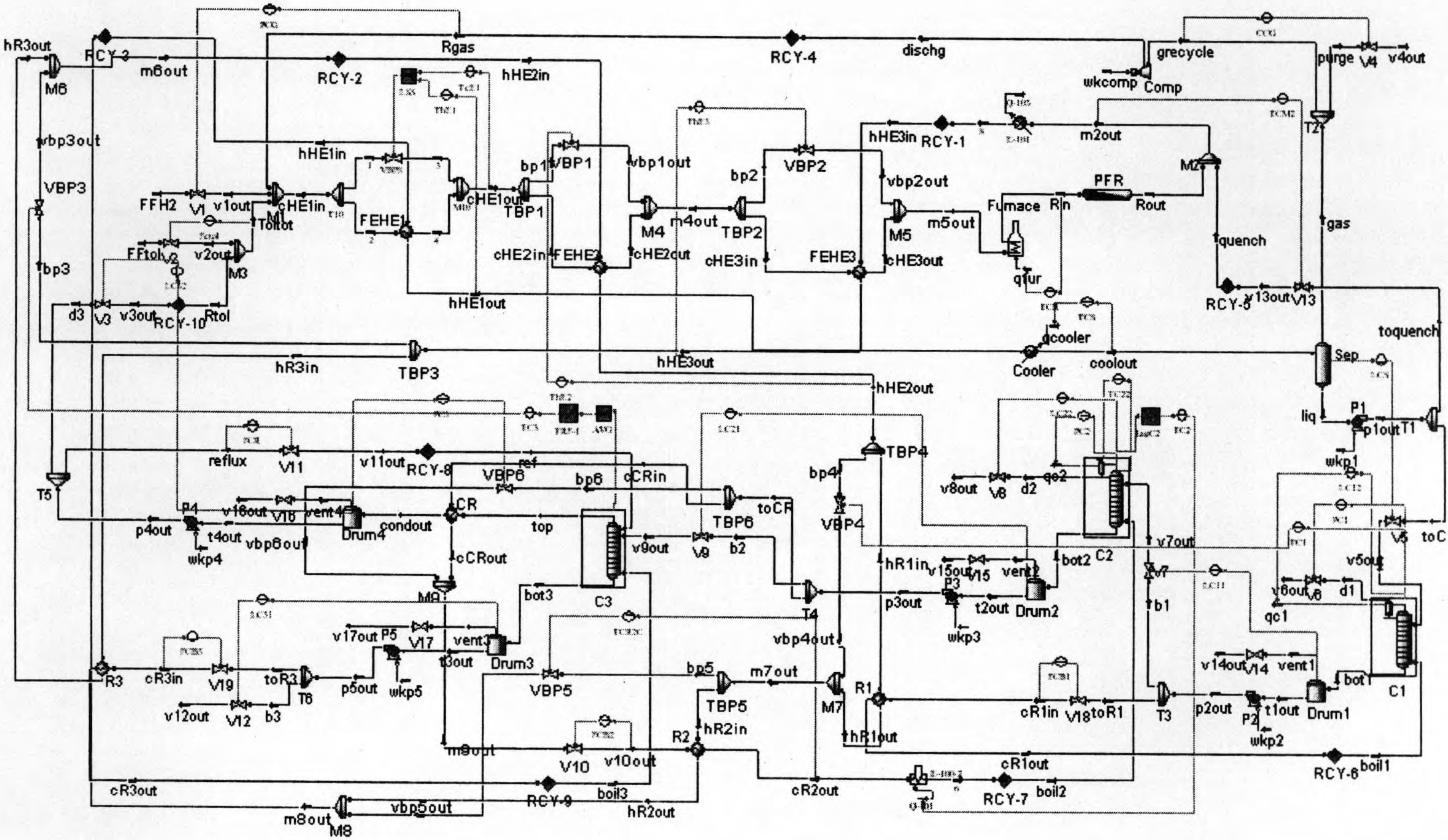


Figure 6.7 Control Structure 3 (CS3) for HDA Process Alternative 6(Basecase) with minimum Auxiliary Utility Unit

Table 6.7 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Unit: Control Structure 3

controller name	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.97	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC21	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
TC22	column C2 tray-17 temperature	column 2 reflux flow rate	PID	6.87	7.34	1.63
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

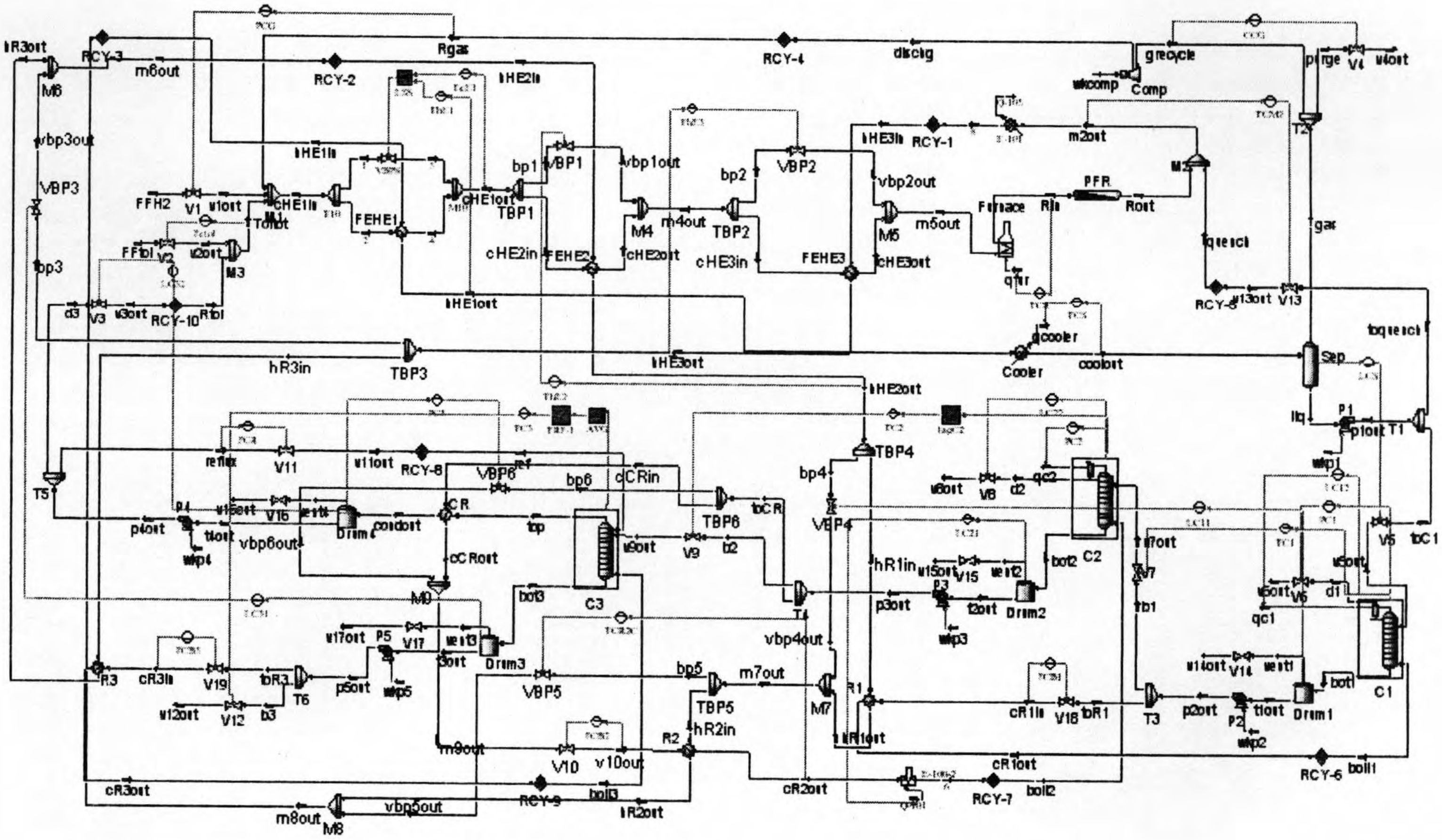


Figure 6.8 Control Structure 4 (CS4) for HDA Process Alternative 6(Basecase) with minimum Auxiliary Utility Unit

Table 6.8 Control Structure and Controller Parameter for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Unit: Control Structure 4

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
ThE3	FEHE3 hot-outlet temperature	FEHE3 bypass cold stream valve (VBP3)	PID	0.566	0.893	0.199
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

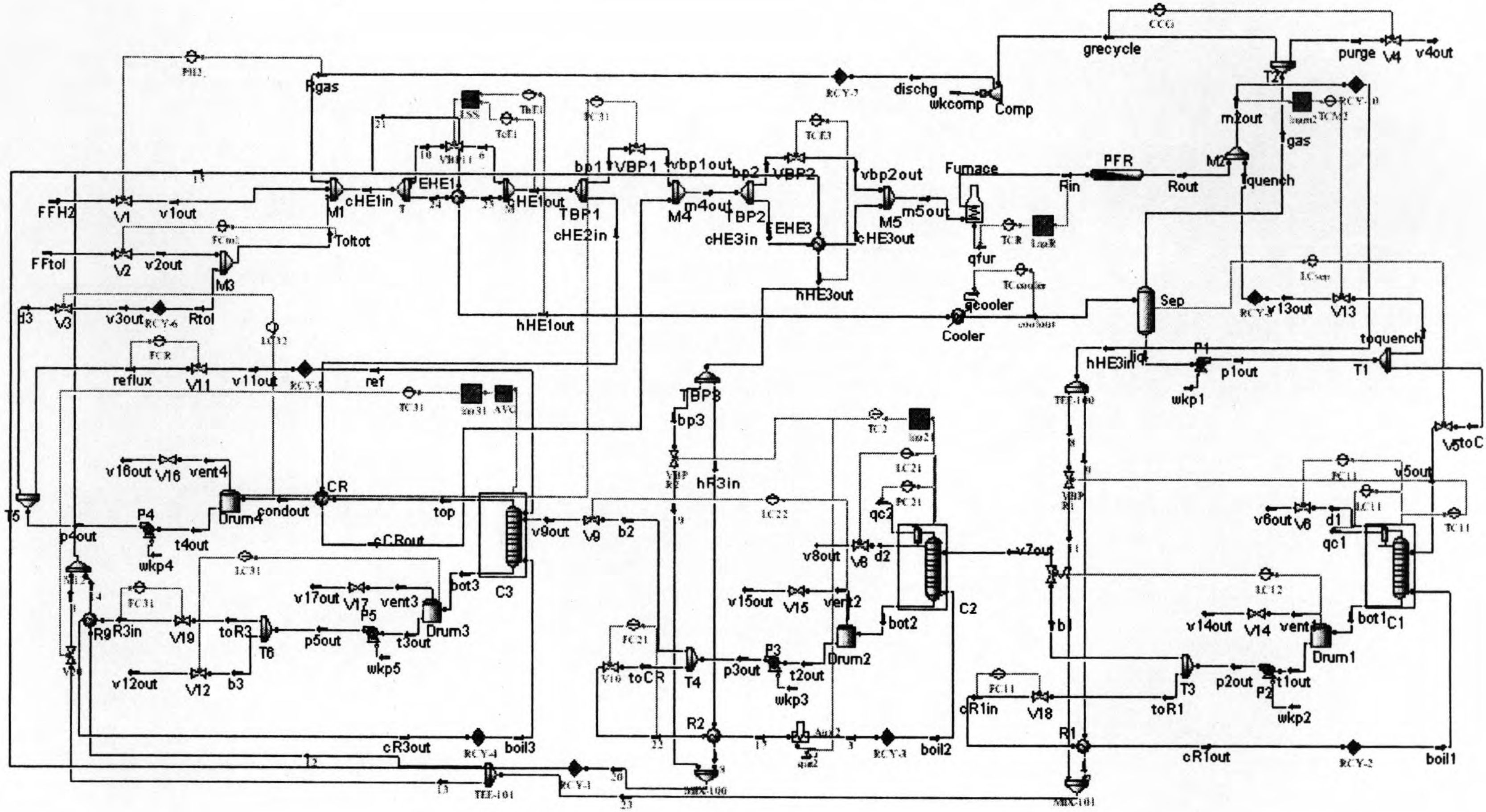


Figure 6.9 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN1 with minimum Auxiliary Utility Unit

Table 6.9 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 1 with minimum Auxiliary Utility Unit: Control Structure 1

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

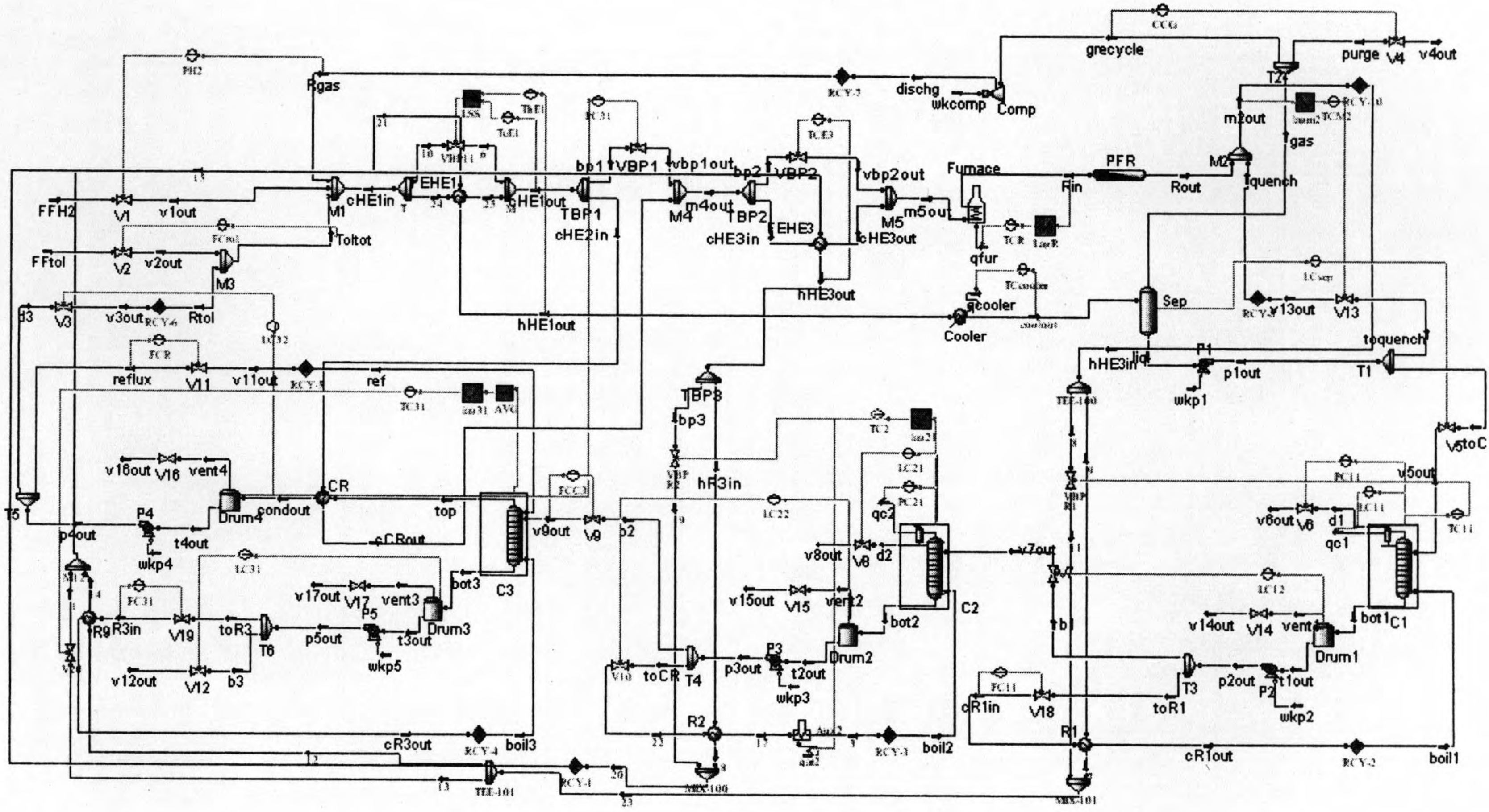


Figure 6.10 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN1 with minimum Auxiliary Utility Unit

Table 6.10 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 1 with minimum Auxiliary Utility Unit: Control Structure 2

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

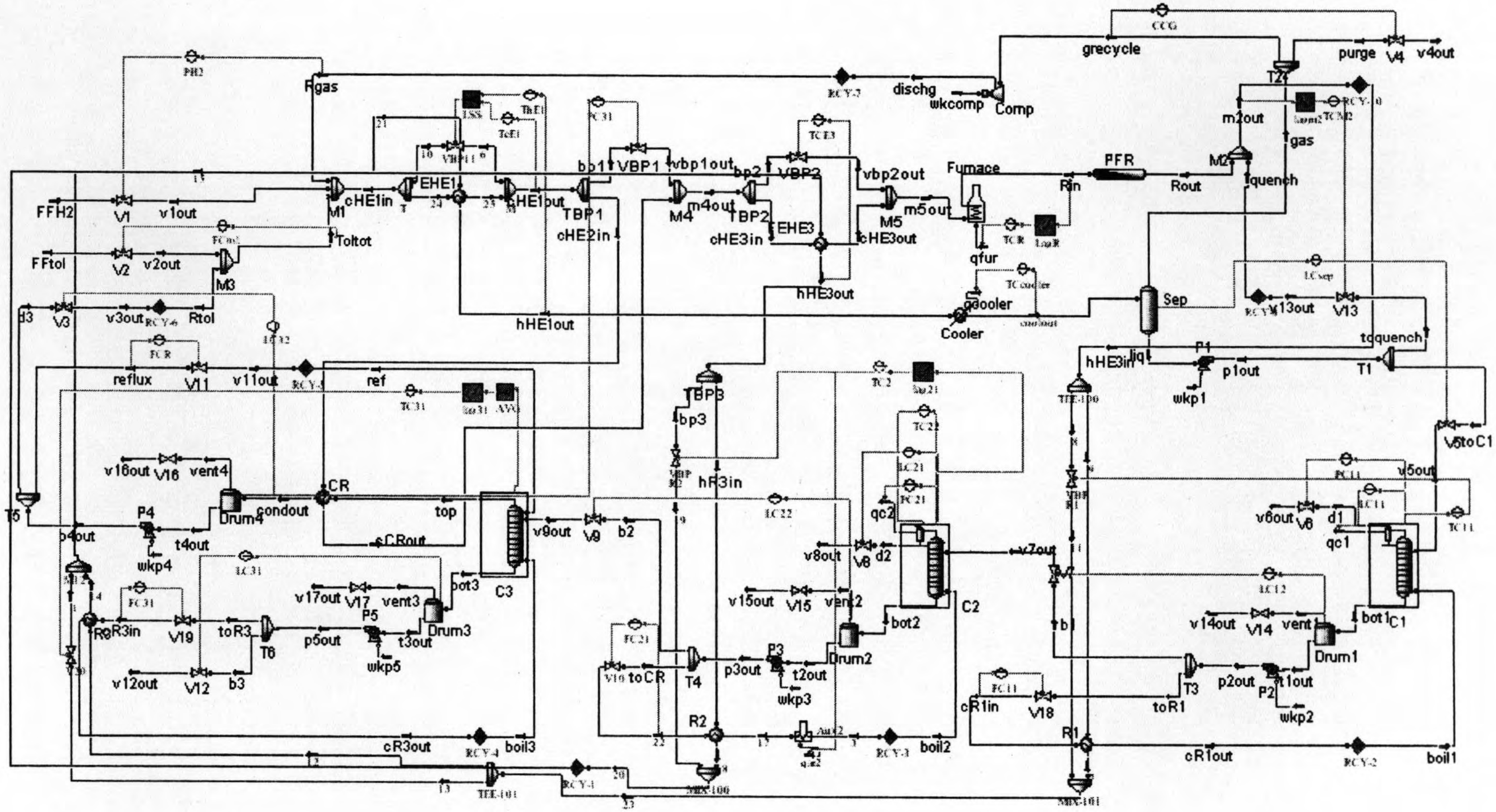


Figure 6.11 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN1 with minimum Auxiliary Utility Unit

Table 6.11 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 1 with minimum Auxiliary Utility Unit: Control Structure 3

controller name	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.97	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC21	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
TC22	column C2 tray-17 temperature	column 2 reflux flow rate	PID	6.87	7.34	1.63
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

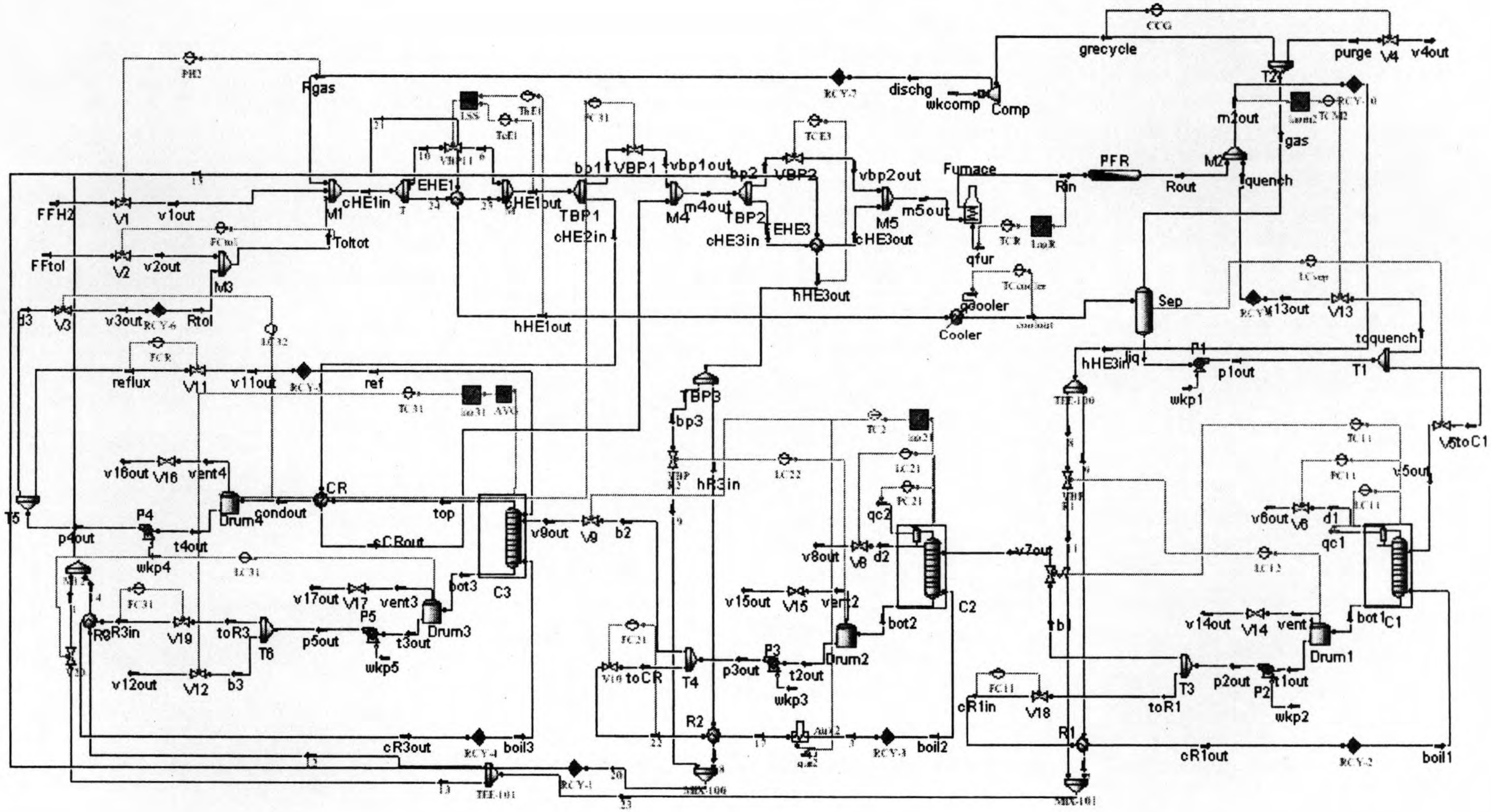


Figure 6.12 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN1 with minimum Auxiliary Utility Unit

Table 6.12 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 1 with minimum Auxiliary Utility Unit: Control Structure 4

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

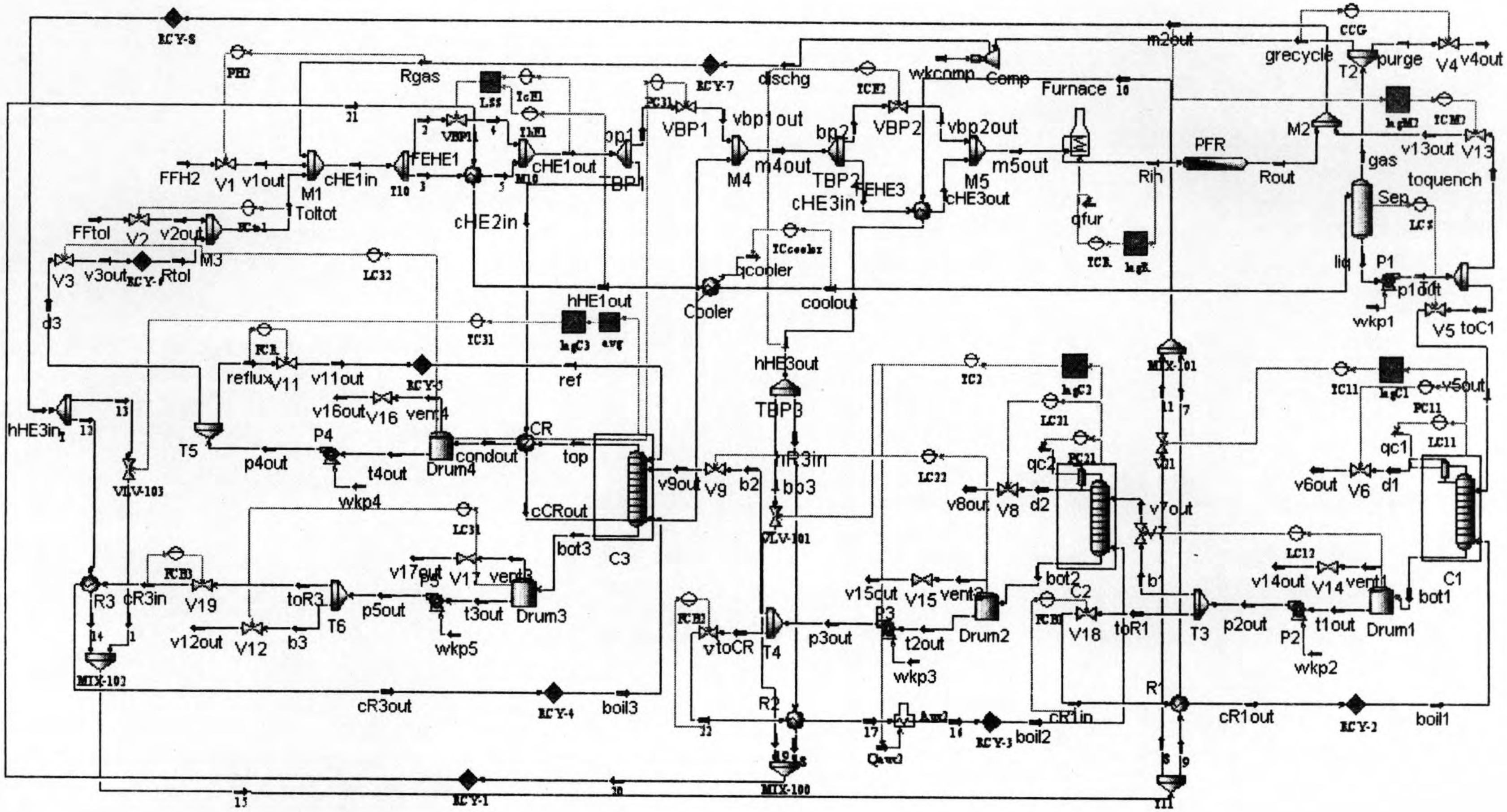


Figure 6.13 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN2 with minimum Auxiliary Utility Unit

Table 6.13 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 2 with minimum Auxiliary Utility Unit: Control Structure 1

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

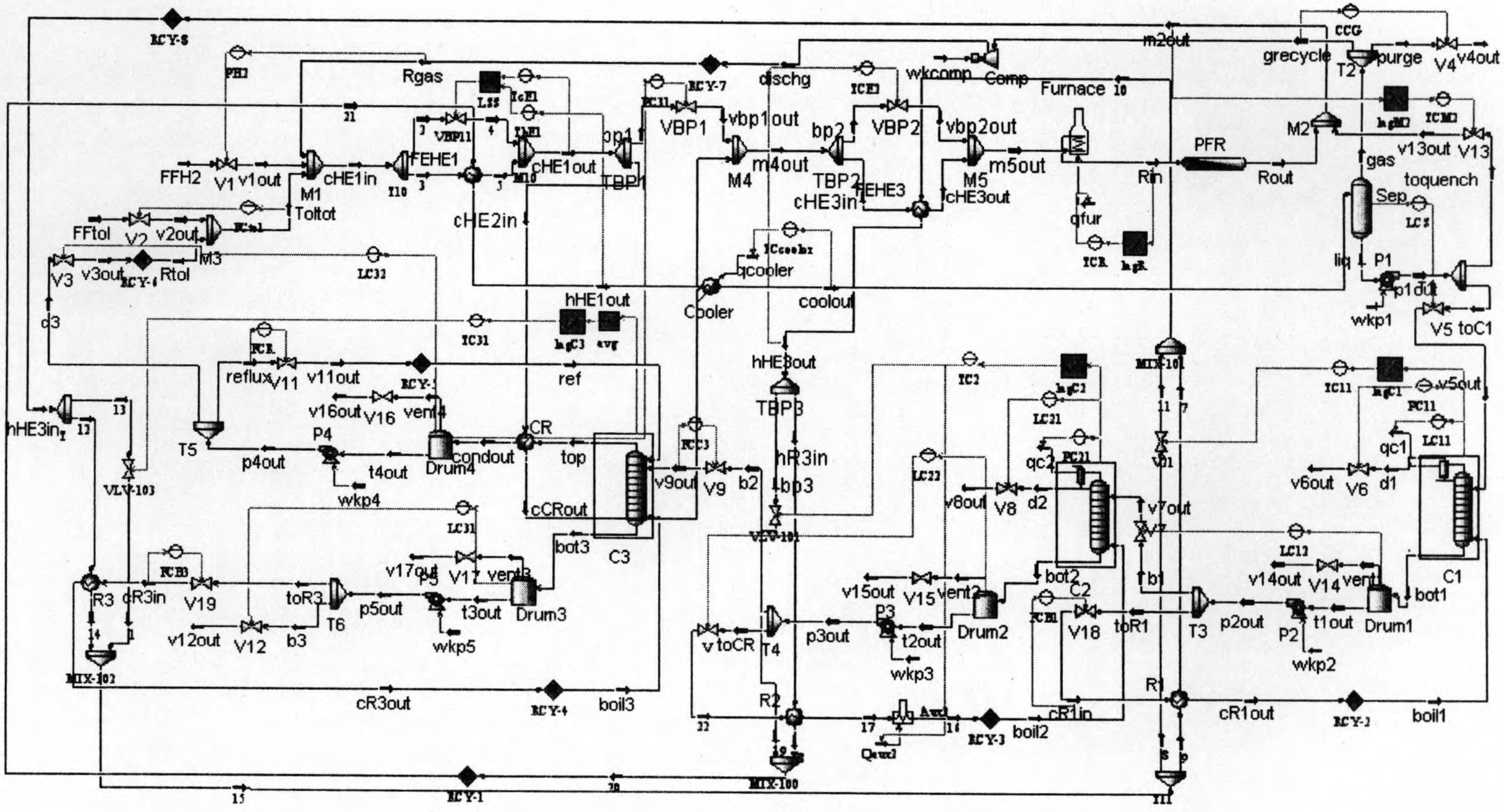


Figure 6.14 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN2 with minimum Auxiliary Utility Unit

Table 6.14 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN2 with minimum Auxiliary Utility Unit: Control Structure 2

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

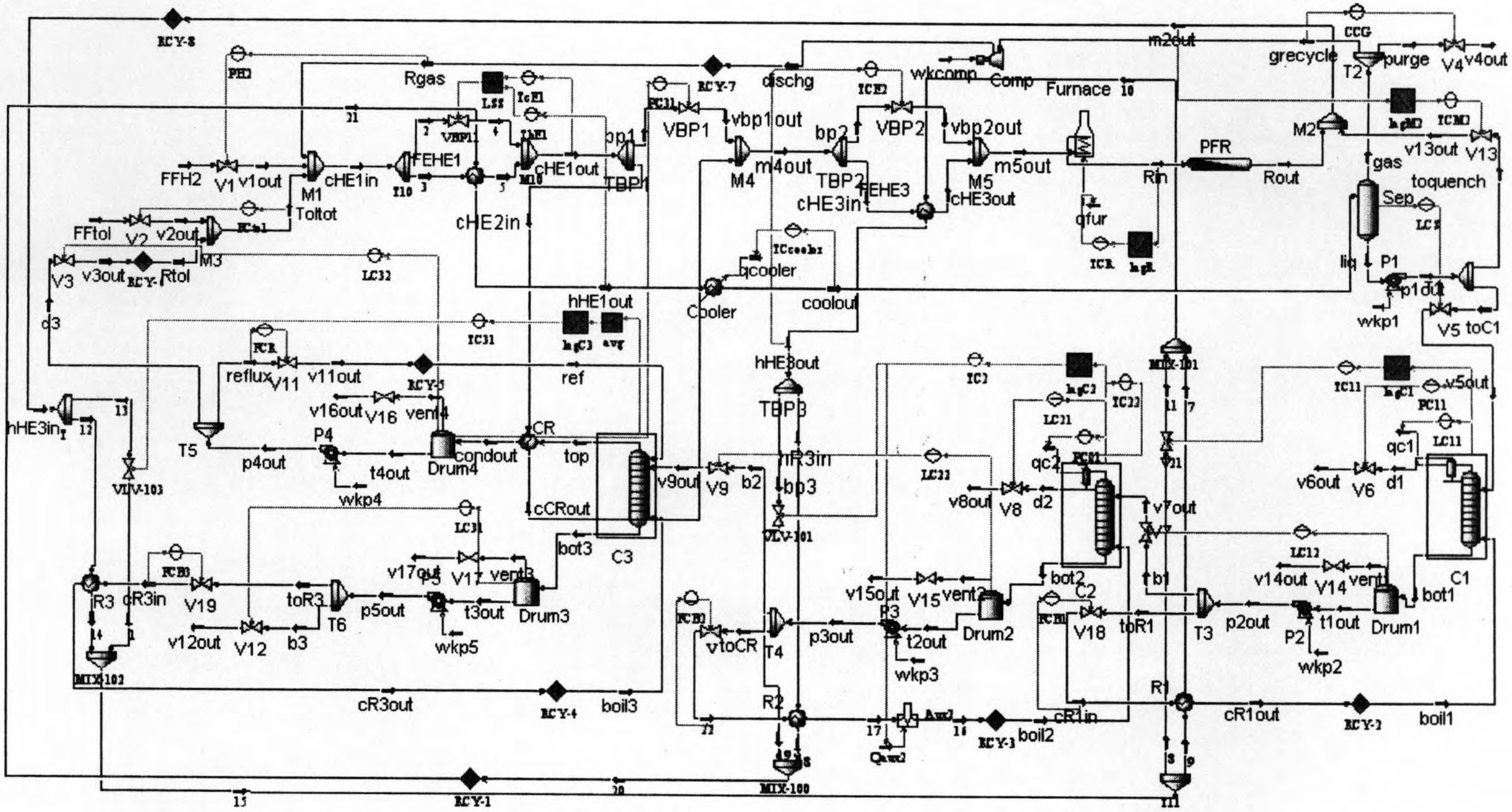


Figure 6.15 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN2 with minimum Auxiliary Utility Unit

Table 6.15 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 2 with minimum Auxiliary Utility Unit: Control Structure 3

controller name	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.97	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC21	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
TC22	column C2 tray-17 temperature	column 2 reflux flow rate	PID	6.87	7.34	1.63
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

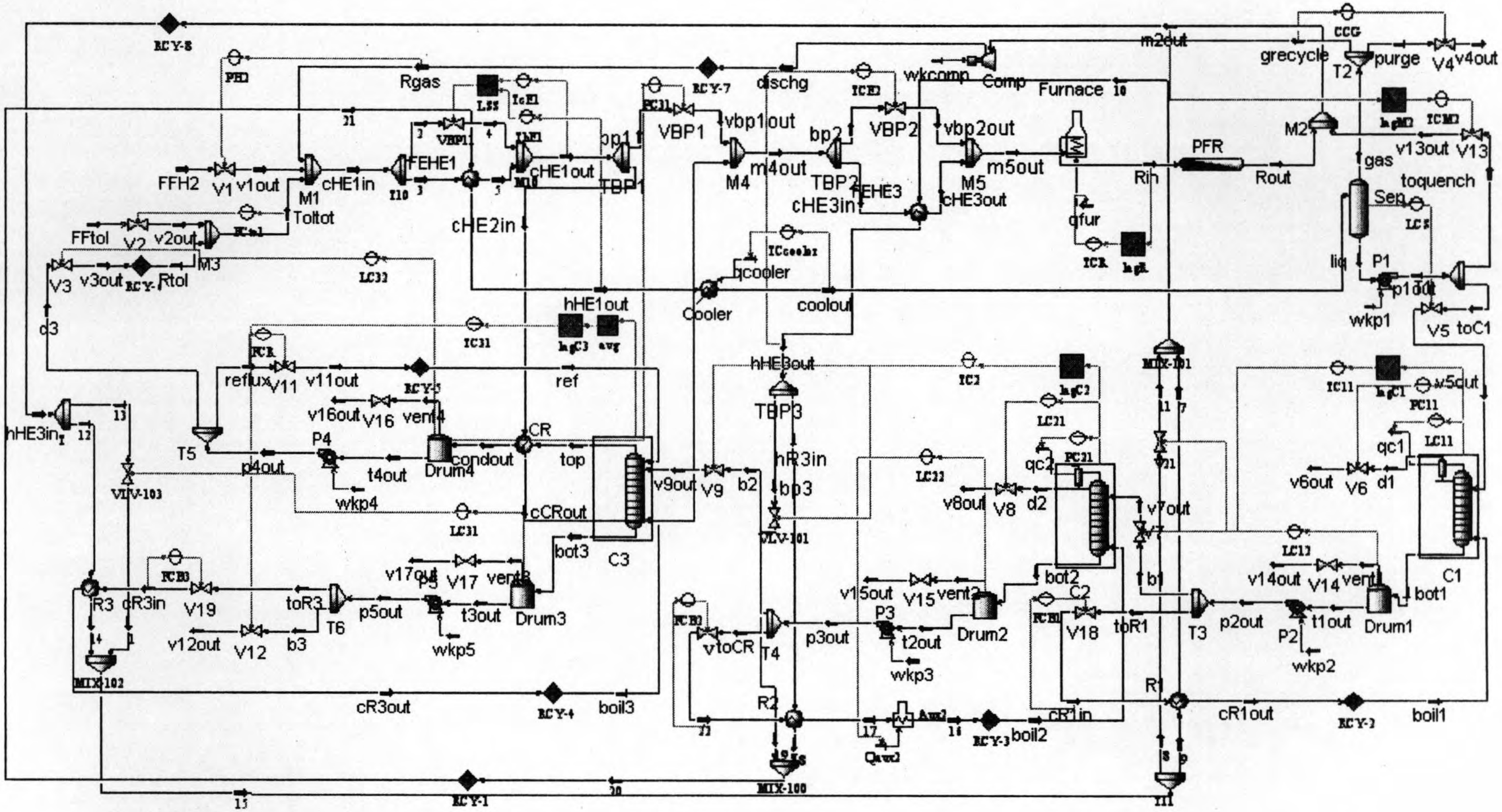


Figure 6.16 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN2 with minimum Auxiliary Utility Unit

Table 6.16 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 2 with minimum Auxiliary Utility Unit: Control Structure 4

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

6.1.17 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN3 with Minimum Auxiliary utility unit

The same control structure 1 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.17). Since the number of minimum auxiliary utility unit for HDA process alternative 6 is only one unit therefore the split range control will employ only one for product column to control the tray temperature. The control structure and controller parameter are given in table 6.17.

6.1.18 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN3 with Minimum Auxiliary utility unit

The same control structure 2 for HDA process alternative 6 with four auxiliary utility units is employed to HDA process alternative 6 with minimum auxiliary utility units (figure 6.18). We apply the CS1 by changing the manipulated variable of the column C2 base level control from the feed flowrate of recycle column to the cold inlet flowrate of R2 and the feed flowrate of recycle column is flow-controlled for to reduce the material and flow fluctuation before propagate to the recycle column when the disturbance occurs. The control structure and controller parameter are given in table 6.18.

6.1.19 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.19 and the control configuration is given in table 6.19. The major loops in this control structure are the same as CS1 except for temperature control in product distillation column. The temperature control in product distillation column is two point controls as the tray 12 and tray 17 temperatures.

6.1.20 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN2 with Minimum Auxiliary utility unit

This control structure is shown in Figure 6.20 and the control configuration is given in table 6.20. The major loops in this control structure are the same as CS1 except for control loop for FEHE. The all bypass of 2 FEHEs will be on hot side.

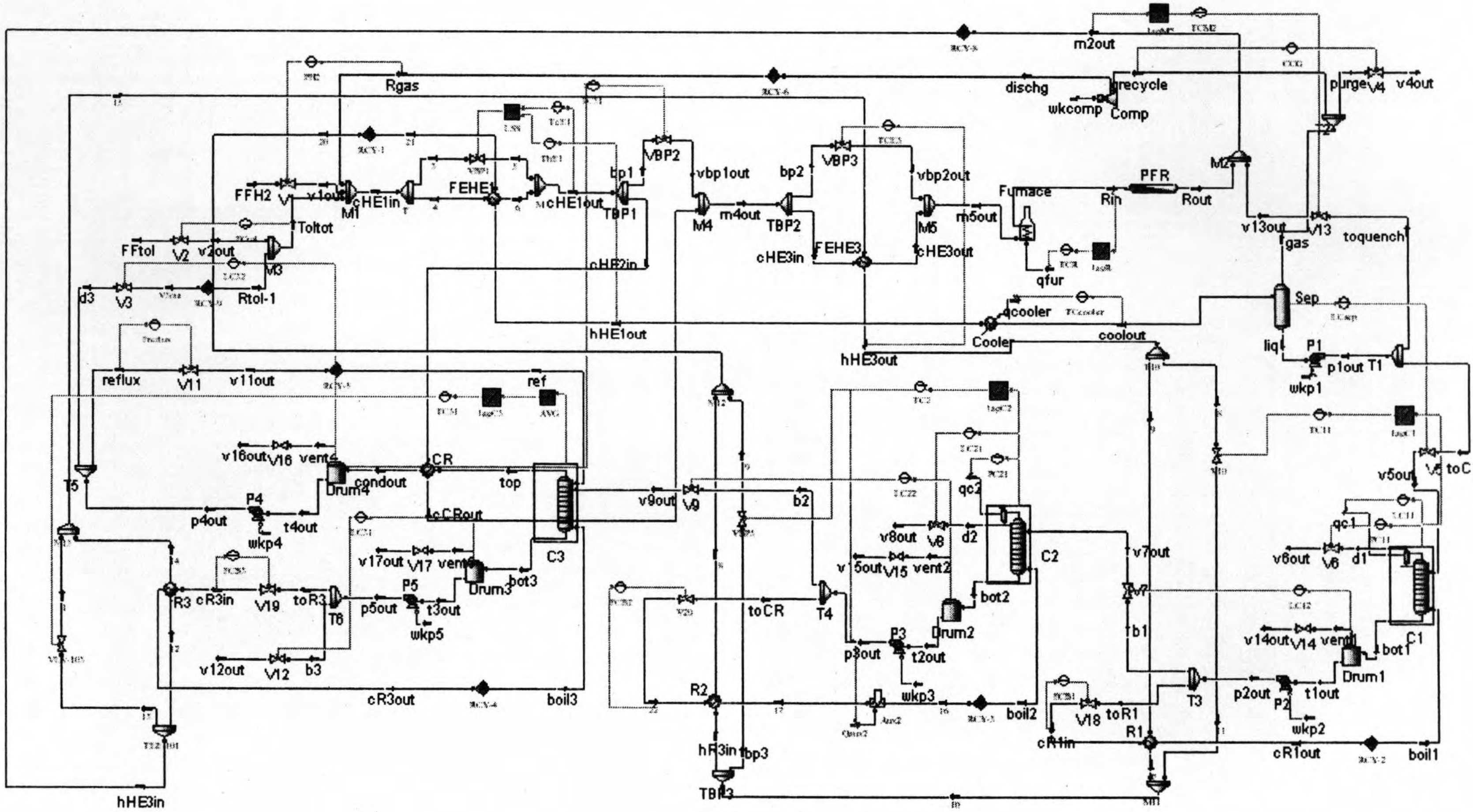


Figure 6.17 Control Structure 1 (CS1) for HDA Process Alternative 6: RHEN3 with minimum Auxiliary Utility Unit

Table 6.17 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 3 with minimum Auxiliary Utility Unit: Control Structure 1

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

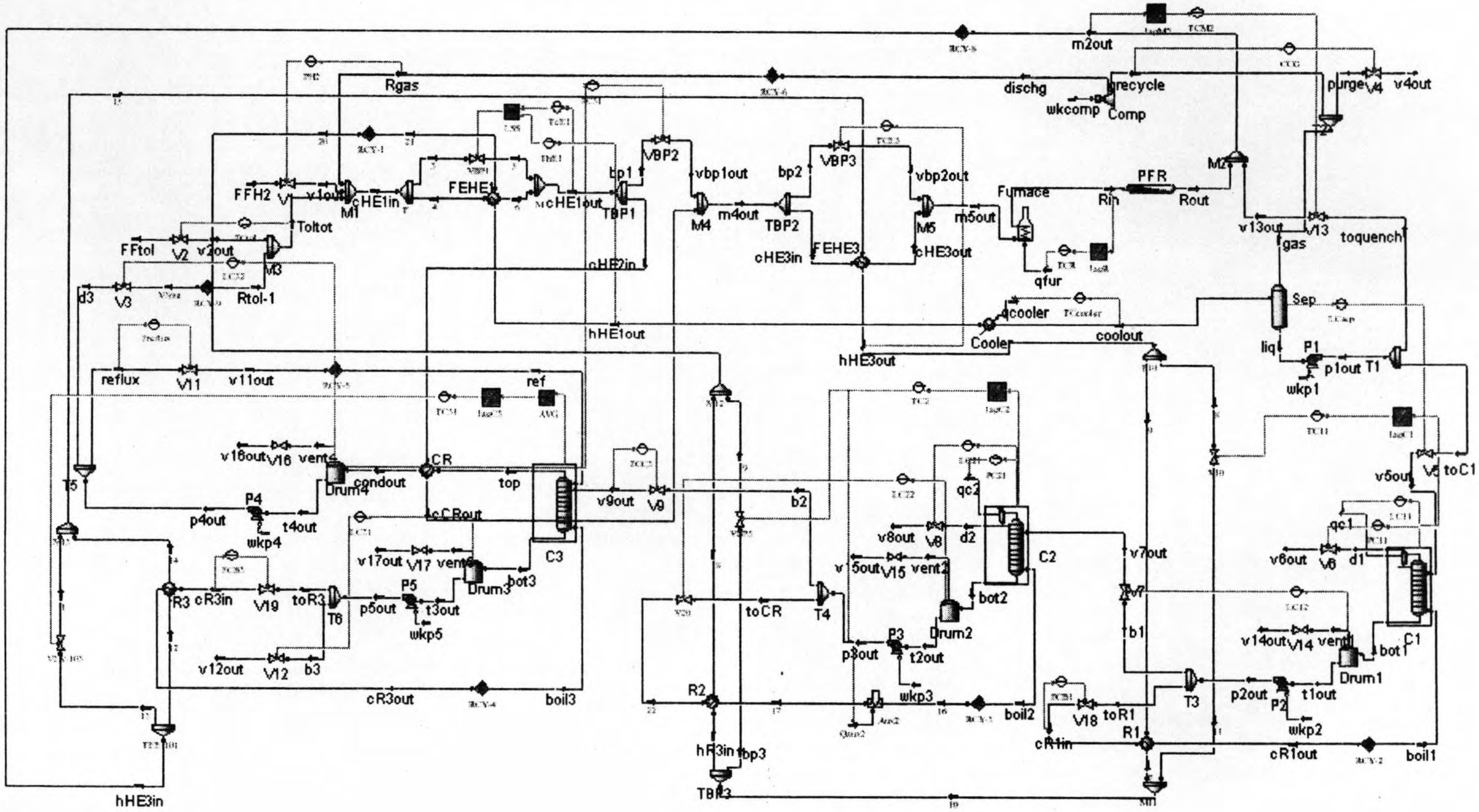


Figure 6.18 Control Structure 2 (CS2) for HDA Process Alternative 6: RHEN3 with minimum Auxiliary Utility Unit

Table 6.18 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN3 with minimum Auxiliary Utility Unit: Control Structure 2

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

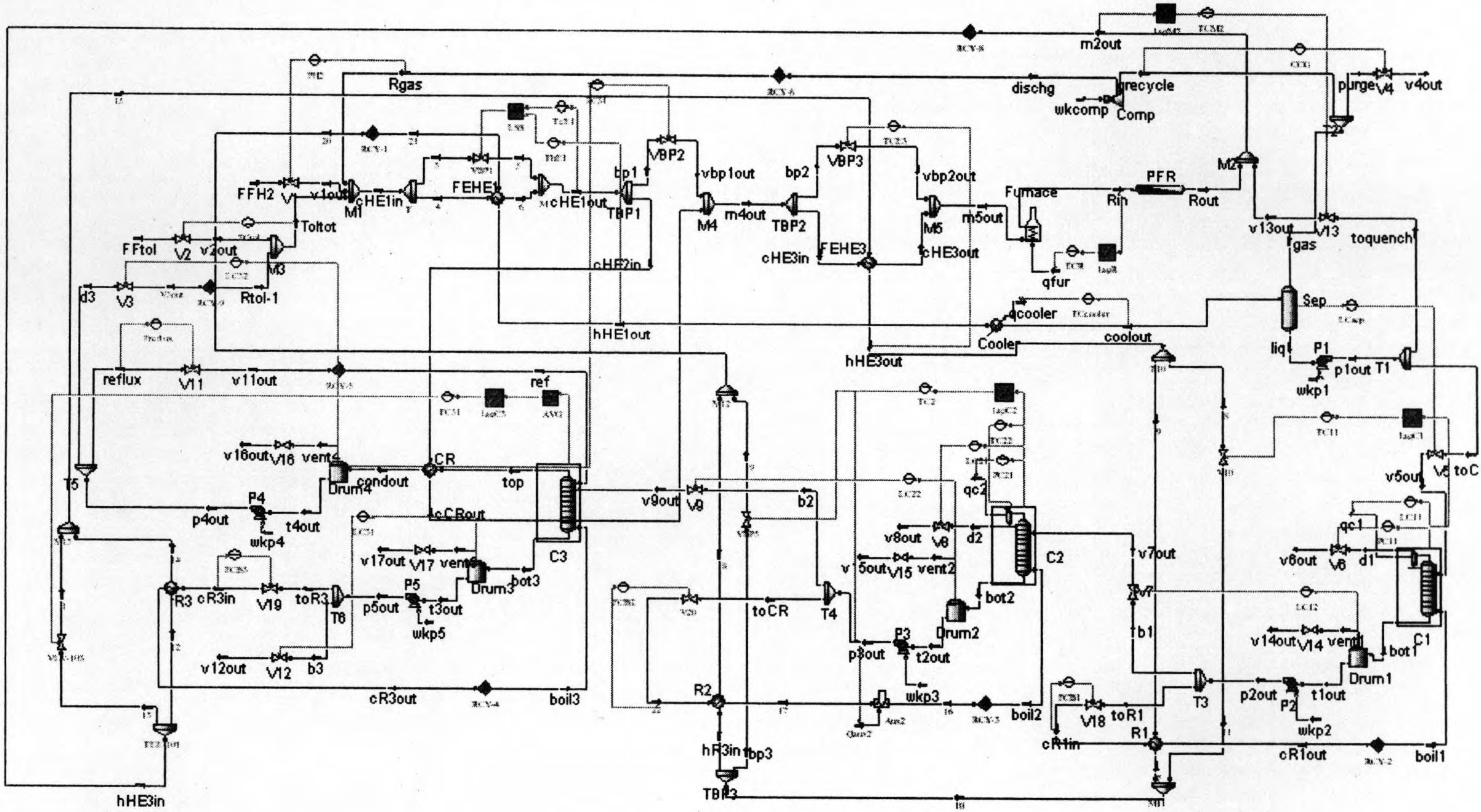


Figure 6.19 Control Structure 3 (CS3) for HDA Process Alternative 6: RHEN3 with minimum Auxiliary Utility Unit

Table 6.19 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 3 with minimum Auxiliary Utility Unit: Control Structure 3

controller name	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	9.97	0.319	0.071
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC21	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
TC22	column C2 tray-17 temperature	column 2 reflux flow rate	PID	6.87	7.34	1.63
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum level	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCB3	column C3 boil up flow rate	R3 cold-inlet valve (V15)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

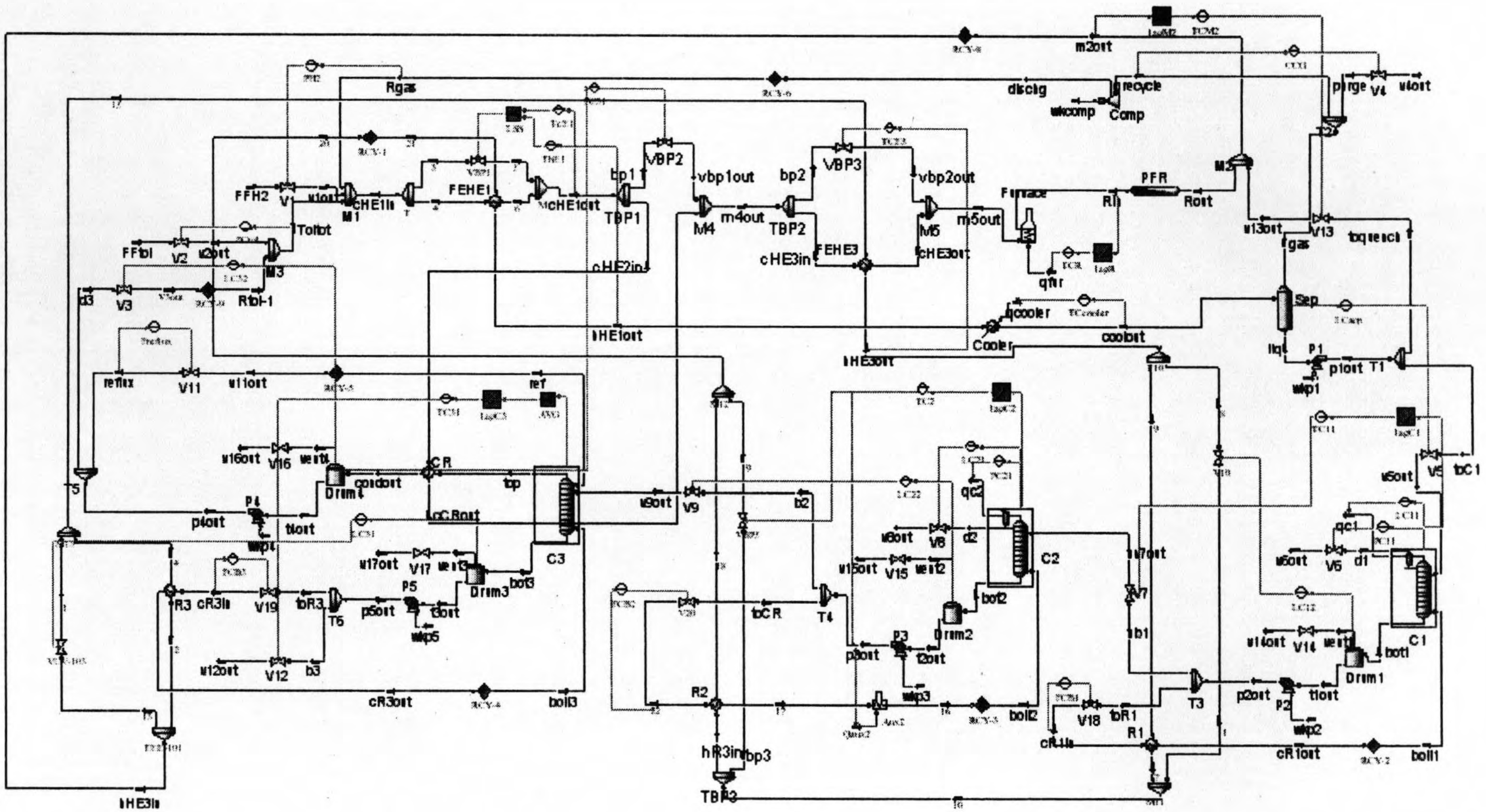


Figure 6.20 Control Structure 4 (CS4) for HDA Process Alternative 6: RHEN3 with minimum Auxiliary Utility Unit

Table 6.20 Control Structure and Controller Parameter for HDA Process Alternative 6: RHEN 3 with minimum Auxiliary Utility Unit: Control Structure 4

controller	controlled variable	manipulated variable	type	Kc	Ti	Td
FCtol	total toluene flow rate	fresh feed toluene valve (V2)	PI	0.5	0.3	-
PCG	gas recycle stream pressure	fresh feed hydrogen valve (V1)	PI	2	10	-
CCG	methane in gas recycle	purge valve (V4)	PI	0.5	15	-
TCQ	quenched temperature	quench valve (V6)	PID	2.3	0.303	0.067
TCR	reactor inlet temperature	furnace duty (qfur)	PID	0.344	0.419	0.093
TCS	separator temperature	cooler duty (qcooler)	PID	0.813	0.374	0.083
TcE1	FEHE2 cold inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	3.93	1.40	0.312
ThE1	cooler inlet temperature	FEHE1 bypass cold stream valve (VBP1)	PID	14.4	1.36	0.303
LSS	output of TCE1c and TCE1h	FEHE1 bypass cold stream valve (VBP1)	Min	-	-	-
ThE2	FEHE2 hot-outlet temperature	FEHE2 bypass cold stream valve (VBP2)	PID	1.24	0.207	0.046
LCS	separator liquid level	column C1 feed valve (V5)	P	2	-	-
PC1	column C1 pressure	column C1 gas valve (V7)	PI	2	10	-
TC1	column C1 tray-6 temperature	R1 bypass valve (VBP3)	PID	3.93	1.40	0.312
LC11	column C1 base level	column C2 feed valve (V8)	P	2	-	-
LC12	column C1 reflux drum	column C1 condenser duty (qc1)	P	3	-	-
FCB1	column C1 boil up	cold-inlet valve of R1 flow rate (V9)	PI	0.5	0.3	-
PC2	column C2pressure	column C2 condenser duty (qc2)	PI	2	10	-
TC2	column C2 tray-12 temperature	R2 bypass valve (VBP4) and auxiliary reboiler 2 (AR2) duty	PID	6.90	6.90	1.53
LC21	column C2 base level	column C3 feed valve (V11)	P	2	-	-
LC22	column C2 reflux drum	column C2 product valve level (V10)	P	2	-	-
FCB2	column C2 boil up flow rate	R2 cold-inlet valve (V12)	PI	0.5	0.3	-
PC3	column C3 pressure	CR bypass valve (VBP5)	PI	2	10	-
TC3	AVG avg. temp. of C3-tray 1,2, 3, and 4	R3 bypass valve (VBP4)	PID	0.575	1.46	0.325
LC31	column C3 base level	C3 bottom valve (V14)	P	2	-	-
LC32	column C3 reflux drum level	toluene recycle valve (V3)	P	2	-	-
FCC3	column C3 flow rate	inlet valve (V9)	PI	0.5	0.3	-
FCR	column C3 reflux flow rate	reflux valve (V13)	PI	0.5	0.3	-

6.2 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: CS1

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.21 to 6.23. Results for individual disturbance load changes are as follows:

6.2.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.21 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

Again, the heat load disturbance of the hot stream can be shifted to the cold stream, since the hot outlet temperature of FEHE3 has to be kept constant. Both positive and negative disturbance loads of the hot stream are shifted to a furnace utility. When the hot temperature decreases, it will result in decrease of the furnace inlet temperature (Figure 6.21.h). Consequently, the furnace duty increases (Figure 6.21.l). On the other hand, when the positive disturbance load is originating from the hot stream (i.e. the hot inlet temperature increases), the furnace duty will be decreased, since the furnace inlet temperature increases. The tray temperature in the recycle column has a deviation about 2°C and it takes long time to return to its nominal value of 290.3°C (Figure 6.21.p). Besides, the separator temperature and the reactor inlet temperature are quite well controlled (Figure 6.21.b and c).

6.2.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.22 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

Both the cold and hot outlet temperatures of FEHE1 decrease as the cold inlet temperature decreases. As a result, the hot outlet temperature of FEHE1 decreases and the cooler duty decreases (Figure 6.22.f and m).

When the cold inlet temperature of FEHE1 increases, both the cold and hot outlet temperatures of FEHE1 increase. Again, the hot outlet temperature of FEHE1 quickly increases then the hot outlet temperature of FEHE1 back to steady state (Figure 6.22.f) so the cooler duty increases. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.22.b and n), but the oscillations occur in the recycle column temperature (Figure 6.22.p).

6.2.3 Change in the Total Toluene Feed Flow Rate

Figure 6.23 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

Energy integration causes the plant will be more difficult to control. Though HDA plant with energy integration (alternative 6) can recover more energy, but the control system in this complex energy integrated plant cannot handle large amount of disturbances.

To increase in total toluene flowrate raises the reaction rate, so the benzene product flowrate increases (Figure 6.23.q). On the other hand, the drop in total toluene feed flowrate reduces the reaction rate, so the benzene product flowrates drops but the benzene product quality is rarely affected by this change (Figure 6.23.q). The separator temperature is slightly well controlled (Figure 6.23.d), but the oscillations occur in the tray temperature of the stabilizer column and the reactor inlet temperature (Figure 6.23.i and h). For the tray temperature of the product column, it is quite well controlled when this disturbance occurs (Figure 6.23.o), but the tray temperature in the recycle column has a deviation about 5°C and it takes long time to return to its nominal value of 290.3°C (Figure 6.23.p).

6.3 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: CS2

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.24 to 6.26. Results for individual disturbance load changes are as follows

6.3.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.24 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

The dynamic responses of this control structure are better than CS1 when the change in the disturbance load of the hot stream occurs, since the feed flowrate of the recycle column is flow-controlled. Then, the effect of this disturbance does not propagate to downstream unit operation like recycle column. Thus, the tray temperatures in the stabilizer and recycle column provide well controlled (Figure 6.24.n and p). The separator temperature, the reactor inlet temperature is slightly well controlled (Figure 6.24.d) but the oscillation happens in the tray temperature of the product column (Figure 6.24.o.).

6.3.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.25 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of this control structure are better than that CS1 when the change in the disturbance load of the cold stream happens. Particularly, the tray temperature in the recycle column provides a well controlled (Figure 6.25.p) because the feed flowrate of the recycle column is fixed for to reduce the propagation when disturbance occurs. In addition, the other dynamic responses are similar to the earlier control structures. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.25.d and n) and the smooth control response happens in the tray temperature of the recycle column. But the small oscillations occur in the tray temperature of the product column (Figure 6.25.o).

6.3.3 Change in the Total Toluene Feed Flow rate

Figure 6.26 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of CS2 are worser than that of the CS 1 when this disturbance occurs. Particularly, the tray temperature in the recycle column provides the well controlled (Figure 6.26.p) because the feed flowrate of the recycle column is flow-controlled for reducing the material and flow propagation during the disturbance occurs. In addition, the separator temperature is quite well controlled (Figure 6.26.d), the oscillations occur in the tray temperature of the product column (Figure 6.26.o).

6.4 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: CS3

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.27 to 6.29. Results for individual disturbance load changes are as follows:

6.4.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.27 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

The dynamic responses of this control structure are better than CS1 when the change in the disturbance load of the hot stream occurs, since the temperature of the product column is two-point control .Thus, the tray temperatures in the product and stabilizer column provide well controlled (Figure 6.27.o, p and n). The separator temperature, the reactor inlet temperature is slightly well controlled (Figure 6.27.d) but the oscillation happens in the tray temperature of the recycle column (Figure 6.27.p.).

6.4.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.28 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of this control structure are better than that CS1 when the change in the disturbance load of the cold stream happens. Particularly, the tray temperature in the product column provides a well controlled (Figure 6.28.o and p) because the temperature of the product column is two-point control. In addition, the other dynamic responses are similar to the earlier control structures. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.28.d and n) and the smooth control response happens in the tray temperature of the recycle column. The molar flow of benzene is well controlled (figure 6.28.r).

6.4.3 Change in the Total Toluene Feed Flow rate

Figure 6.29 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of CS2 are better than that of the CS 1 when this disturbance occurs. Particularly, the tray temperature in the product column better control than CS1 (Figure 6.29.o and p) because the temperature of the product column is two-point control In addition, the separator temperature is quite well controlled (Figure 6.29.d), the oscillations occur in the tray temperature of the recycle column (Figure 6.29.q).

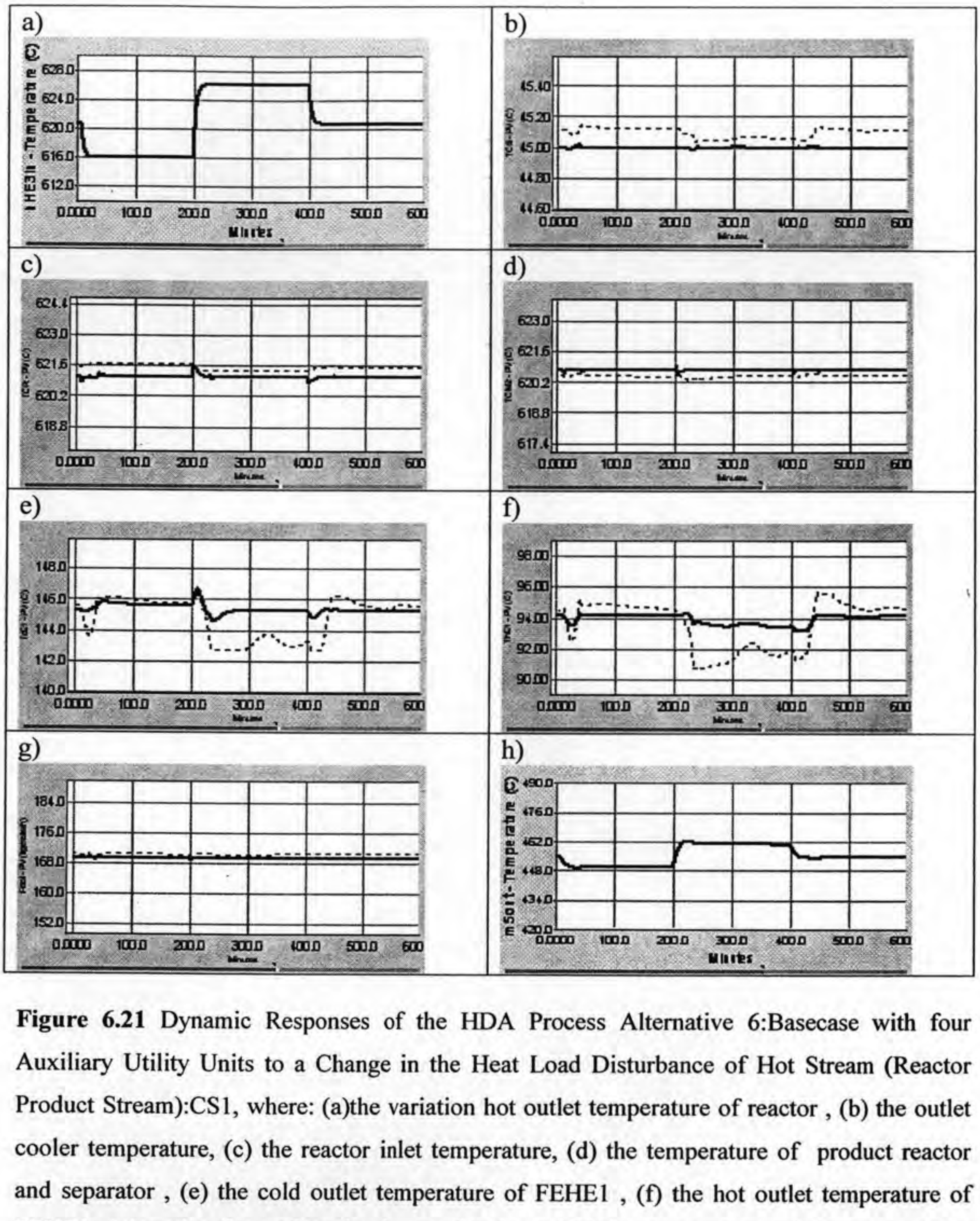


Figure 6.21 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS1, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ⋯⋯ Manipulated variable)

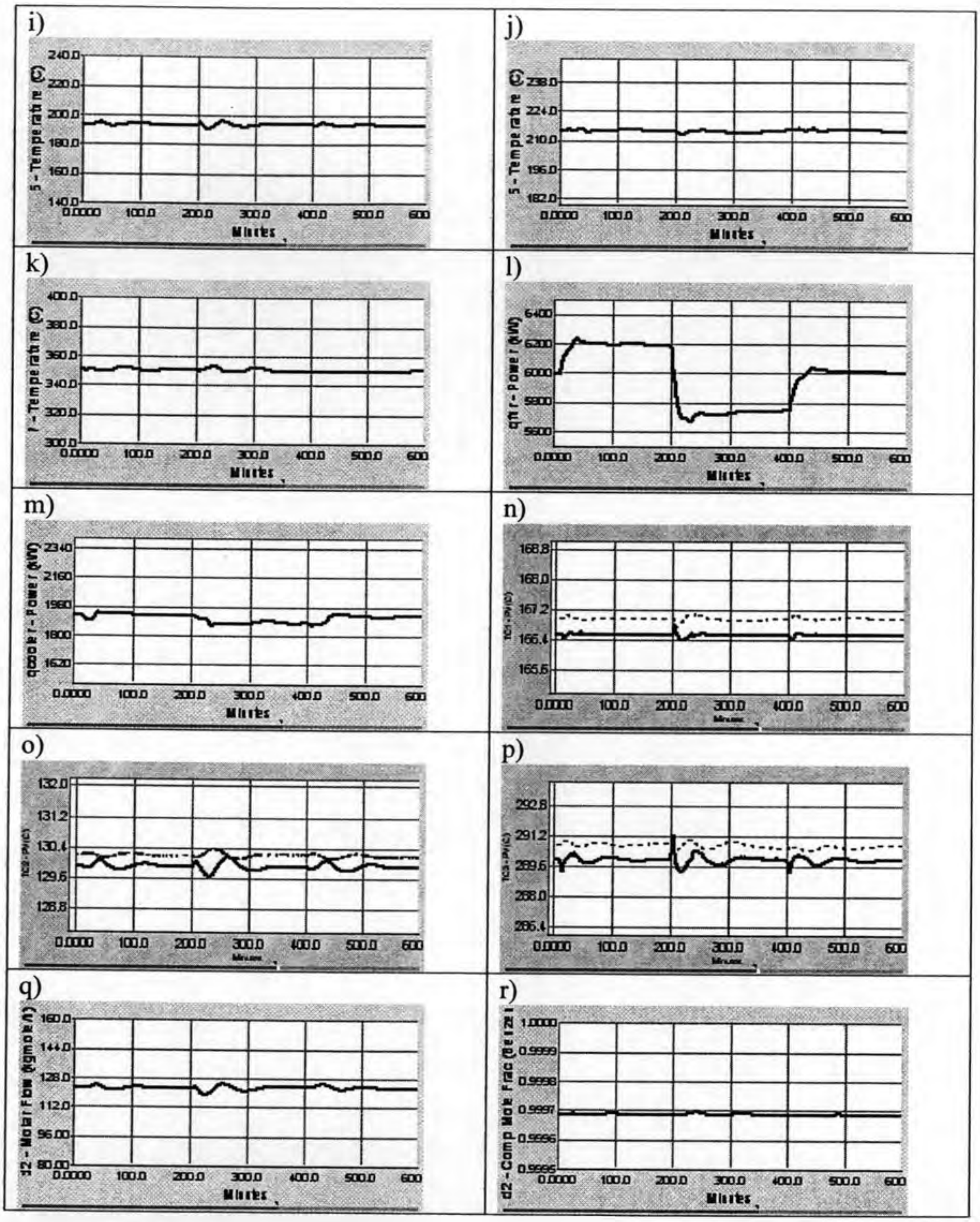


Figure 6.21 (continue)

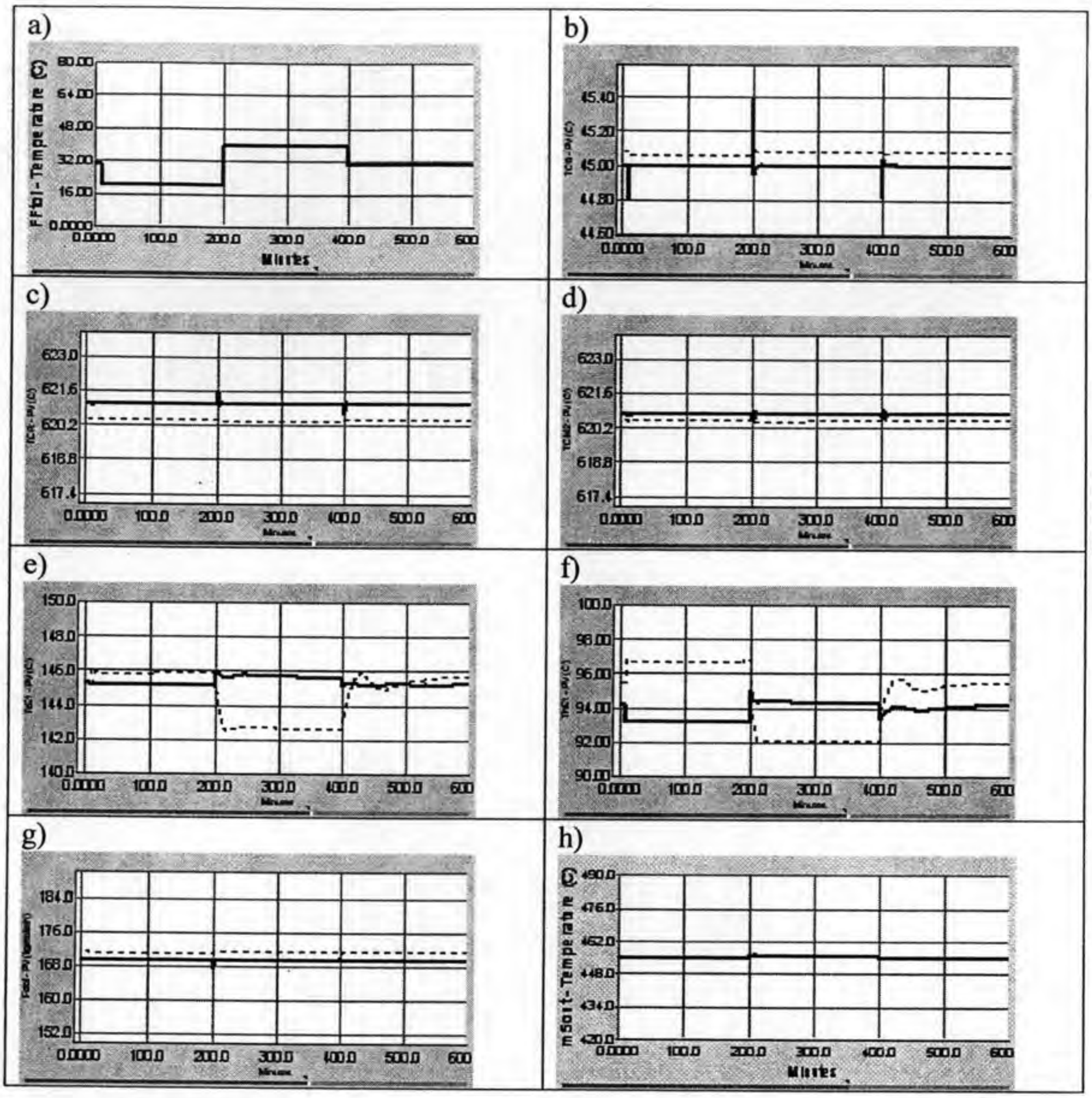
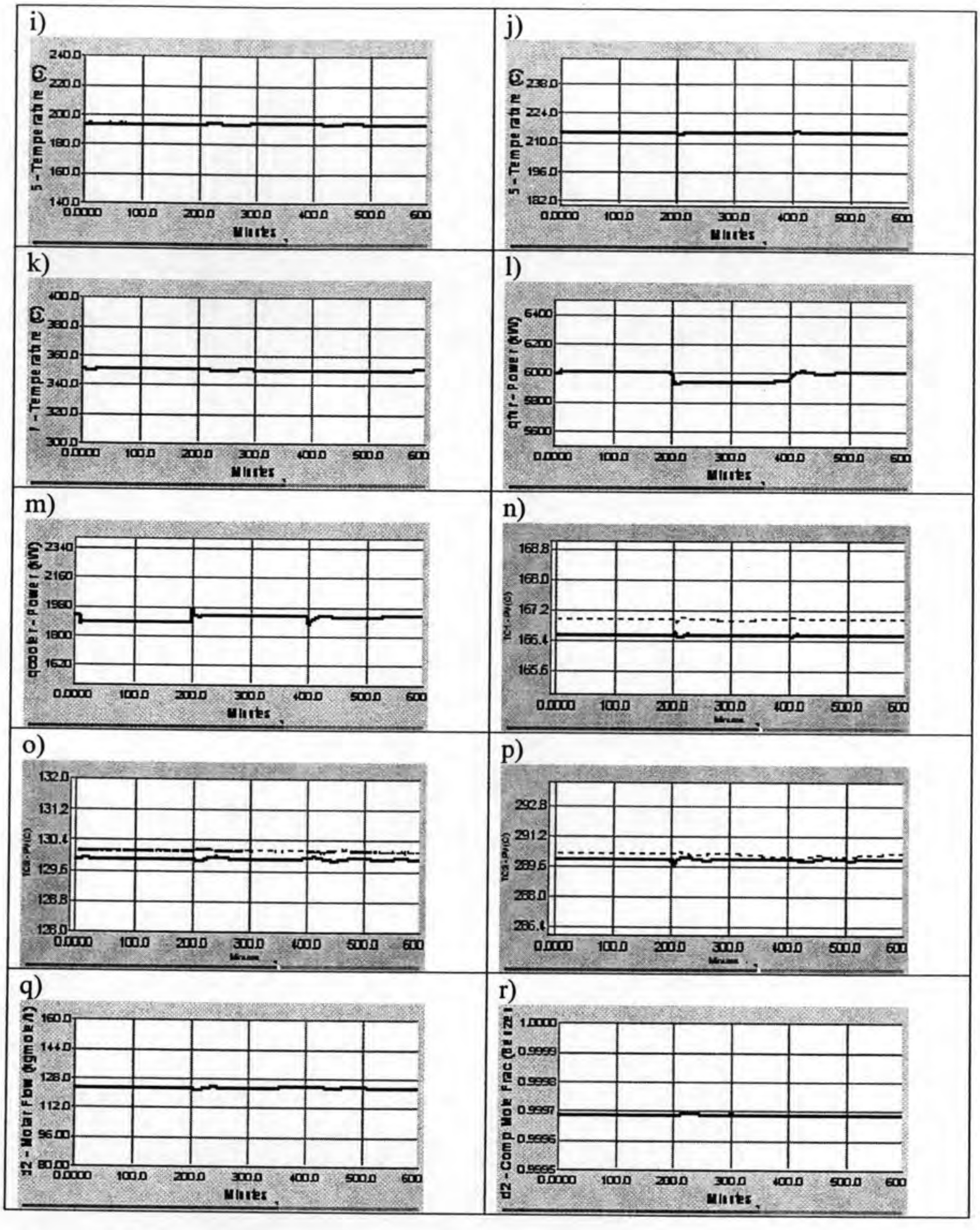


Figure 6.22 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS1, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ▪▪▪▪▪▪ Manipulated variable)



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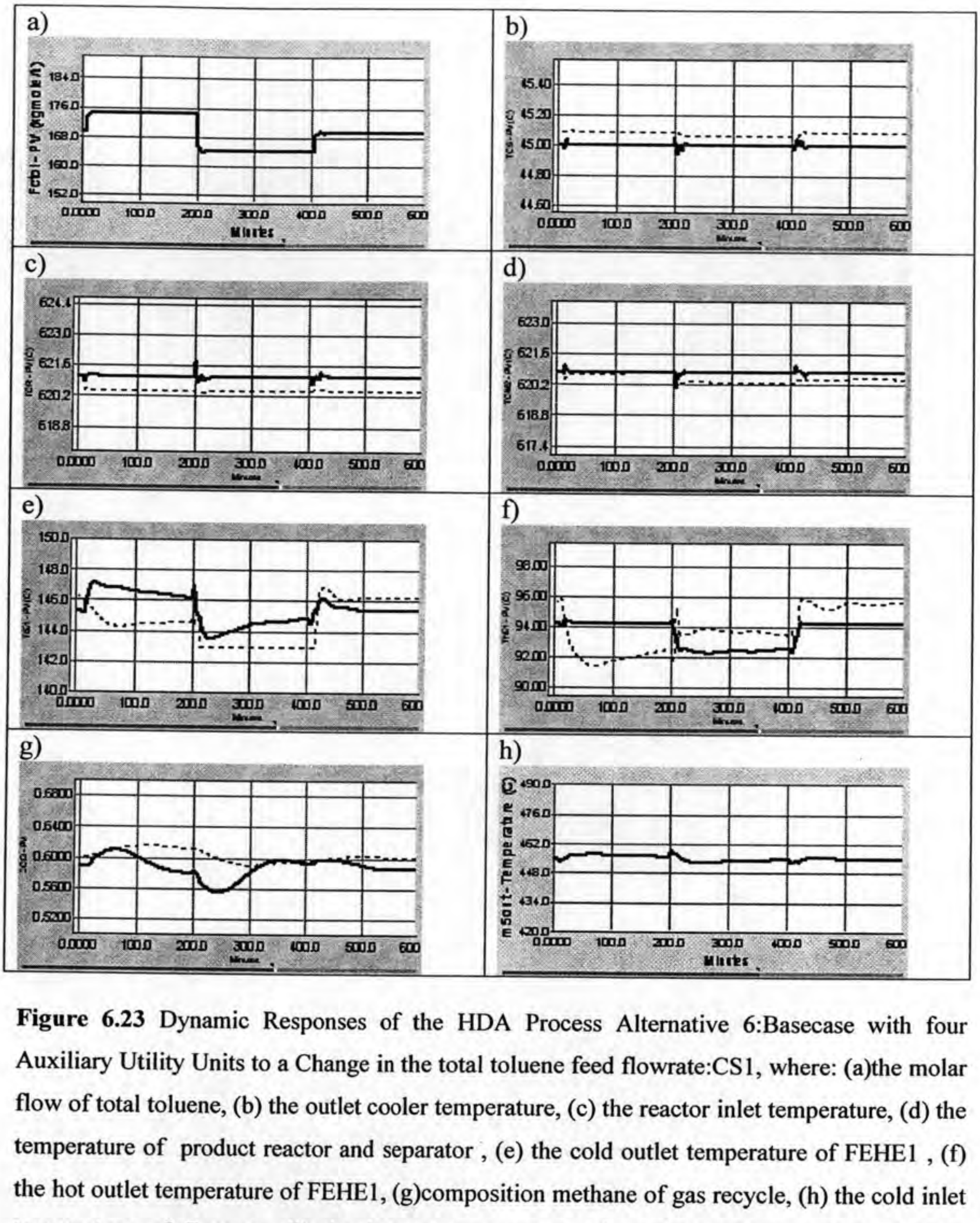


Figure 6.23 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS1, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

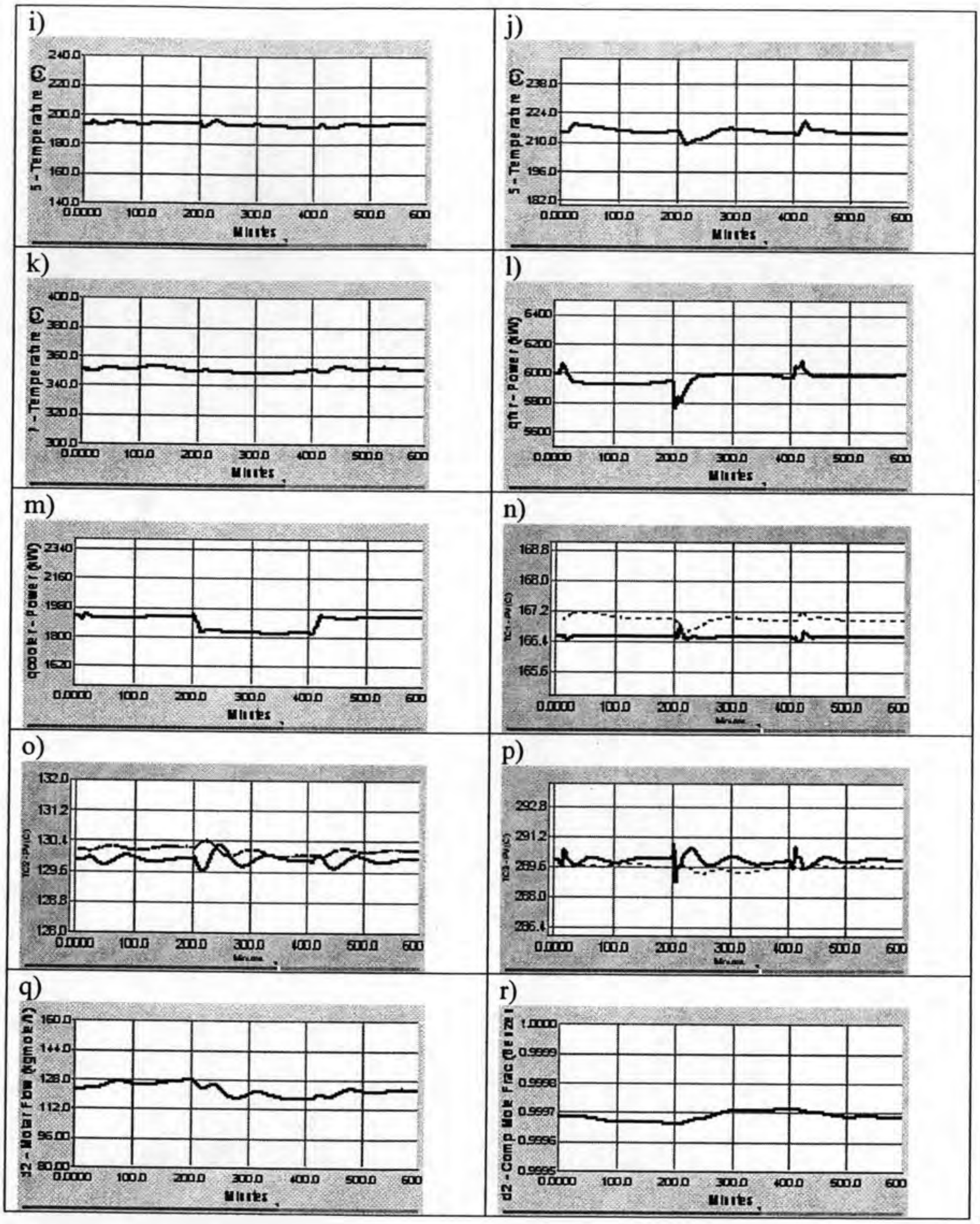


Figure 6.23 (continue)

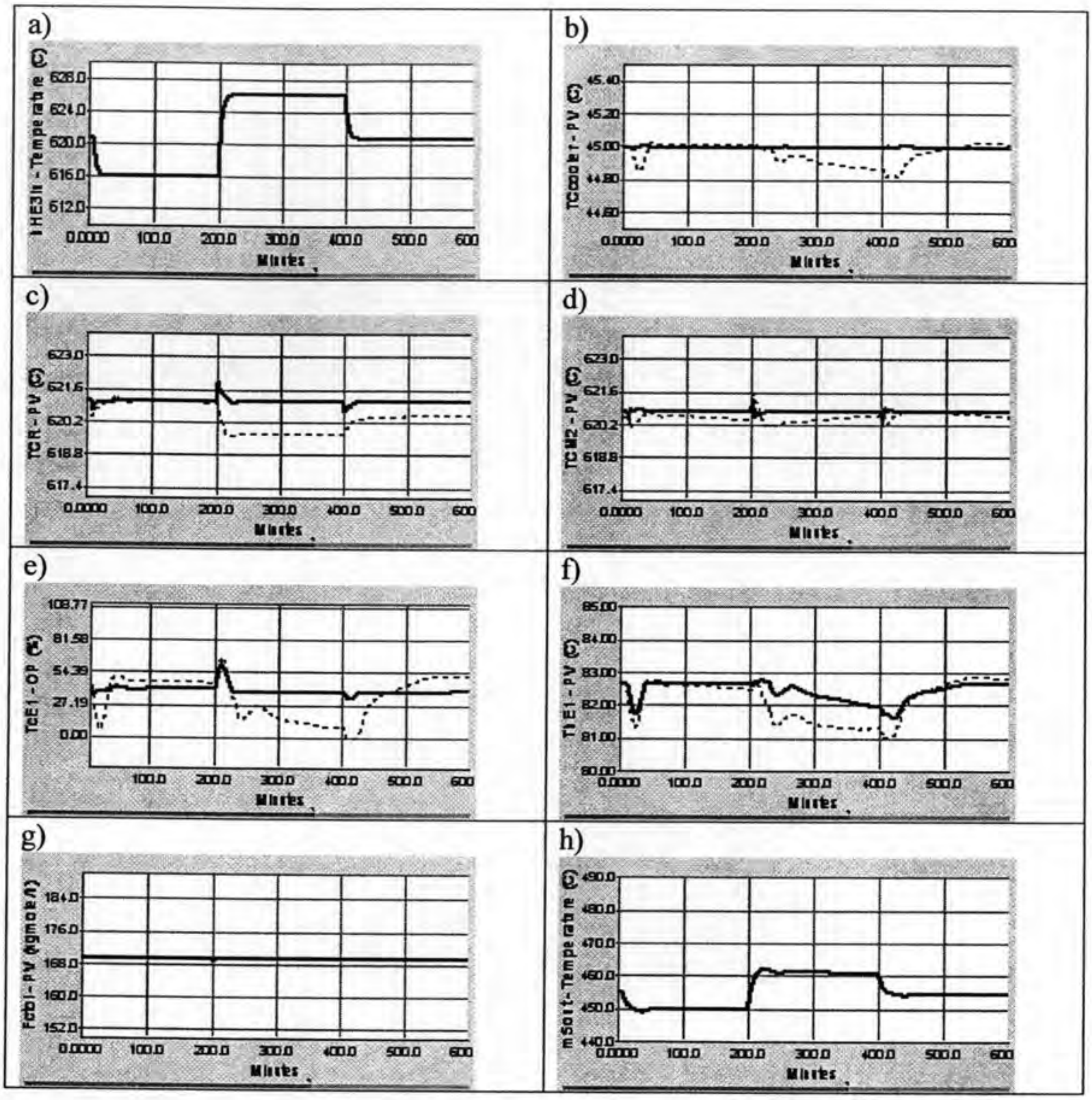


Figure 6.24 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS2, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━━ Process variable (PV) , ······ Manipulated variable)

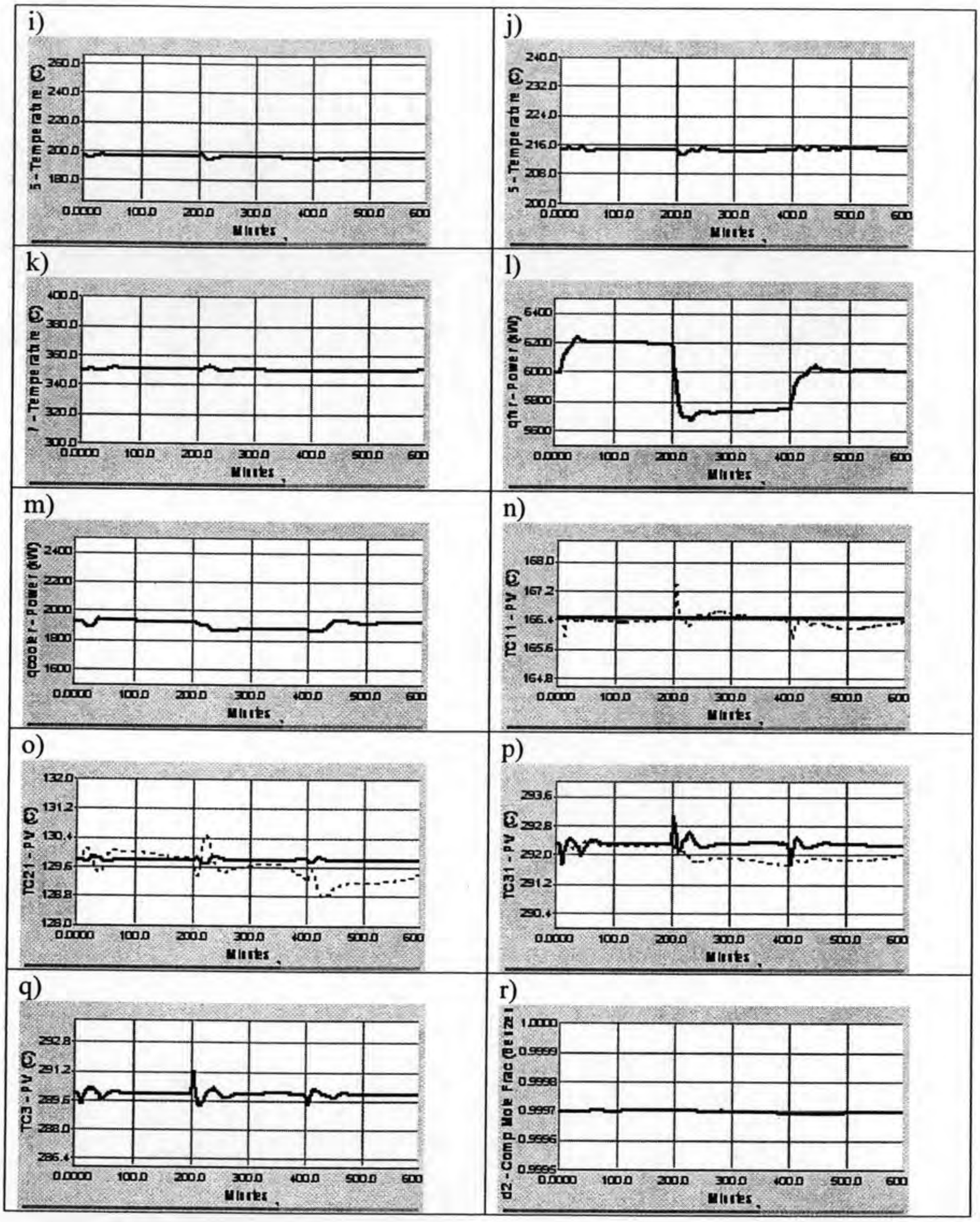

i) j) k) l) m) n) o) p) q) r)

Figure 6.24 (continue)

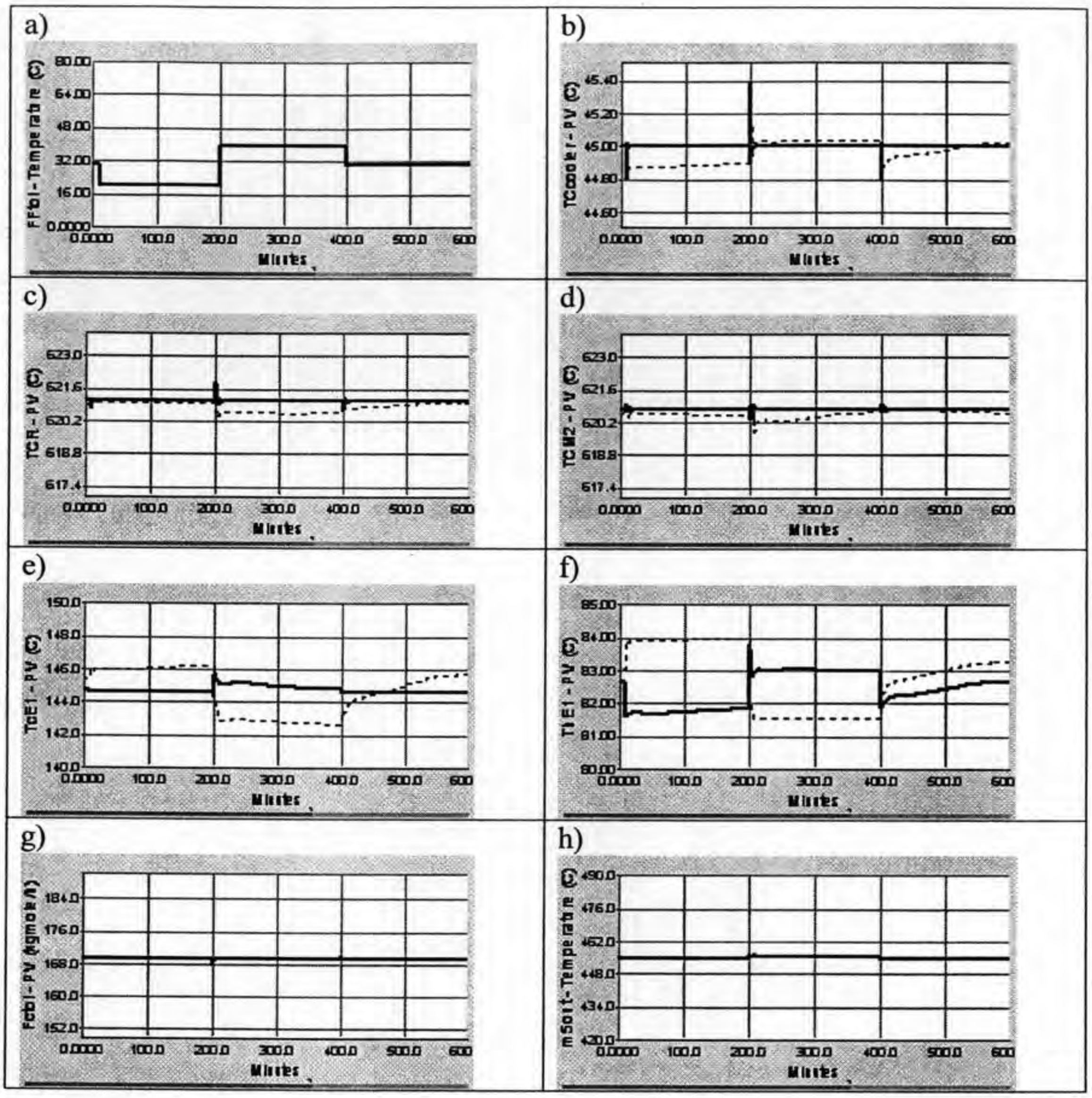


Figure 6.25 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS2, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ―― Process variable (PV) , ······ Manipulated variable)

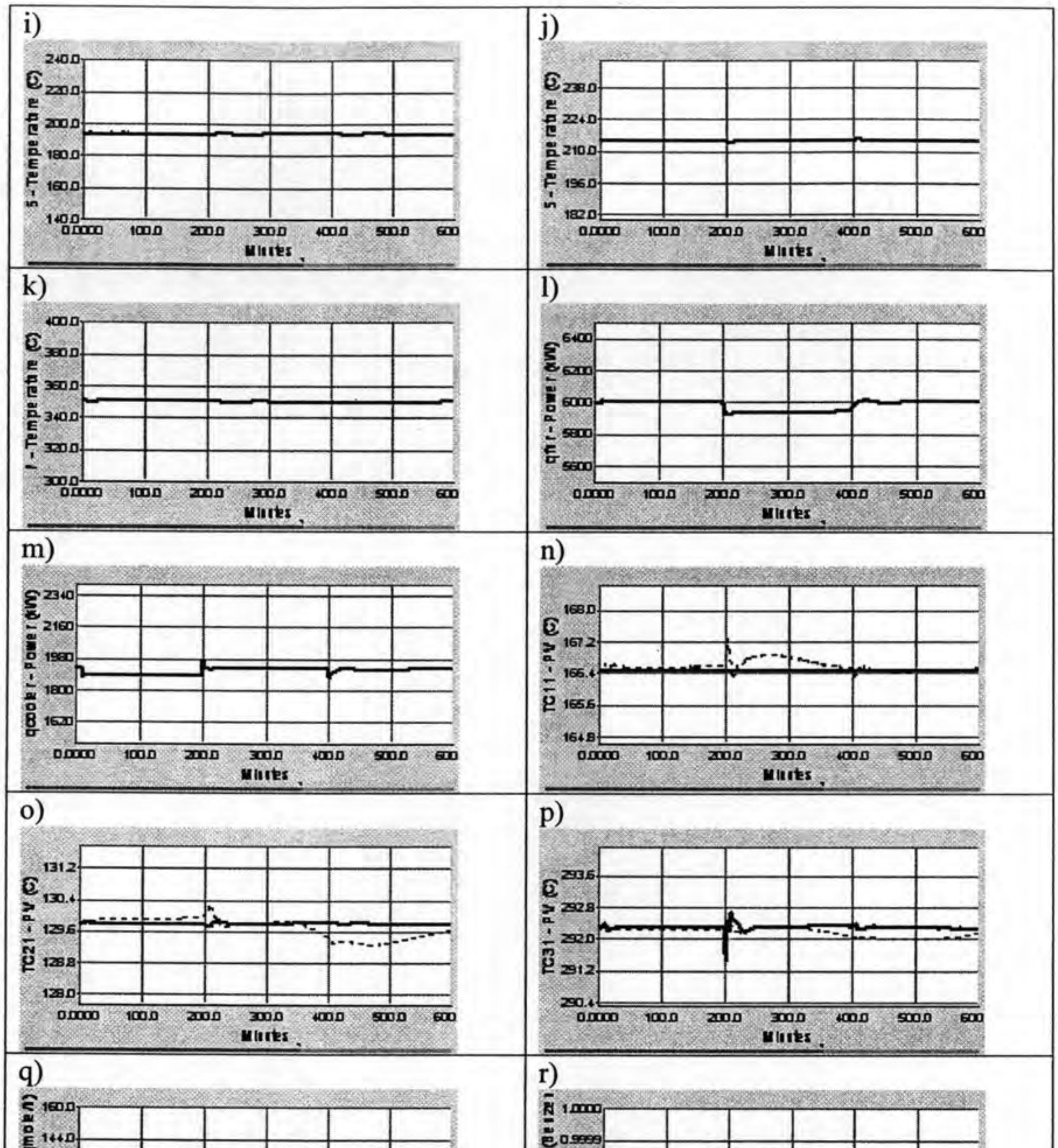


Figure 6.25 (continue)

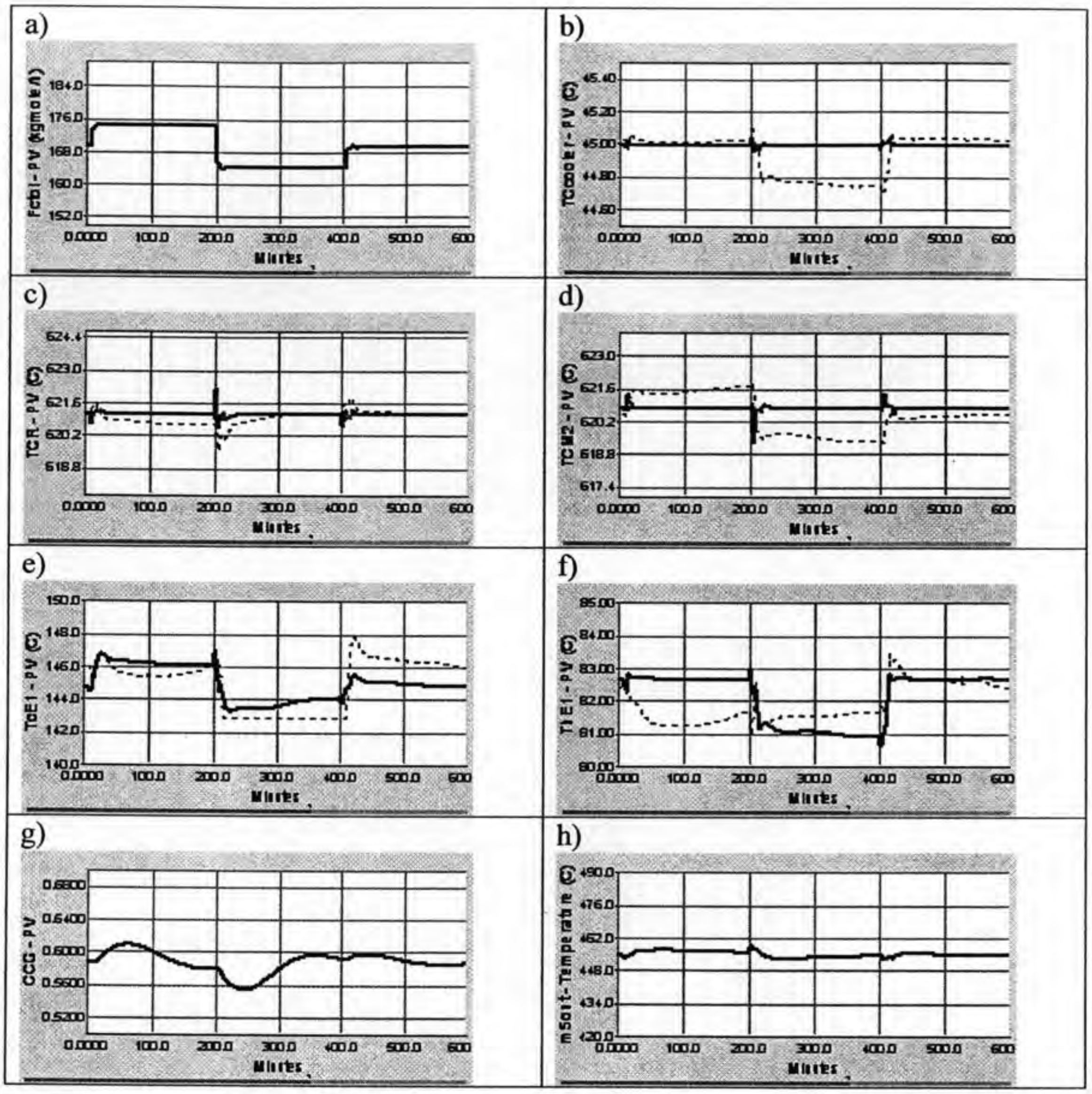


Figure 6.26 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS2, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

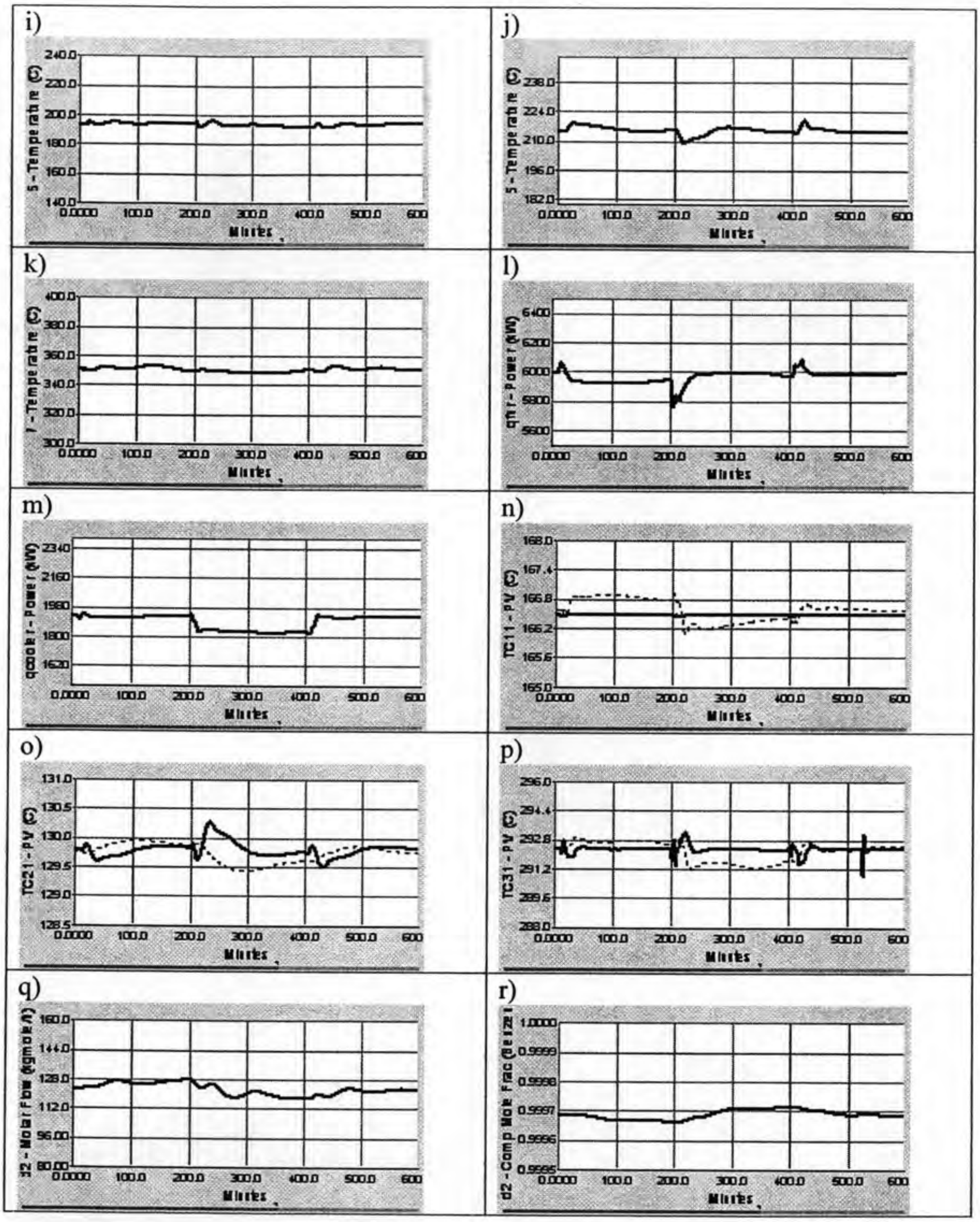


Figure 6.26 (continue)

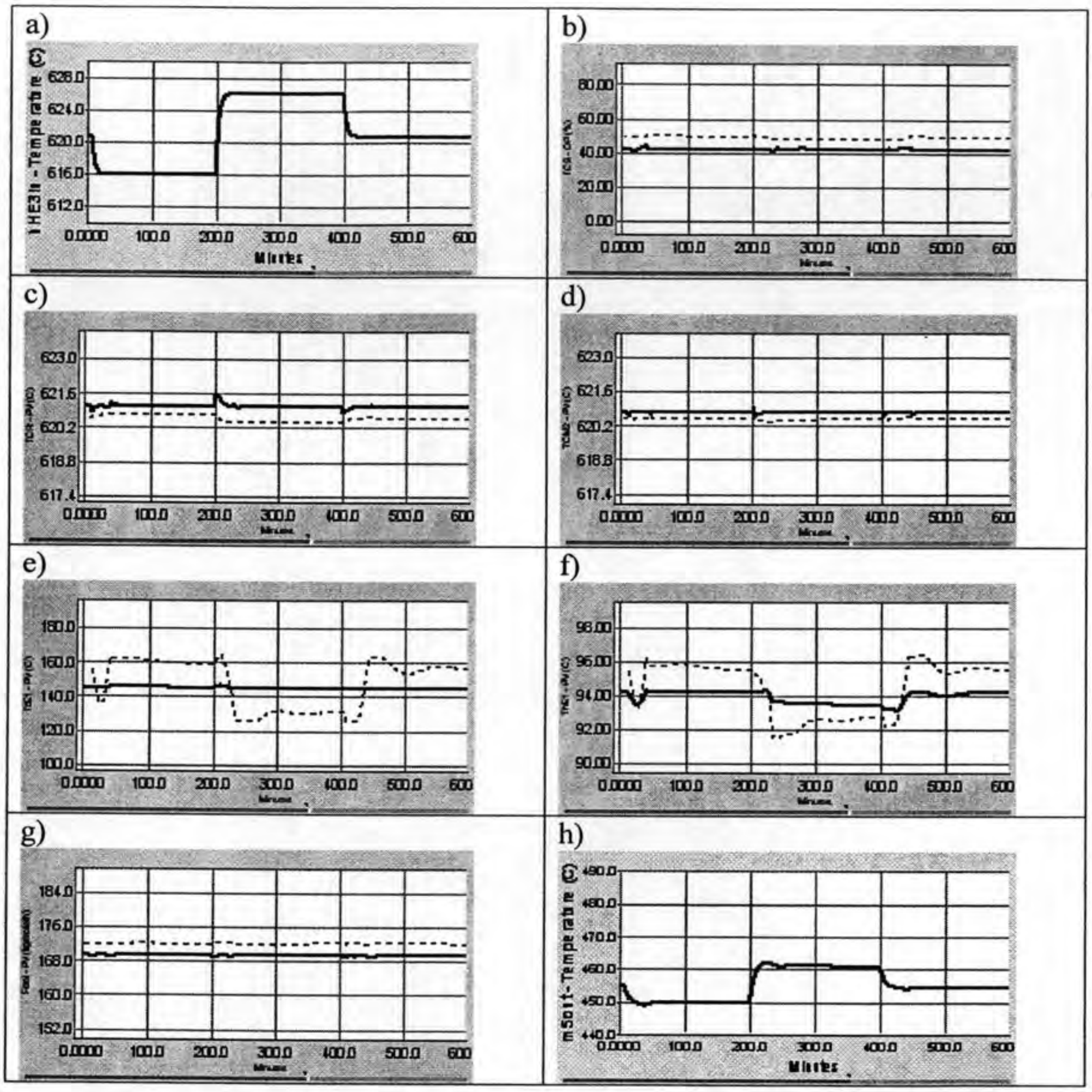
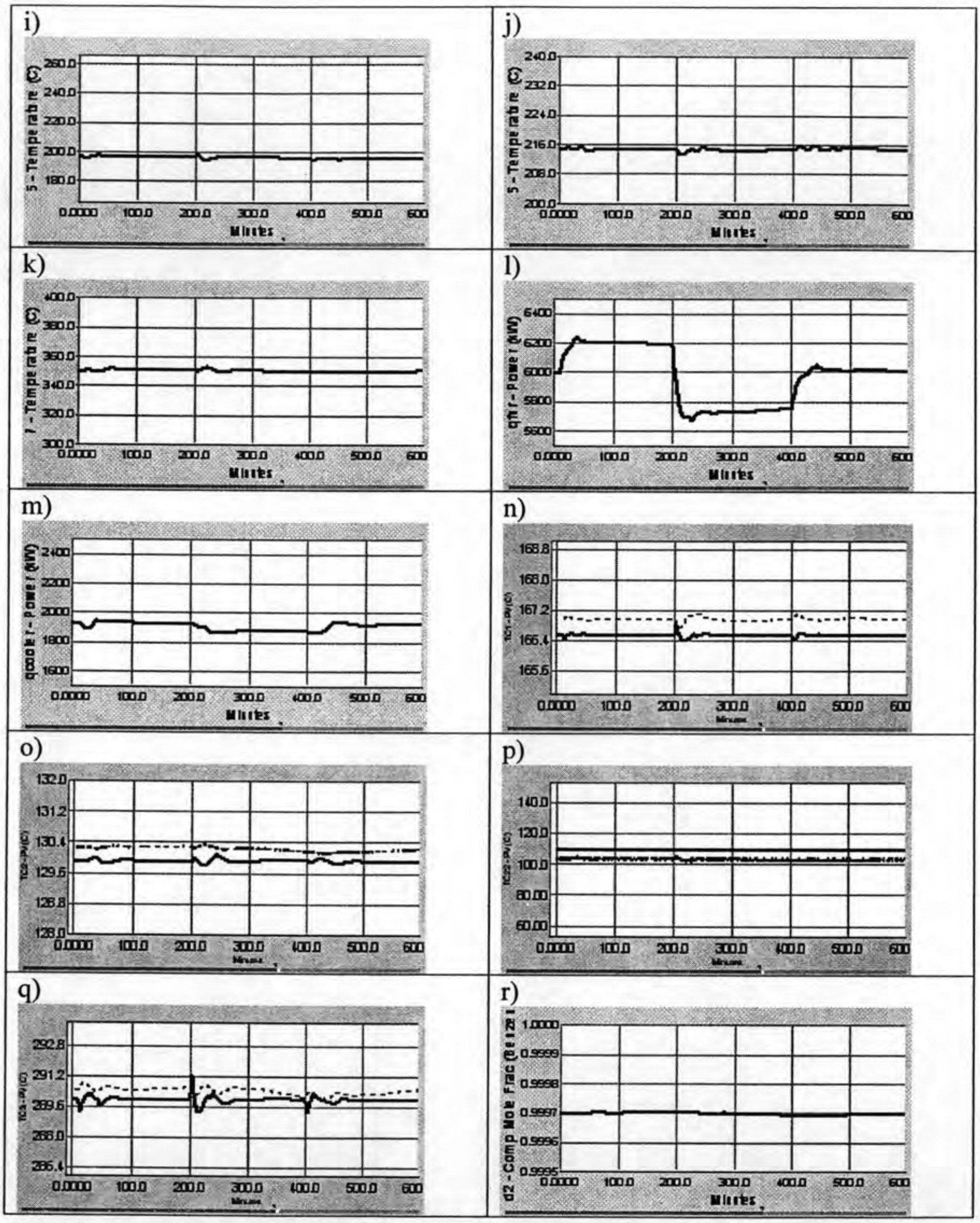


Figure 6.27 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS3, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene of product column

(Note. ▬▬ Process variable (PV) , ⋯⋯ Manipulated variable)



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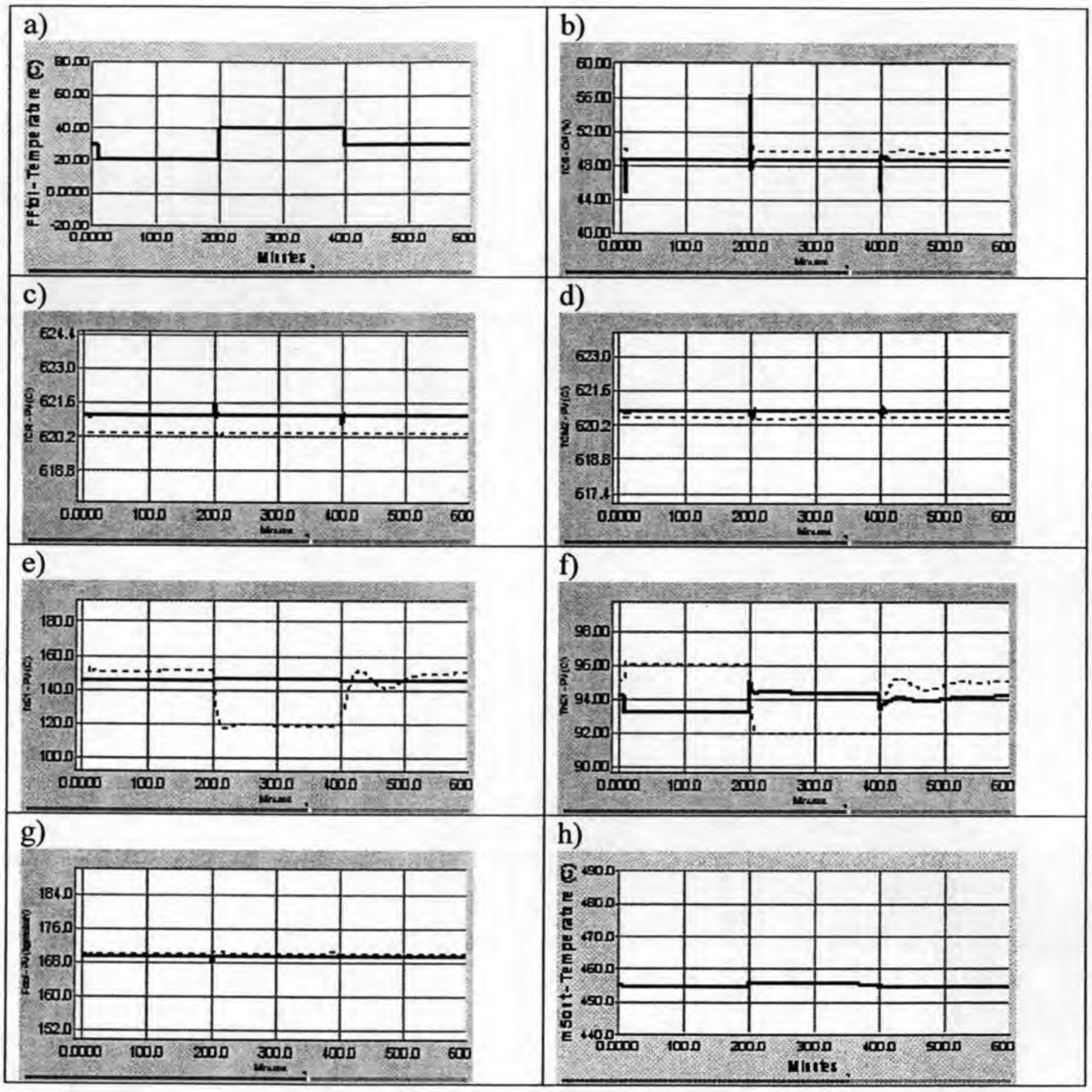
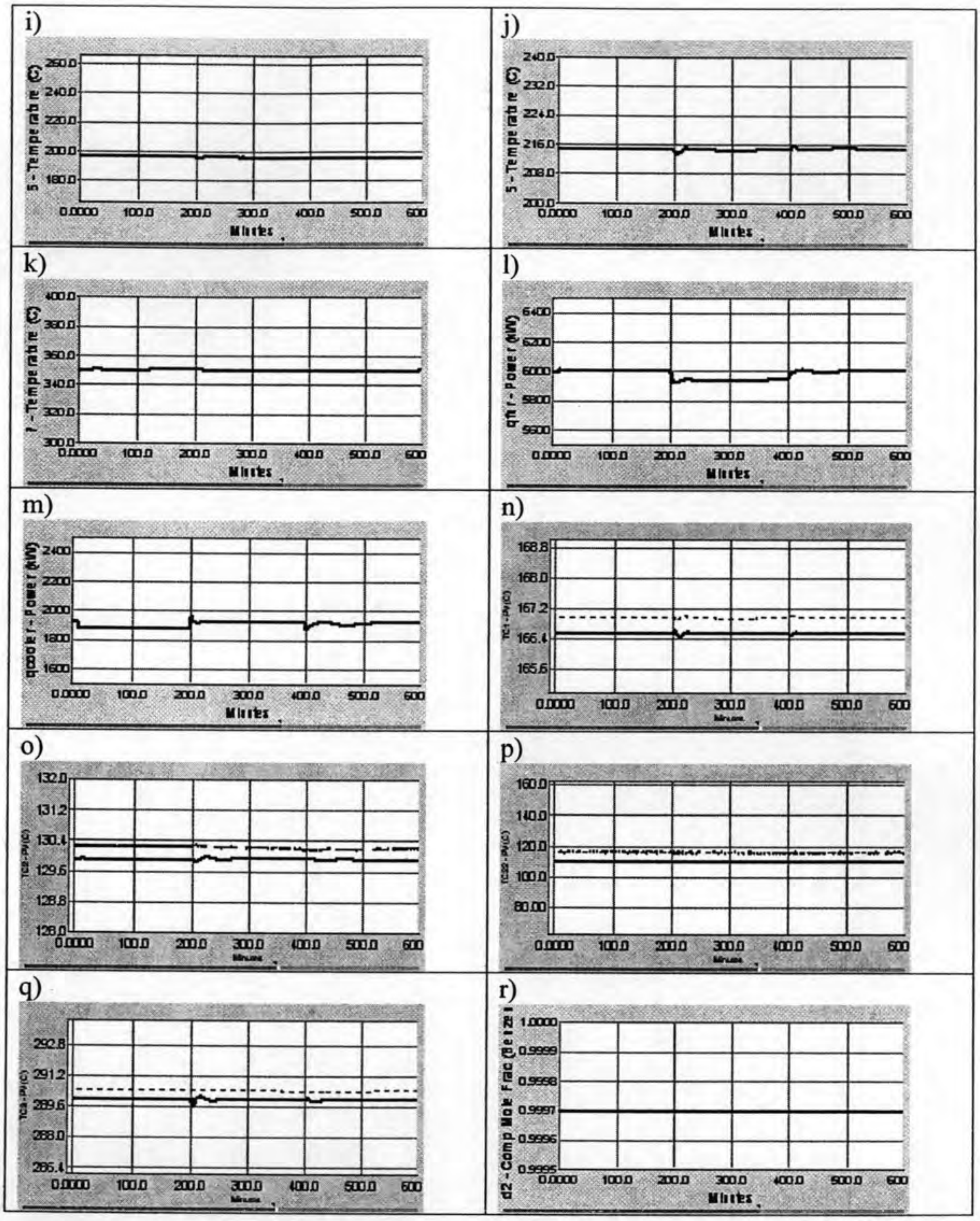


Figure 6.28 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS3, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ▬▬ Process variable (PV) , ⋯⋯ Manipulated variable)



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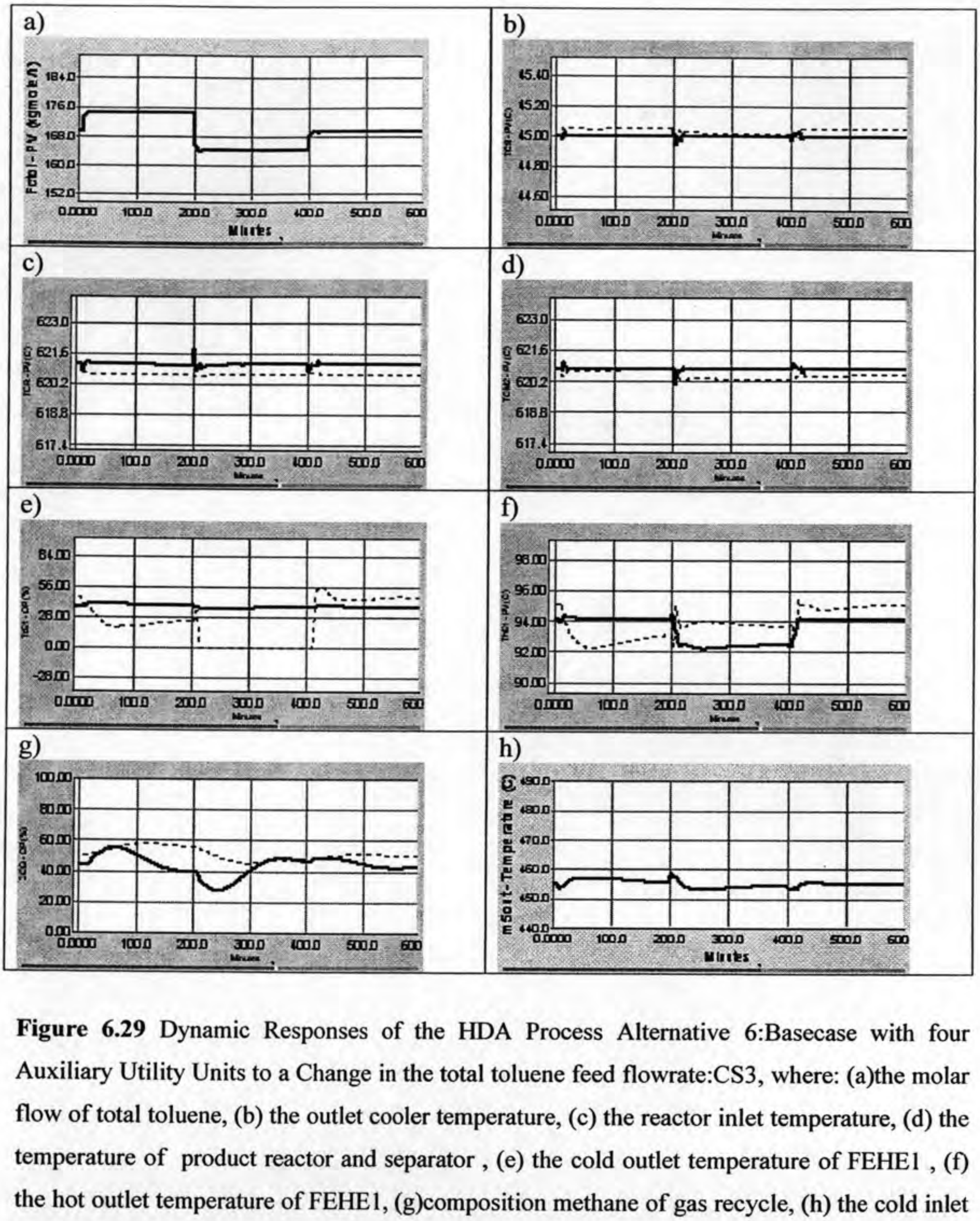


Figure 6.29 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS3, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ▬▬ Process variable (PV) , ▪▪▪▪▪▪ Manipulated variable)

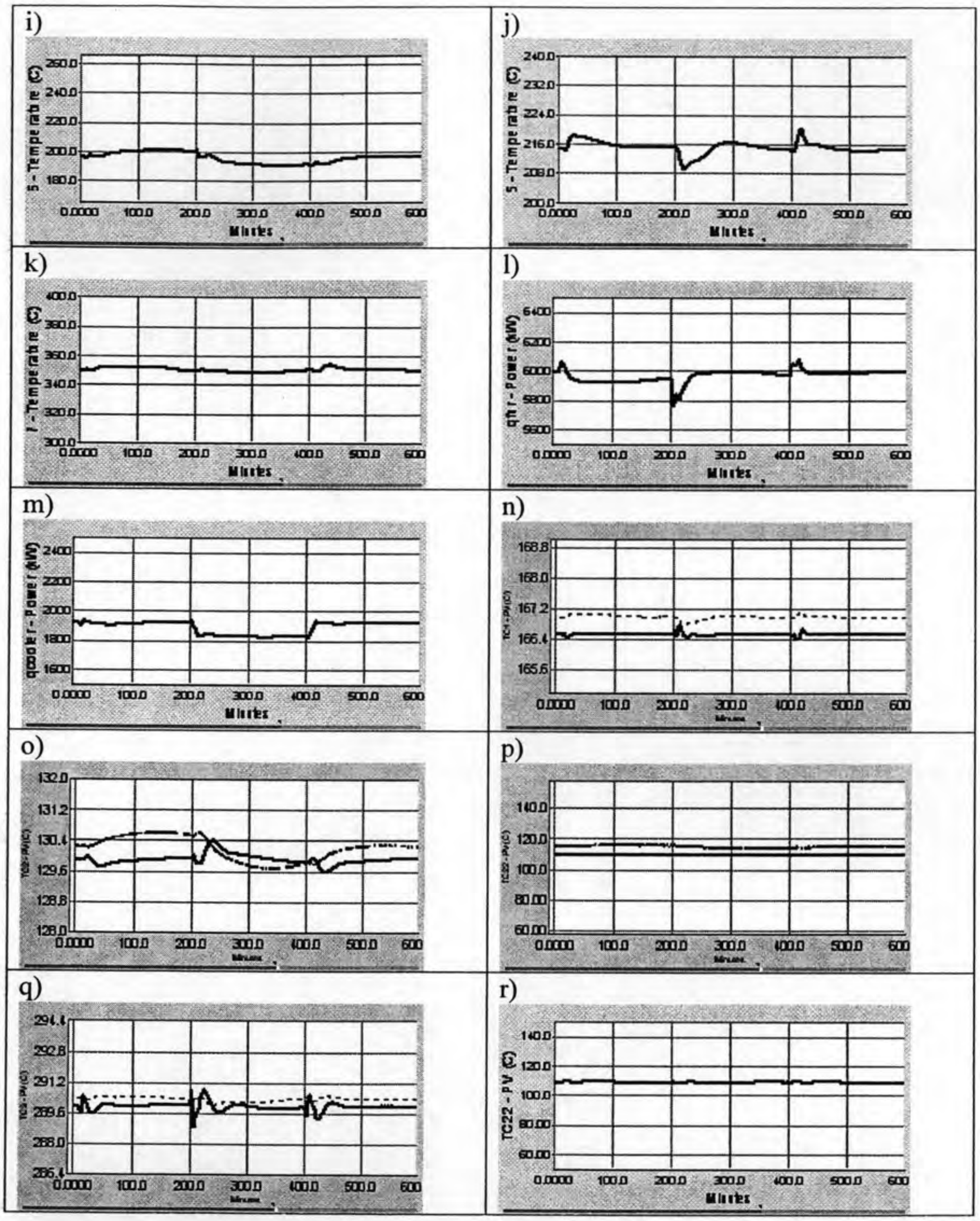


Figure 6.29 (continue)

6.5 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Three Auxiliary Utility Units: CS4

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.30 to 6.32. Results for individual disturbance load changes are as follows:

6.5.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.30 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes

The dynamic responses of this control structure are worse than CS1. Particularly, the tray temperature control in the recycle column provides a poor performance (Figure 6.30.p) because the performance of the tray temperature controlling in distillation column by valve of bottom product is worser than the bypass valve. The separator temperature and the reactor inlet temperature are slightly well controlled (Figure 6.30.d and c), the oscillations occur in the tray temperature of the product column and stabilizer column (Figure 6.30.n and o).

6.5.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.31 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the cold stream occurs, since the performance of the tray temperature controlling in distillation column by valve by-pass is better than that by valve of bottom product. As this disturbance occurs, the effect of this change is reduced before entering to the downstream unit operation Thus, the performances of the tray temperature control in the product and recycle column of this control structure are worse than that of CS1. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.31.d and c). A deviation of 5°C happens in the tray temperature of the recycle column and it takes over 500 minutes to return to its nominal value of 290.^{3o}C (Figure 6.31.p).

6.5.3 Change in the Total Toluene Feed Flow rate

Figure 6.32 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the total toluene occurs, since the performance of the tray temperature controlling in distillation column by valve by-pass is better than that by valve of bottom product. As this disturbance occurs, the effect of this change is reduced before entering to the downstream unit operation Thus, the performances of the tray temperature control in the product and recycle column of this control structure are worse than that of CS1. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.32.d and c). A deviation of 18 °C happens in the tray temperature of the recycle column and it takes over 800 minutes to return to its nominal value of 290.3°C (Figure 6.32.p). A variation of 5 °C happens in the tray temperature of the stabilizer column (Figure 6.32.n) the oscillations occur in the tray temperature of the product column (Figure 6.32.o).

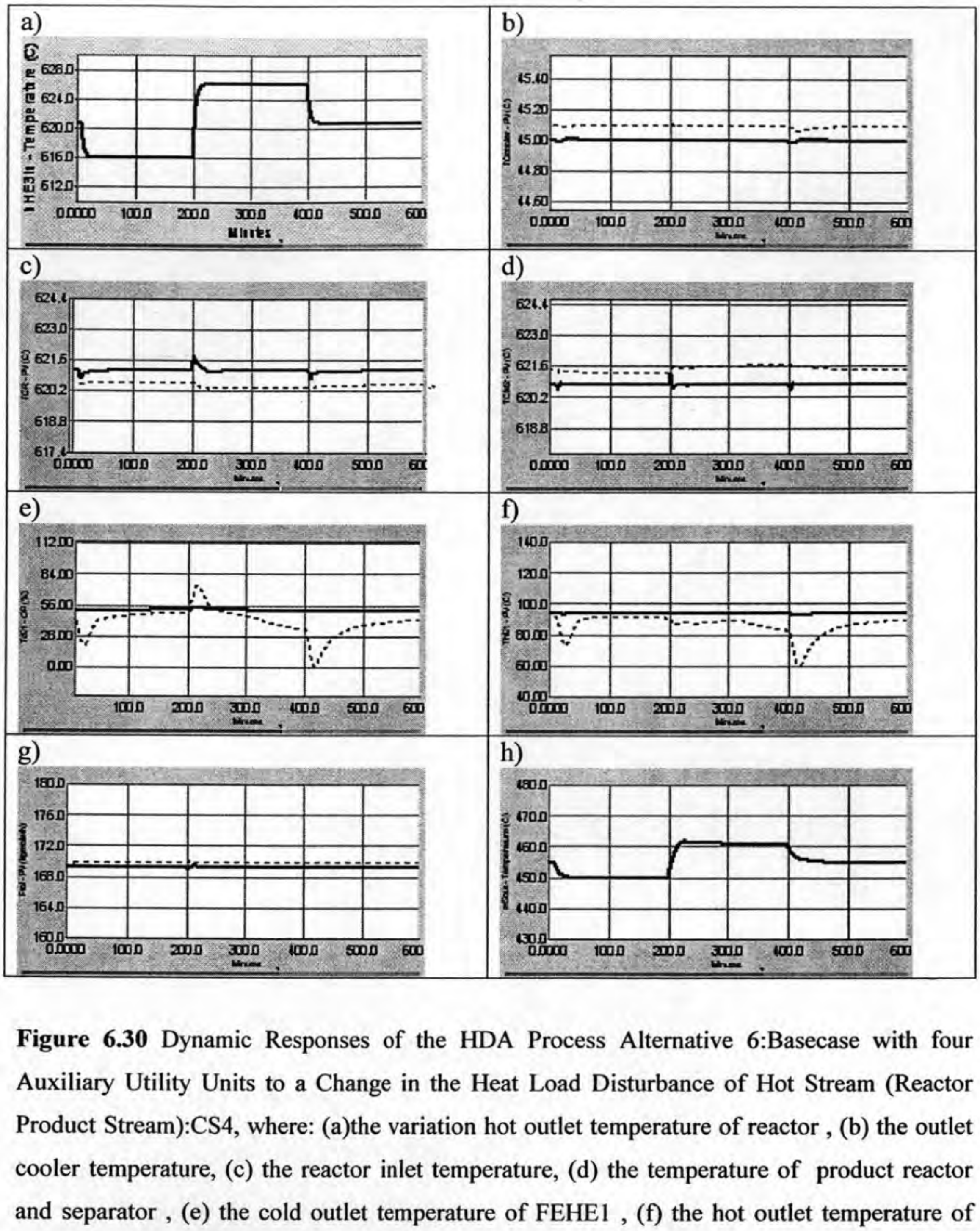
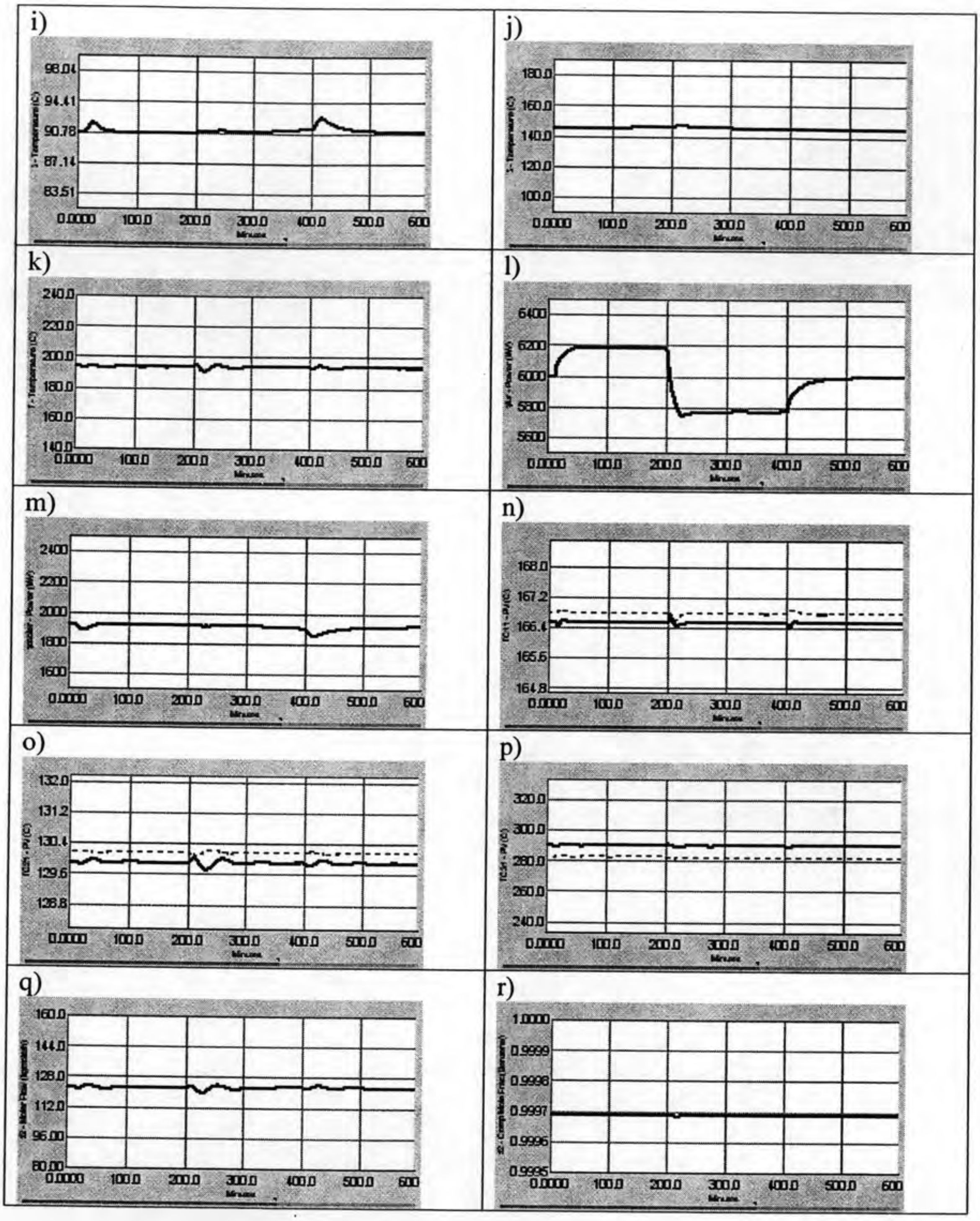


Figure 6.30 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS4, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)



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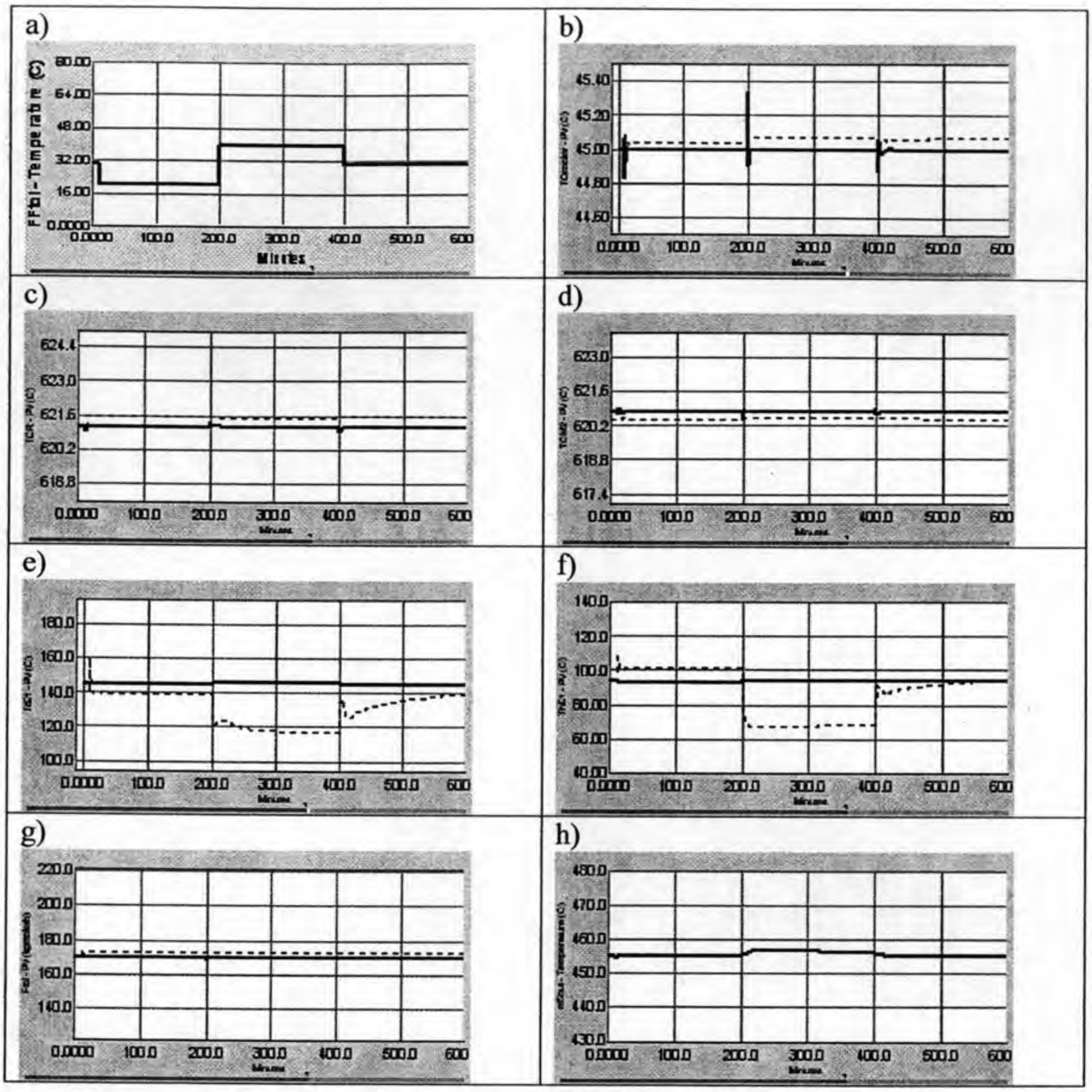
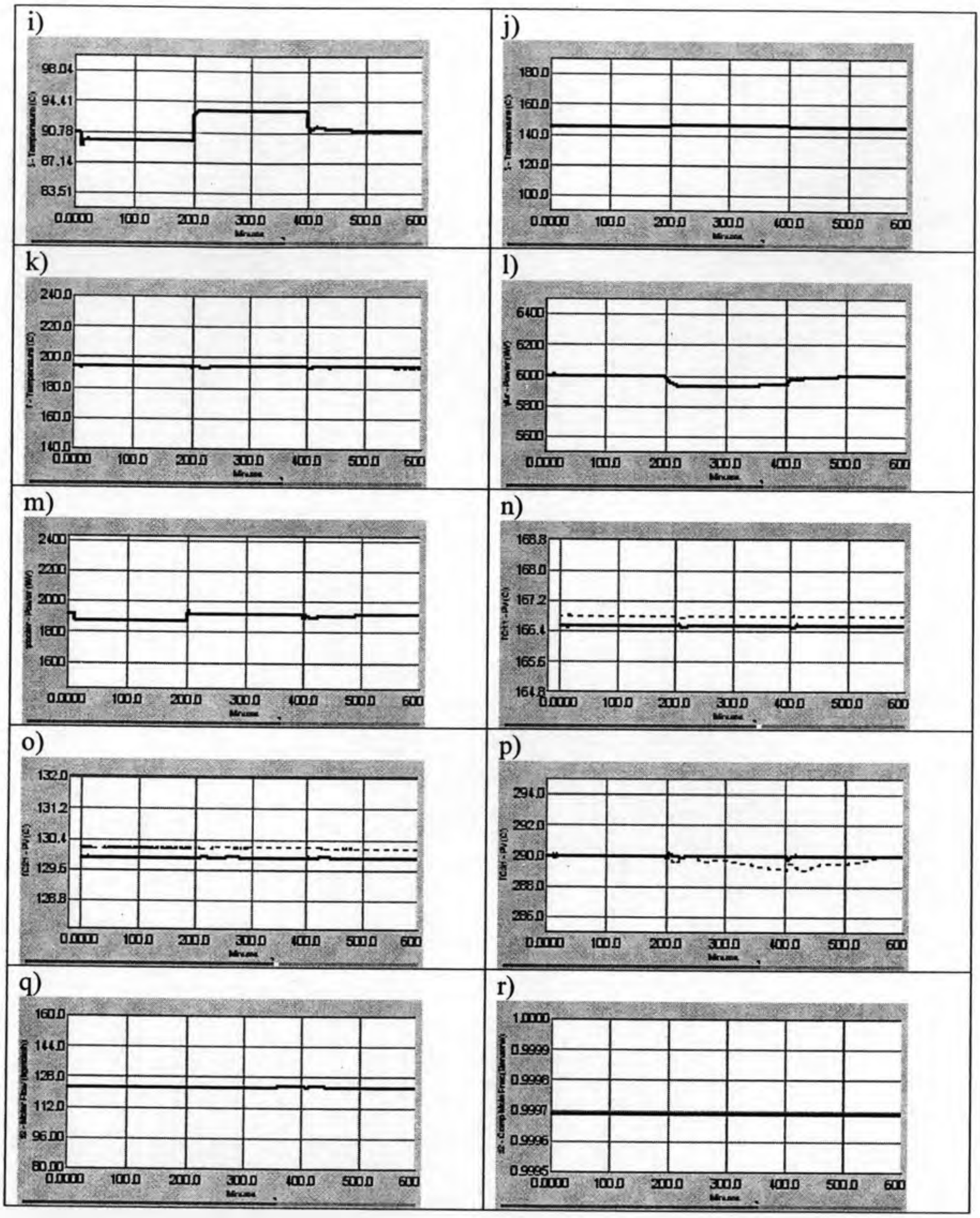


Figure 6.31 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS4, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━━ Process variable (PV) , ······ Manipulated variable)



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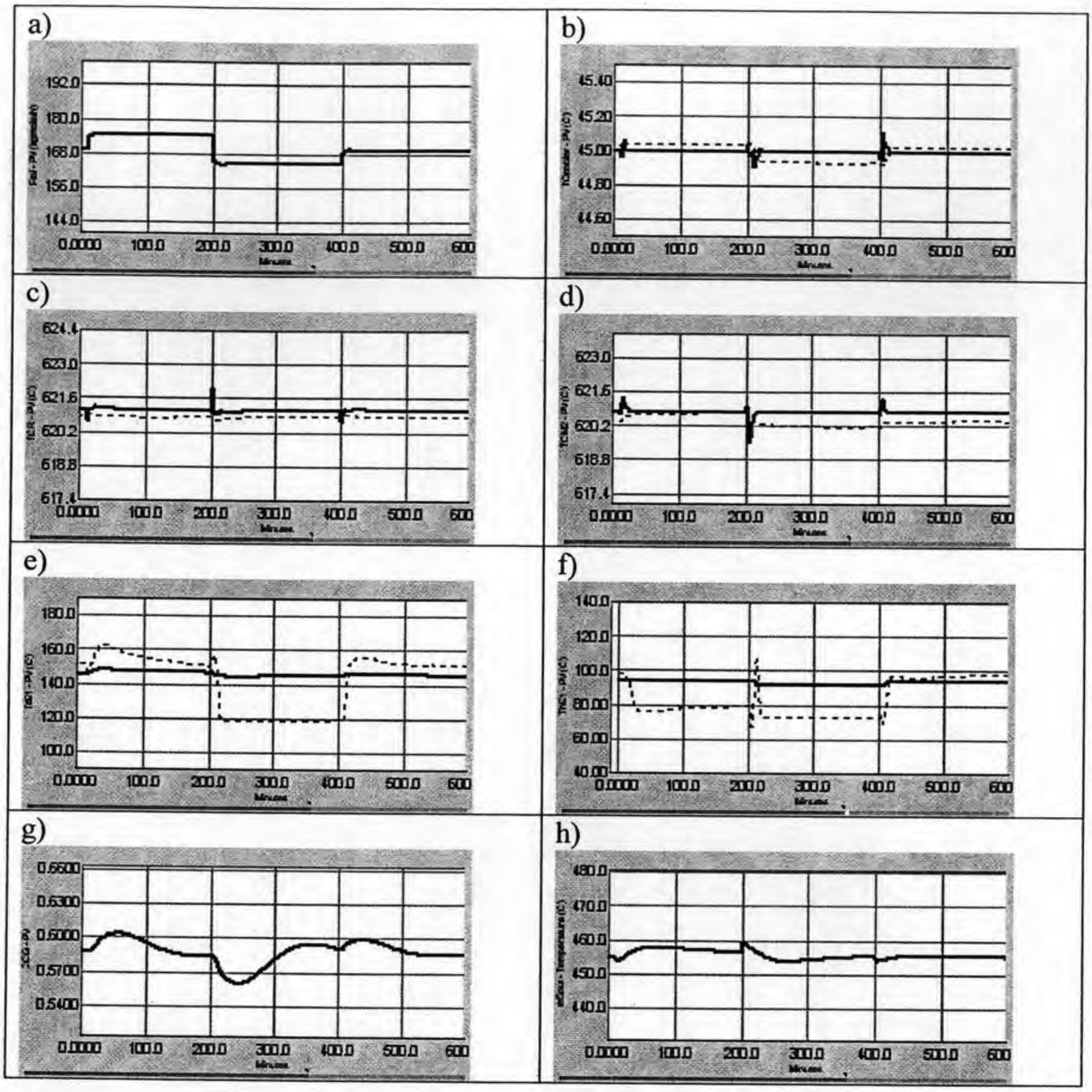


Figure 6.32 Dynamic Responses of the HDA Process Alternative 6:Basecase with four Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS4, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

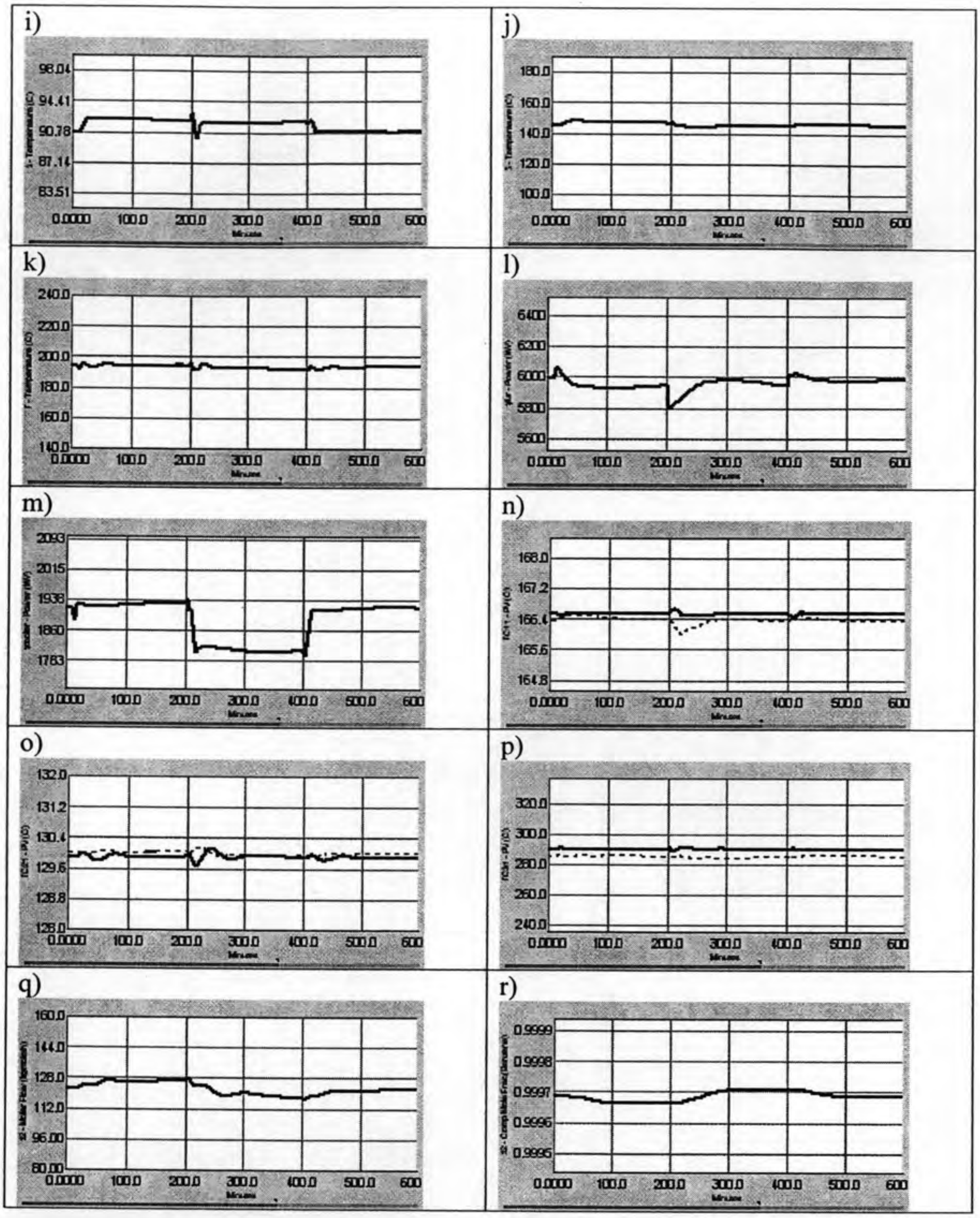


Figure 6.32 (continue)

6.6 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary Utility Units: CS1

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.33 to 6.35. Results for individual disturbance load changes are as follows:

6.6.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.33 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

Again, the heat load disturbance of the hot stream can be shifted to the cold stream, since the hot outlet temperature of FEHE3 has to be kept constant. Both positive and negative disturbance loads of the hot stream are shifted to a furnace utility. When the hot temperature decreases, it will result in decrease of the furnace inlet temperature (Figure 6.33.h). Consequently, the furnace duty increases (Figure 6.33.l). On the other hand, when the positive disturbance load is originating from the hot stream (i.e. the hot inlet temperature increases), the furnace duty will be decreased, since the furnace inlet temperature increases. The tray temperature in the recycle column has a deviation about 2°C and it takes long time to return to its nominal value of 290.3°C (Figure 6.33.p). Besides, the separator temperature and the reactor inlet temperature are quite well controlled (Figure 6.33.b and c).

6.6.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.34 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

Both the cold and hot outlet temperatures of FEHE1 decrease as the cold inlet temperature decreases. As a result, the hot outlet temperature of FEHE1 decreases and the cooler duty decreases (Figure 6.34.f and m).

When the cold inlet temperature of FEHE1 increases, both the cold and hot outlet temperatures of FEHE1 increase. Again, the hot outlet temperature of FEHE1 quickly increases then the hot outlet temperature of FEHE1 back to steady state (Figure 6.34.f) so the cooler duty increases. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.34.b and n), but the oscillations occur in the recycle column temperature (Figure 6.34.p).

6.6.3 Change in the Total Toluene Feed Flow Rate

Figure 6.35 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

Energy integration causes the plant will be more difficult to control. Though HDA plant with energy integration (alternative 6) can recover more energy, but the control system in this complex energy integrated plant cannot handle large amount of disturbances.

To increase in total toluene flowrate raises the reaction rate, so the benzene product flowrate increases (Figure 6.35.q). On the other hand, the drop in total toluene feed flowrate reduces the reaction rate, so the benzene product flowrates drops but the benzene product quality is rarely affected by this change (Figure 6.35.q). The separator temperature is slightly well controlled (Figure 6.35.d), but the oscillations occur in the tray temperature of the stabilizer column and the reactor inlet temperature (Figure 6.35.i and h). For the tray temperature of the product column, it is quite well controlled when this disturbance occurs (Figure 6.35.o), but the tray temperature in the recycle column has a deviation about 5°C and it takes long time to return to its nominal value of 290.3°C (Figure 6.35.p).

6.7 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with Minimum Auxiliary Utility Units: CS2

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.36 to 6.38. Results for individual disturbance load changes are as follows

6.7.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.36 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

The dynamic responses of this control structure are better than CS1 when the change in the disturbance load of the hot stream occurs, since the feed flowrate of the recycle column is flow-controlled. Then, the effect of this disturbance does not propagate to downstream unit operation like recycle column. Thus, the tray temperatures in the stabilizer and recycle column provide well controlled (Figure 6.36.n and p). The separator temperature, the reactor inlet temperature is slightly well controlled (Figure 6.36.d) but the oscillation happens in the tray temperature of the product column (Figure 6.36.o.).

6.7.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.37 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of this control structure are better than that CS1 when the change in the disturbance load of the cold stream happens. Particularly, the tray temperature in the recycle column provides a well controlled (Figure 6.37.p) because the feed flowrate of the recycle column is fixed for to reduce the propagation when disturbance occurs. In addition, the other dynamic responses are similar to the earlier control structures. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.37.d and n) and the smooth control response happens in the tray temperature of the recycle column. But the small oscillations occur in the tray temperature of the product column (Figure 6.37.o).

6.7.3 Change in the Total Toluene Feed Flow rate

Figure 6.38 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of CS2 are worse than that of the CS 1 when this disturbance occurs. Particularly, the tray temperature in the recycle column provides the well controlled (Figure 6.38.p) because the feed flowrate of the recycle column is flow-controlled for reducing the material and flow propagation during the disturbance occurs. In addition, the separator temperature is quite well controlled (Figure 6.38.d), the oscillations occur in the tray temperature of the product column (Figure 6.38.o).

6.8 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Units: CS3

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.39 to 6.41. Results for individual disturbance load changes are as follows:

6.8.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.39 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

The dynamic responses of this control structure are better than CS1 when the change in the disturbance load of the hot stream occurs, since the temperature of the product column is two-point control .Thus, the tray temperatures in the product and stabilizer column provide well controlled (Figure 6.39.o, p and n). The separator temperature, the reactor inlet temperature is slightly well controlled (Figure 6.39.d) but the oscillation happens in the tray temperature of the recycle column (Figure 6.39.p.).

6.8.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.40 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of this control structure are better than that CS1 when the change in the disturbance load of the cold stream happens. Particularly, the tray temperature in the product column provides a well controlled (Figure 6.40.o and p) because the temperature of the product column is two-point control. In addition, the other dynamic responses are similar to the earlier control structures. The separator temperature and the tray temperature in the stabilizer column are well controlled (Figure 6.40.d and n) and the smooth control response happens in the tray temperature of the recycle column. The molar flow of benzene is well controlled (figure 6.40.r).

6.8.3 Change in the Total Toluene Feed Flow rate

Figure 6.41 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of CS2 are better than that of the CS 1 when this disturbance occurs. Particularly, the tray temperature in the product column better control than CS1 (Figure 6.41.o and p) because the temperature of the product column is two-point control In addition, the separator temperature is quite well controlled (Figure 6.41.d), the oscillations occur in the tray temperature of the recycle column (Figure 6.41.q).

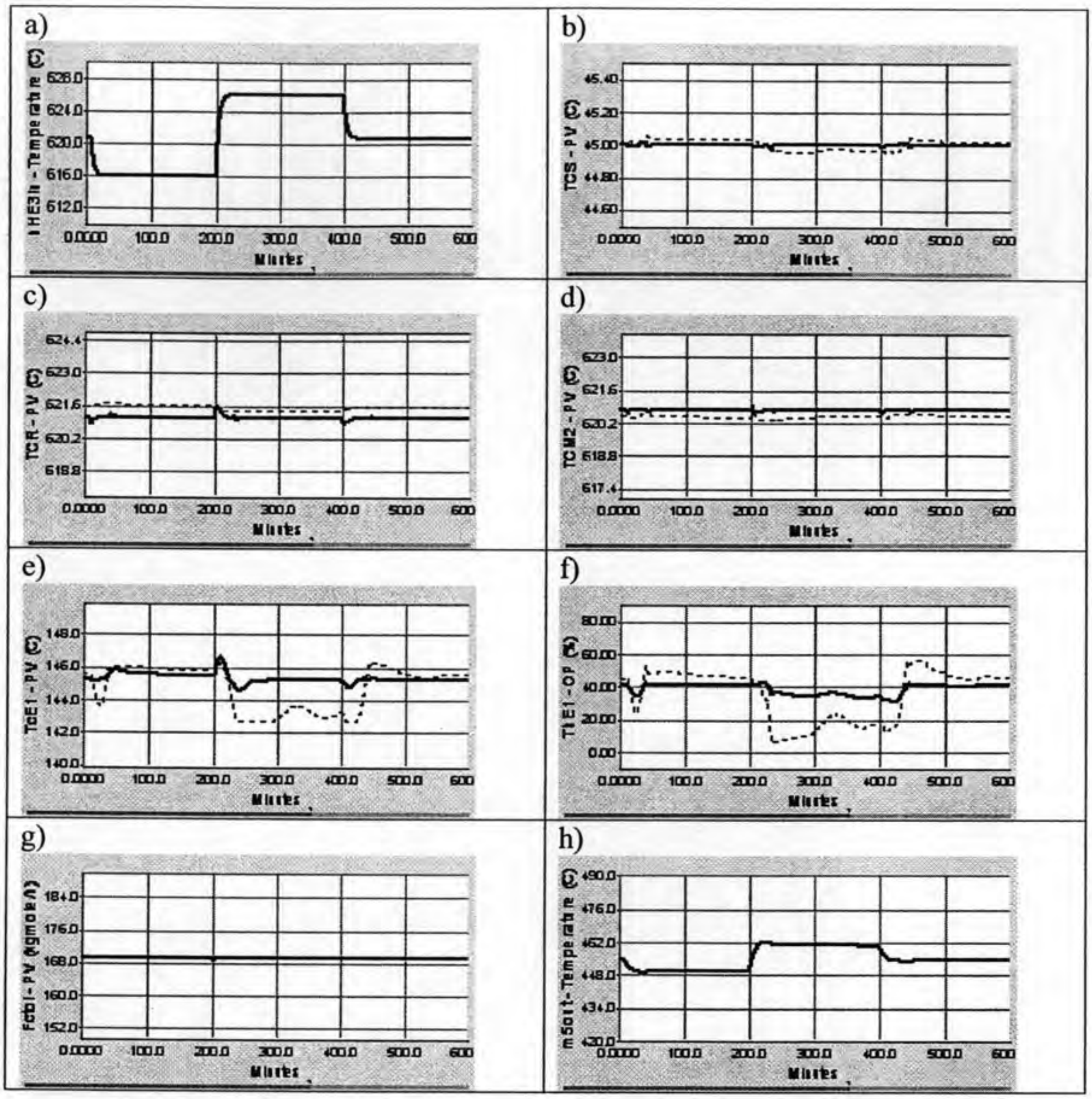
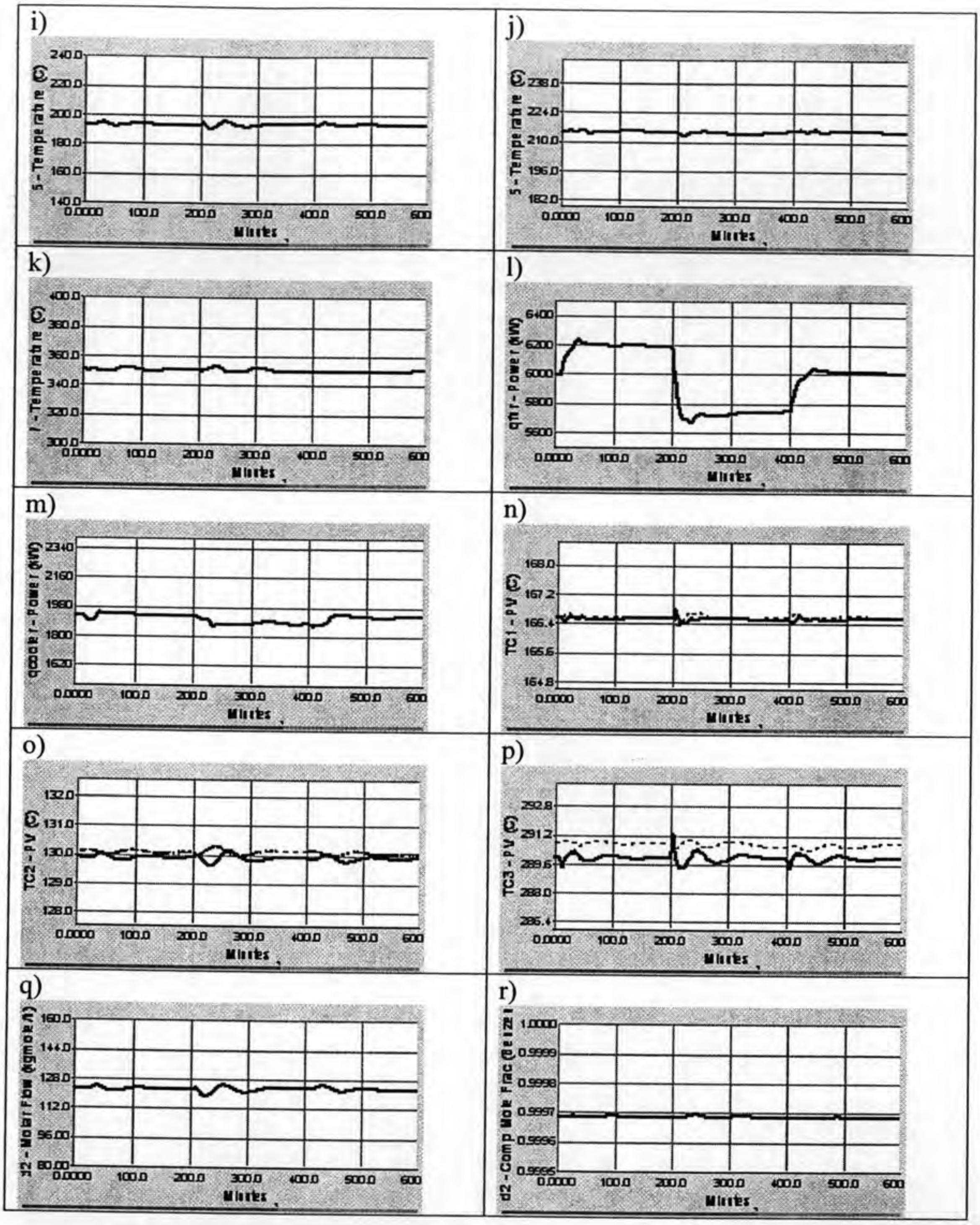


Figure 6.33 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS1, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ―― Process variable (PV) , ······ Manipulated variable)



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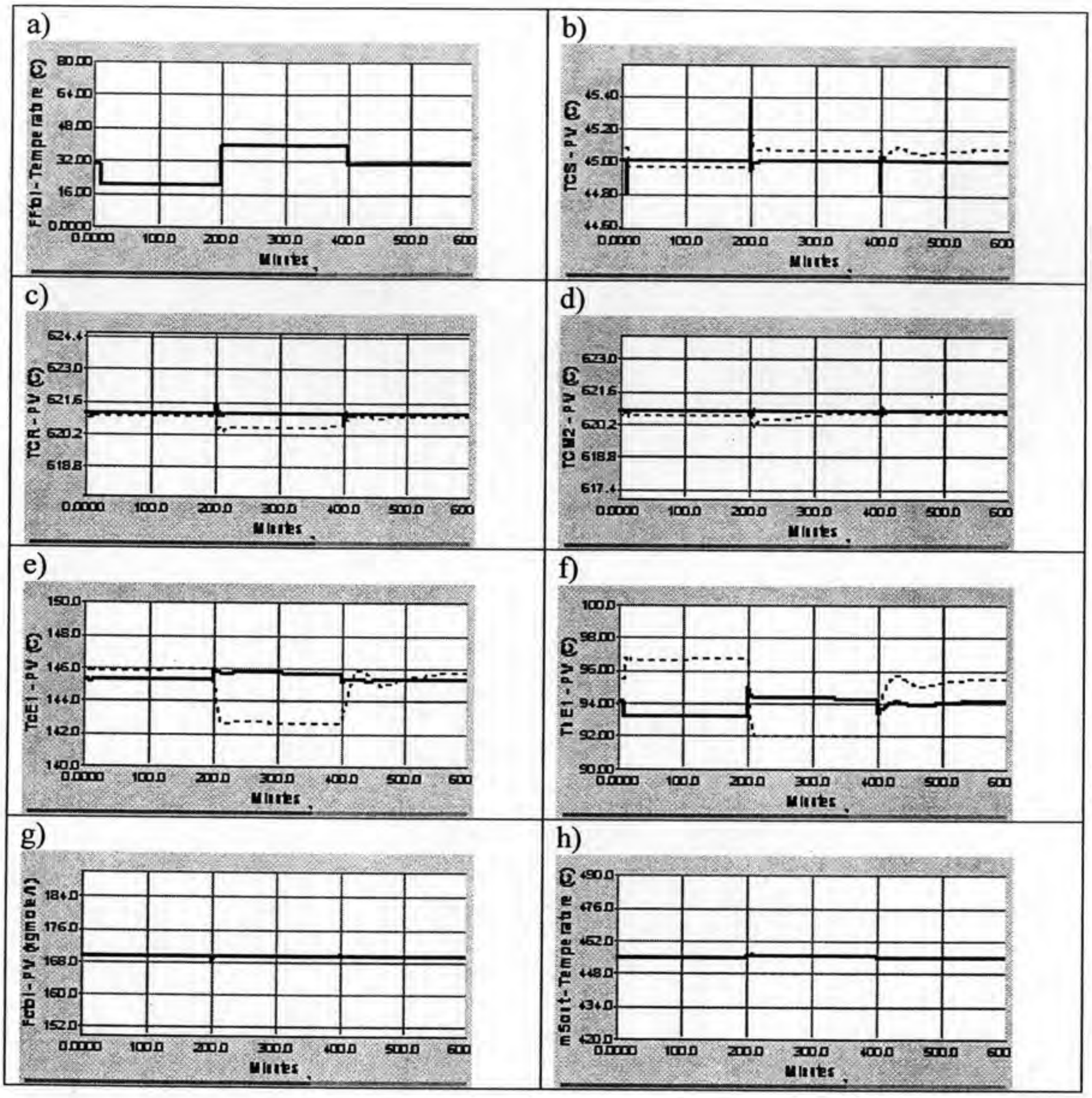
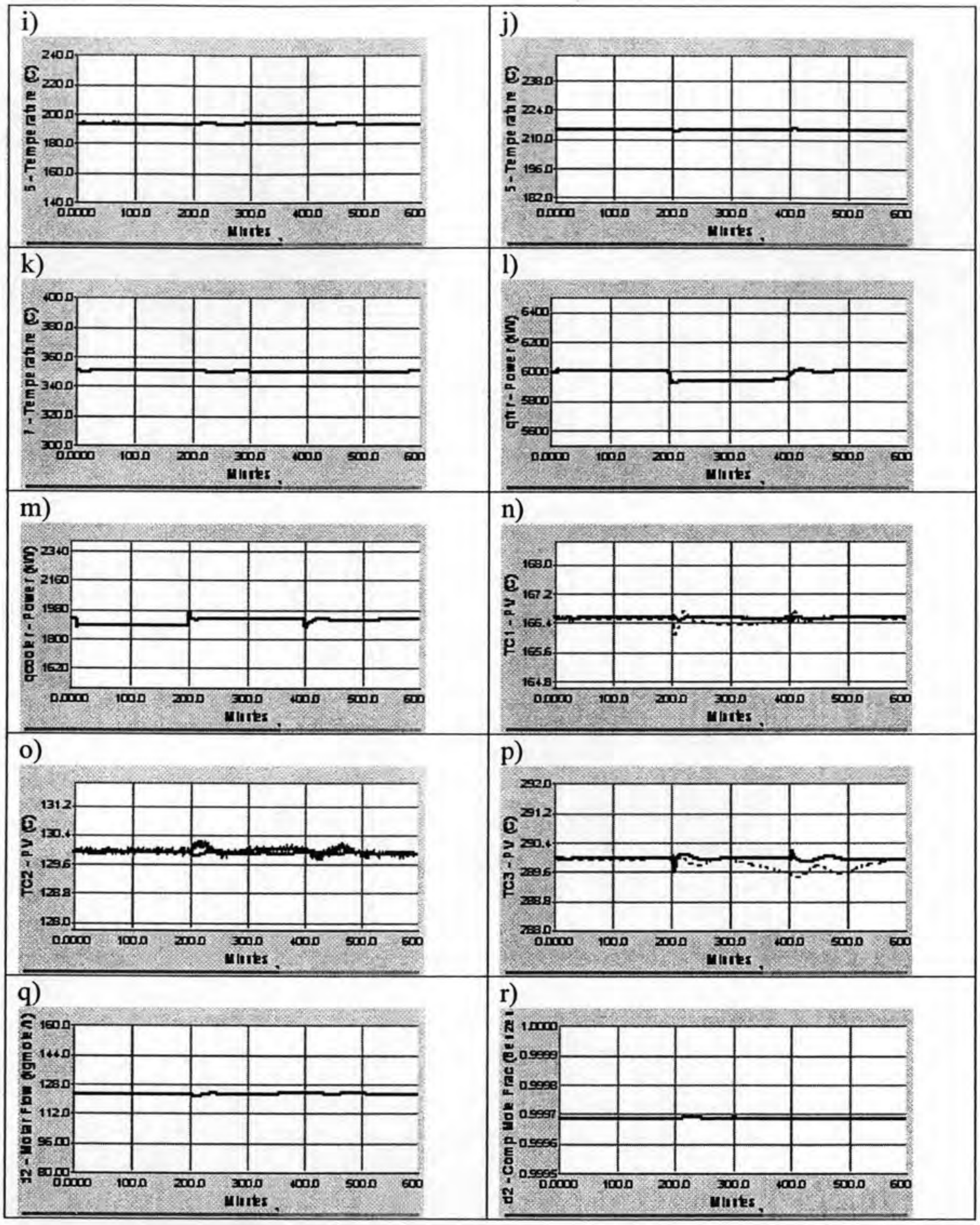


Figure 6.34 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS1, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)



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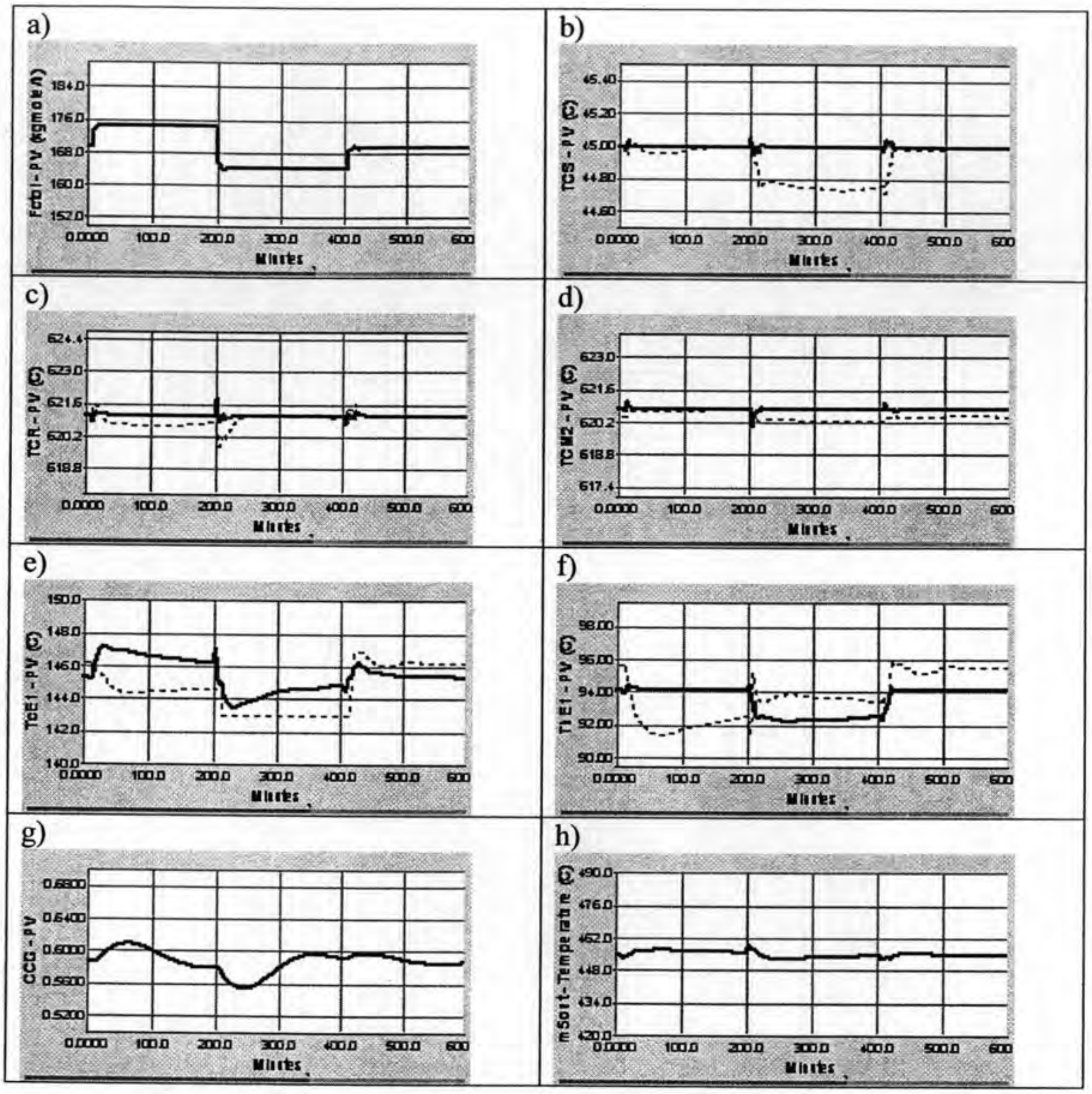
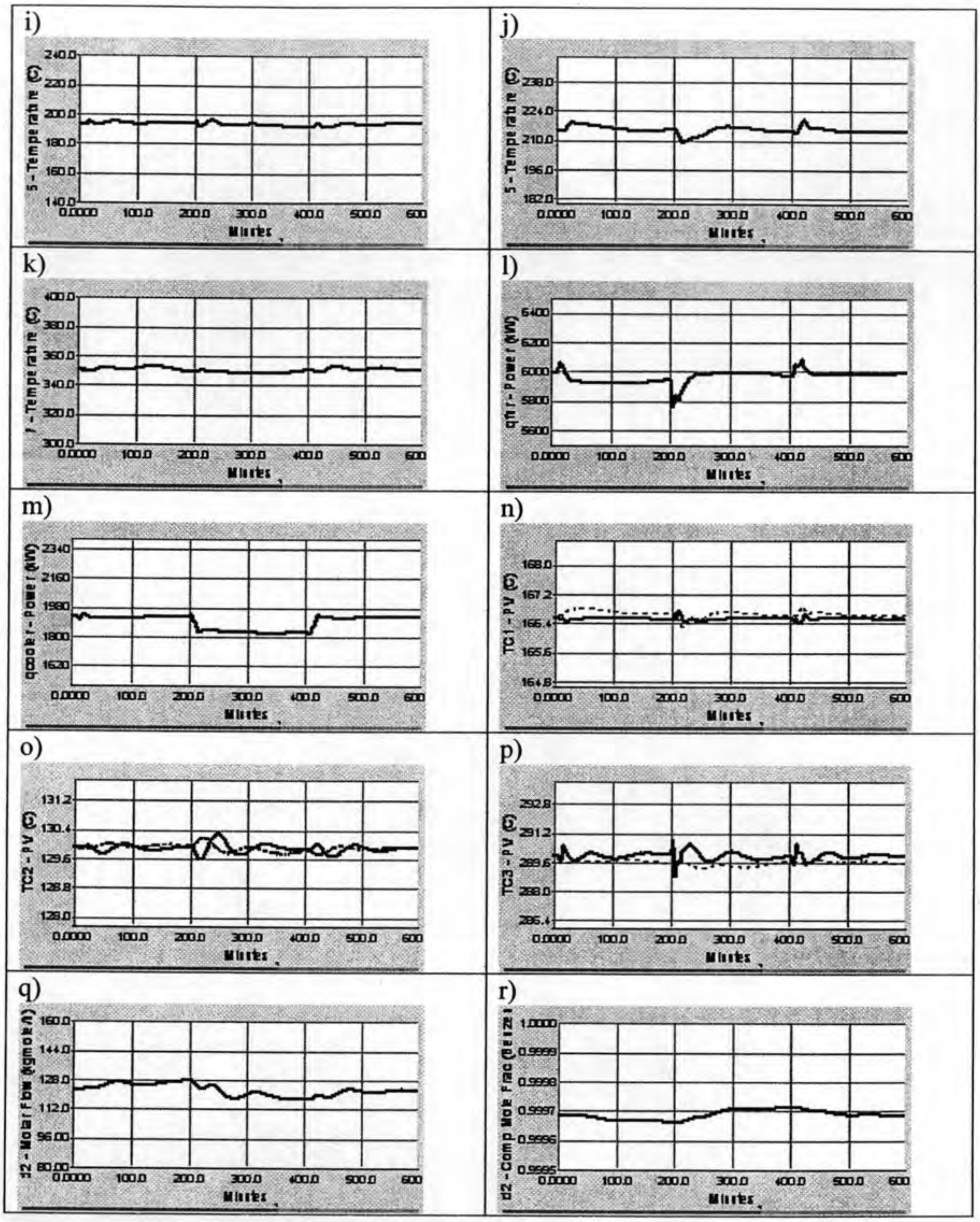


Figure 6.35 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS1, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ······ Manipulated variable)



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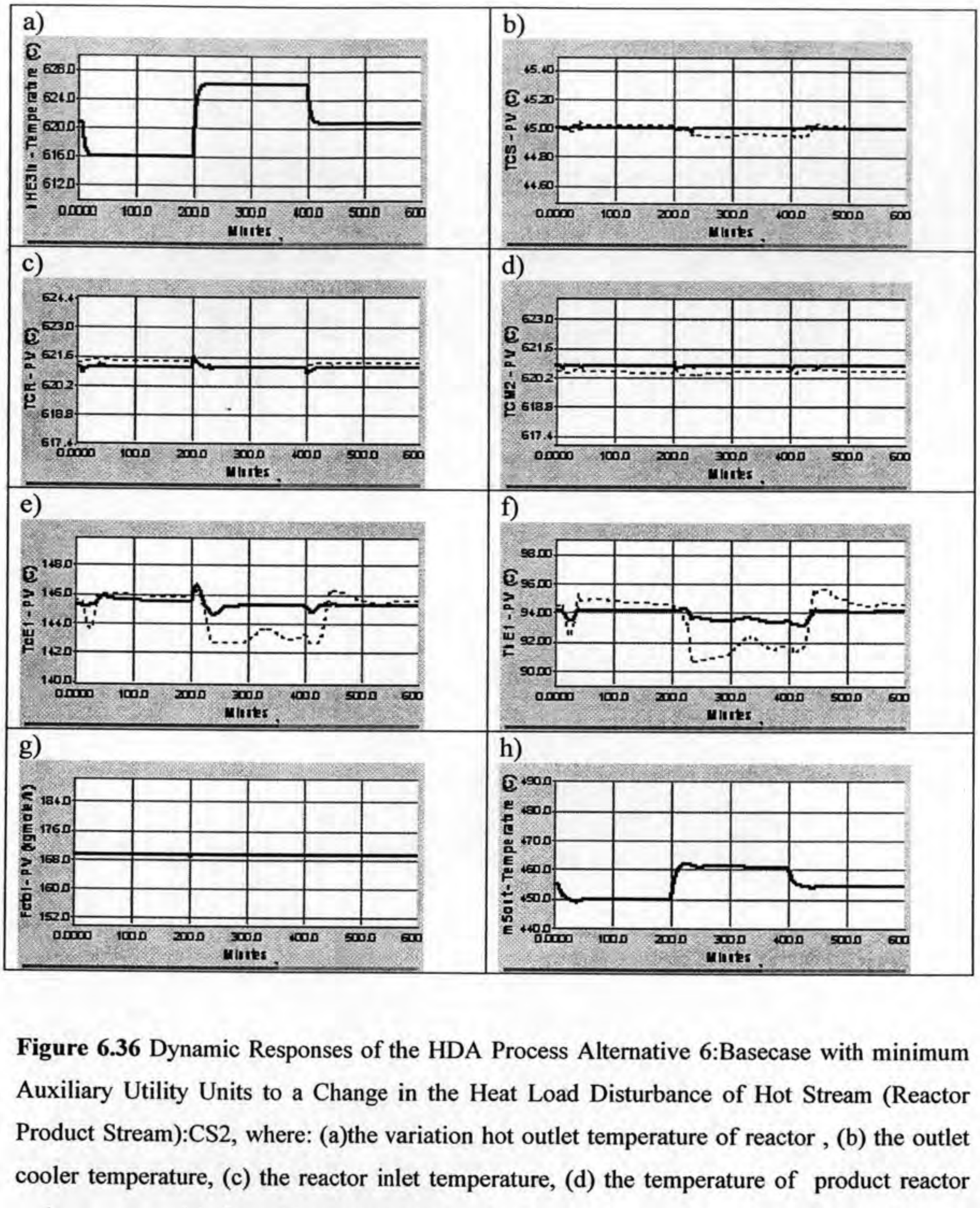
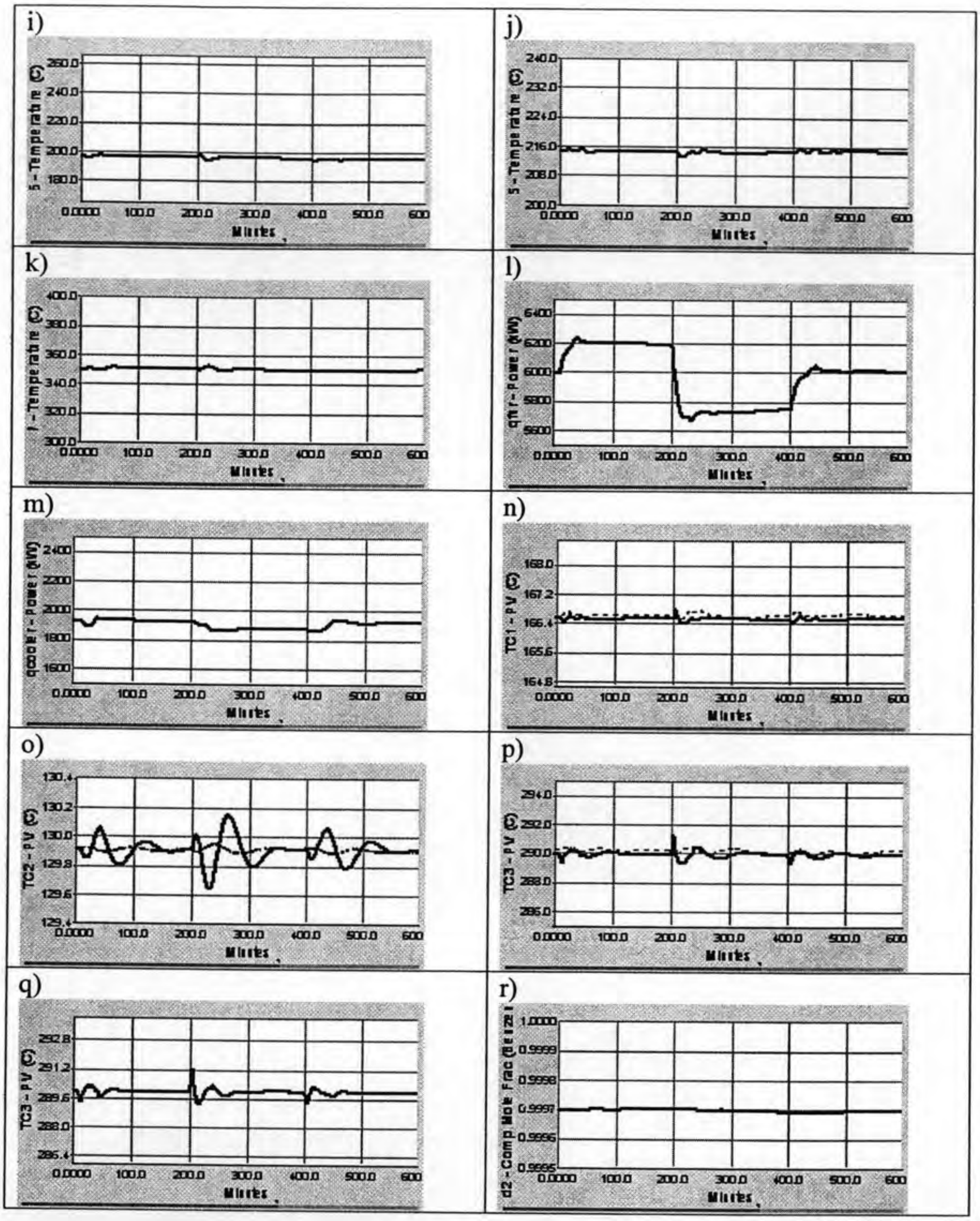


Figure 6.36 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS2, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ⋯⋯ Manipulated variable)



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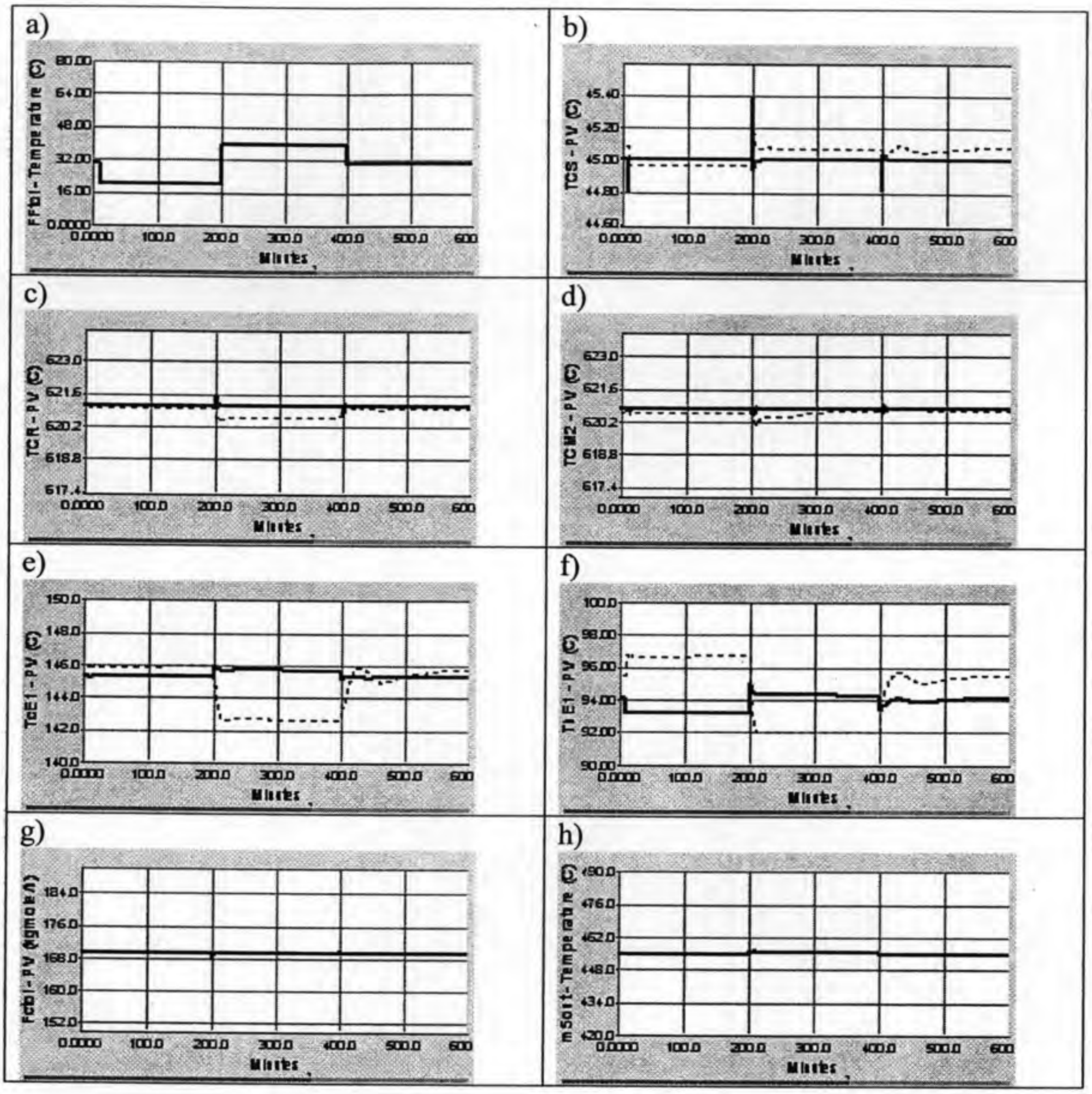
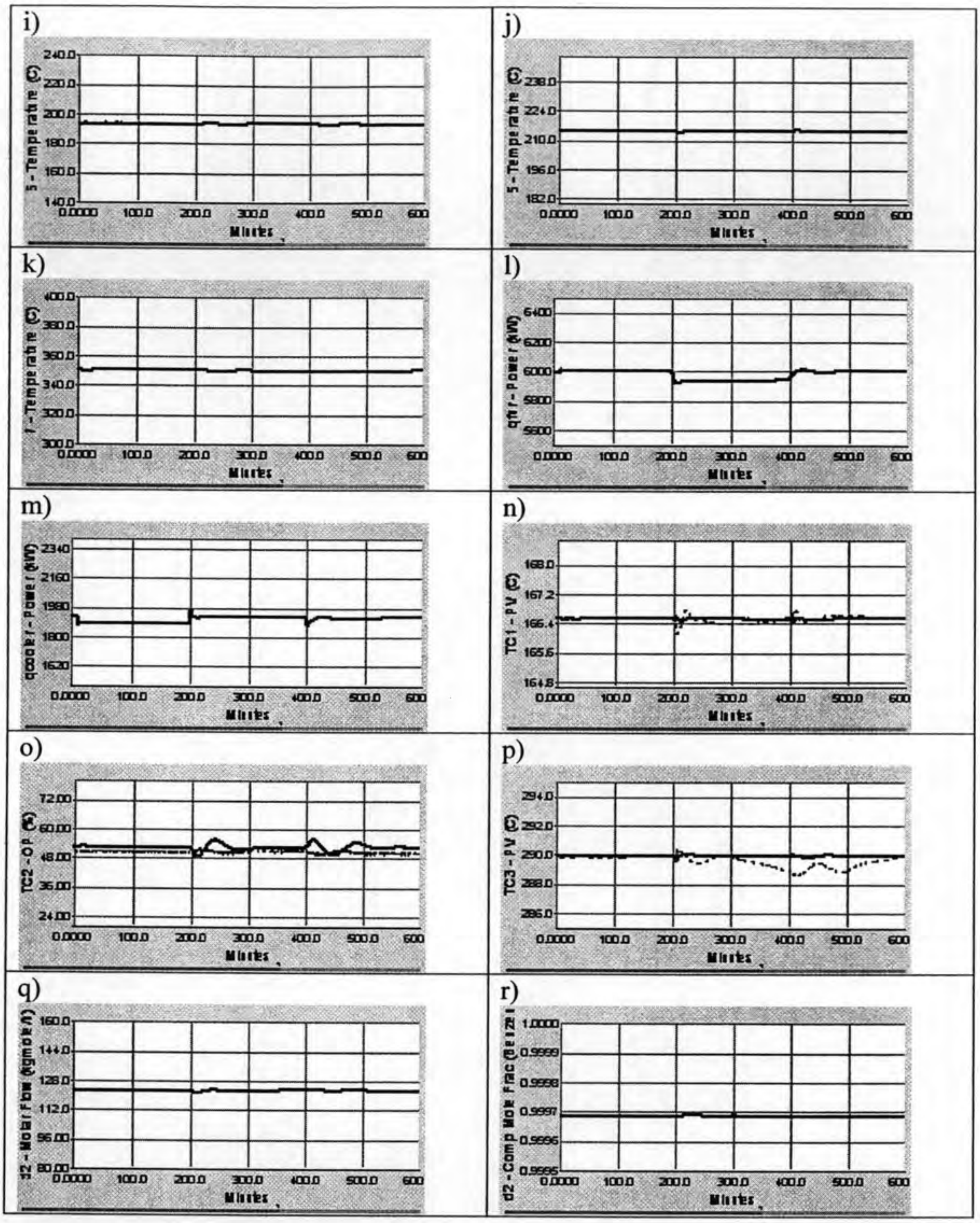


Figure 6.37 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS2, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ▬▬ Process variable (PV) , •••••• Manipulated variable)



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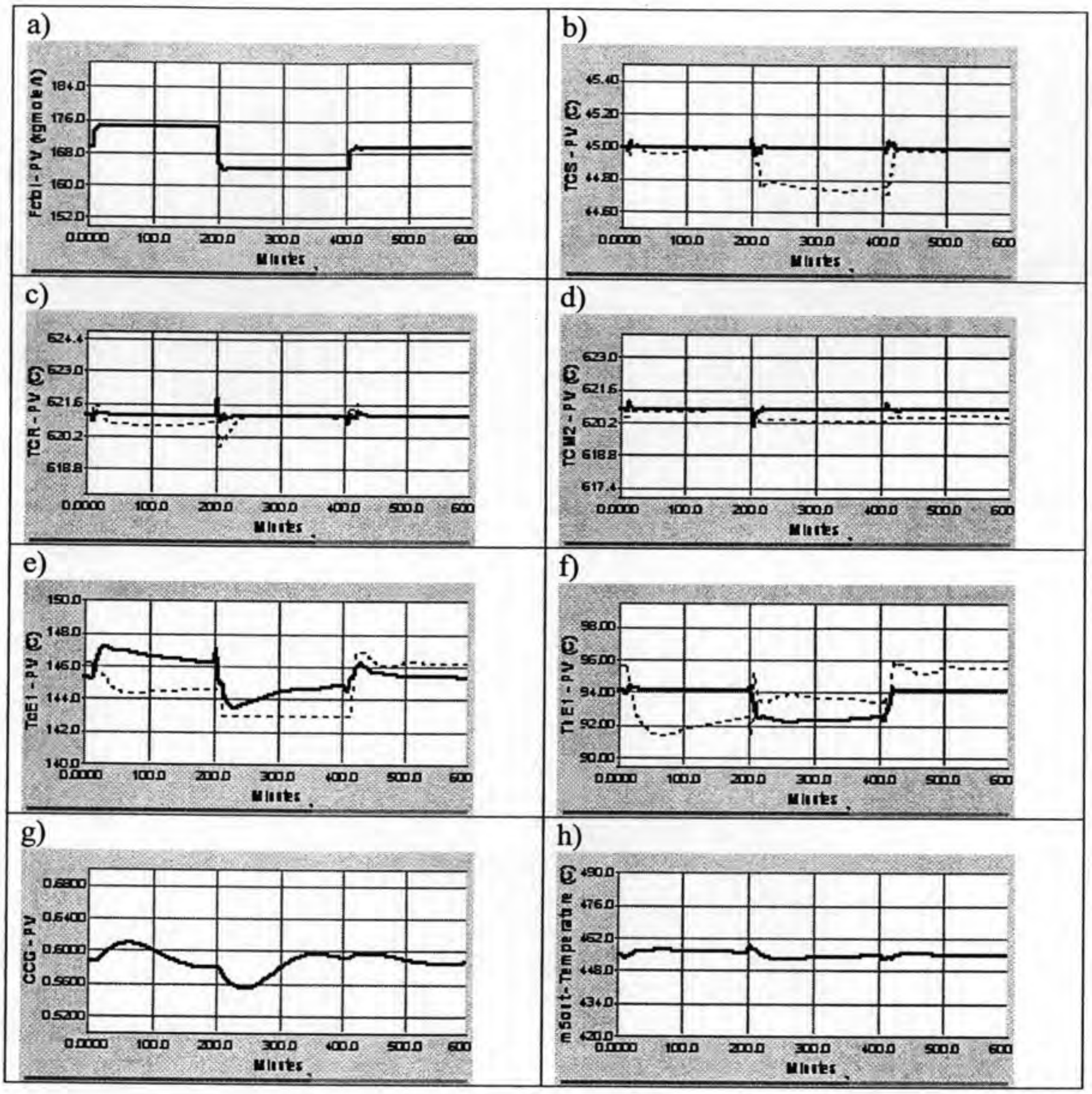
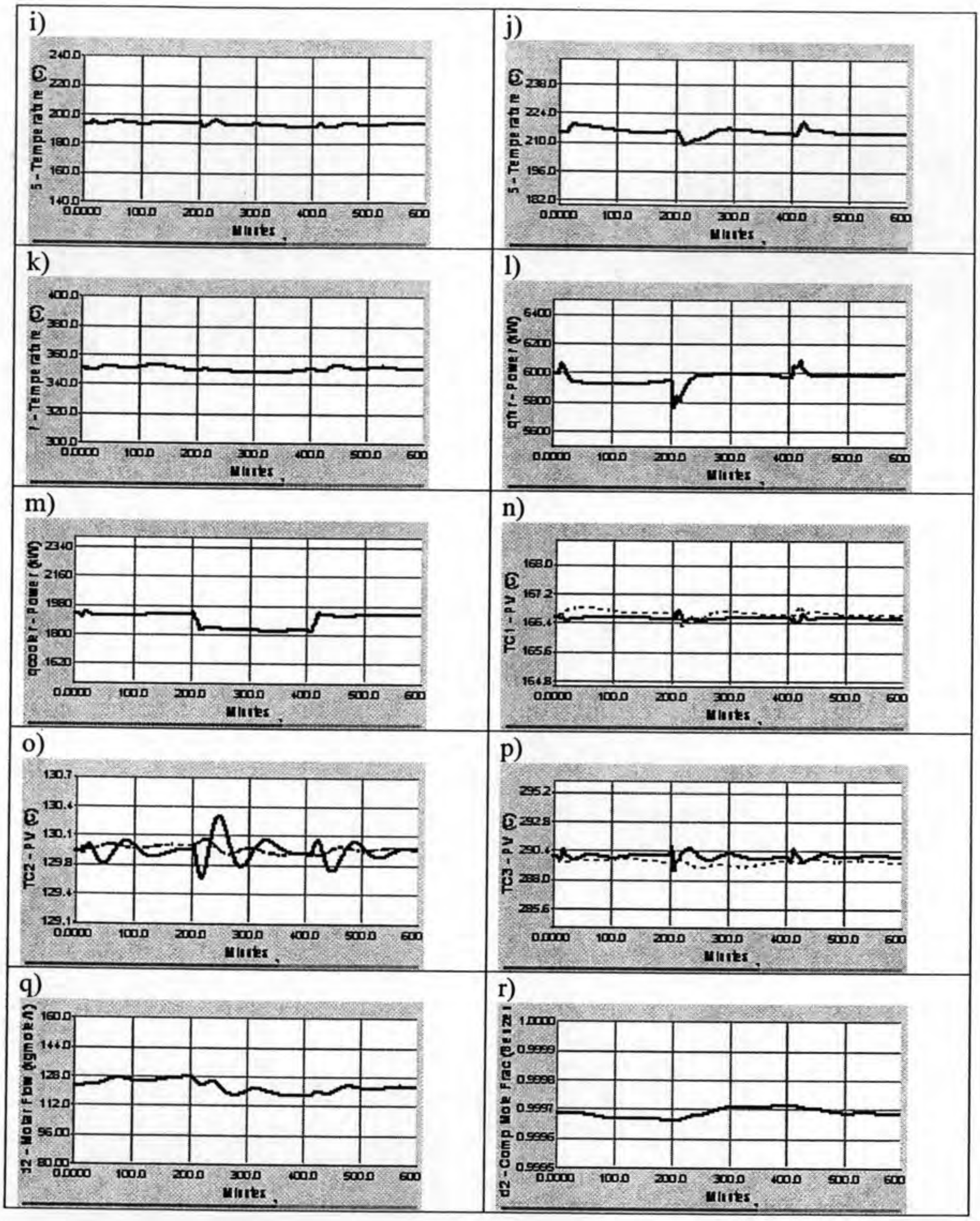


Figure 6.38 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS2, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ─── Process variable (PV) , ······ Manipulated variable)



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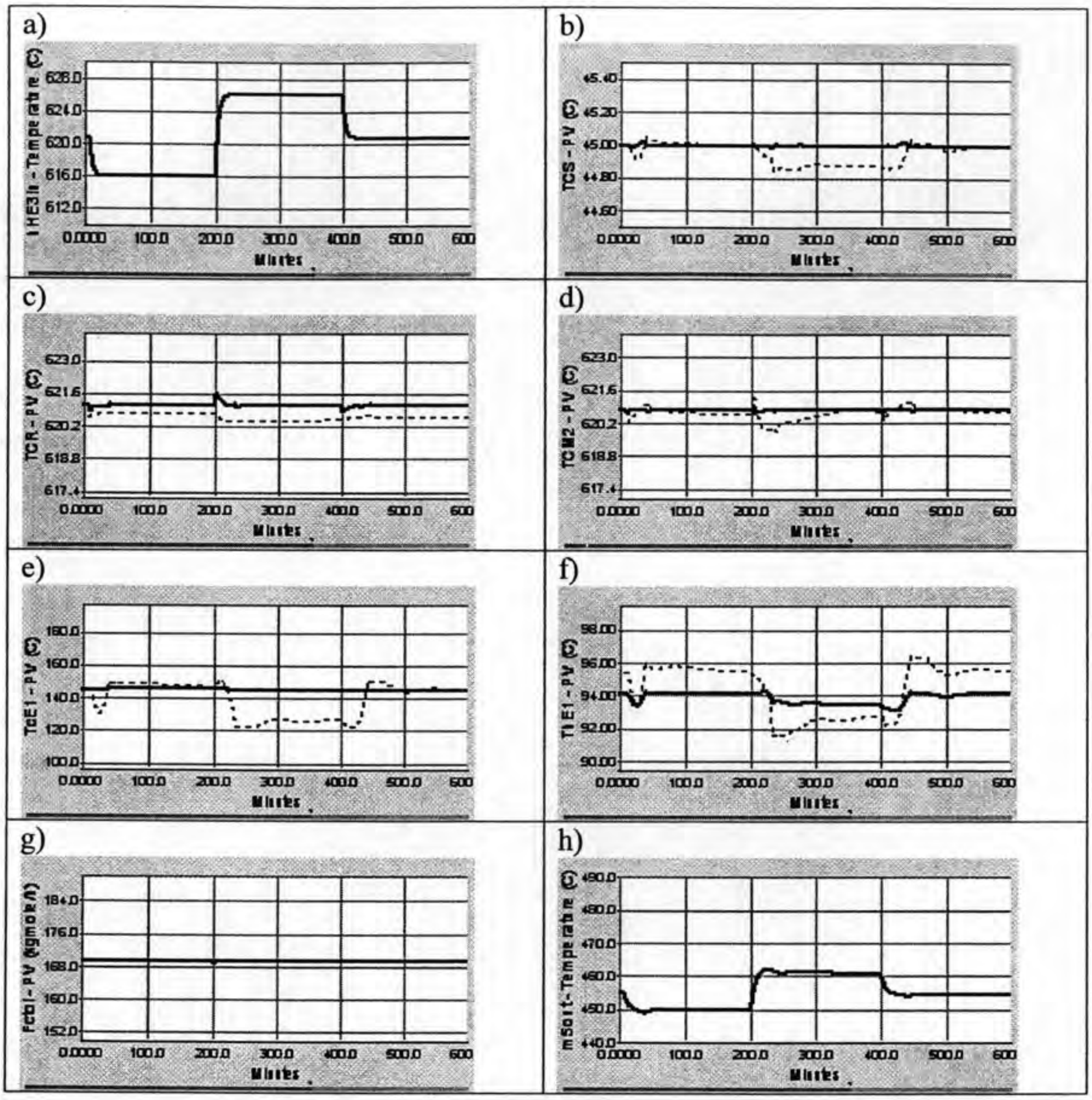

Figure 6.39 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS3, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

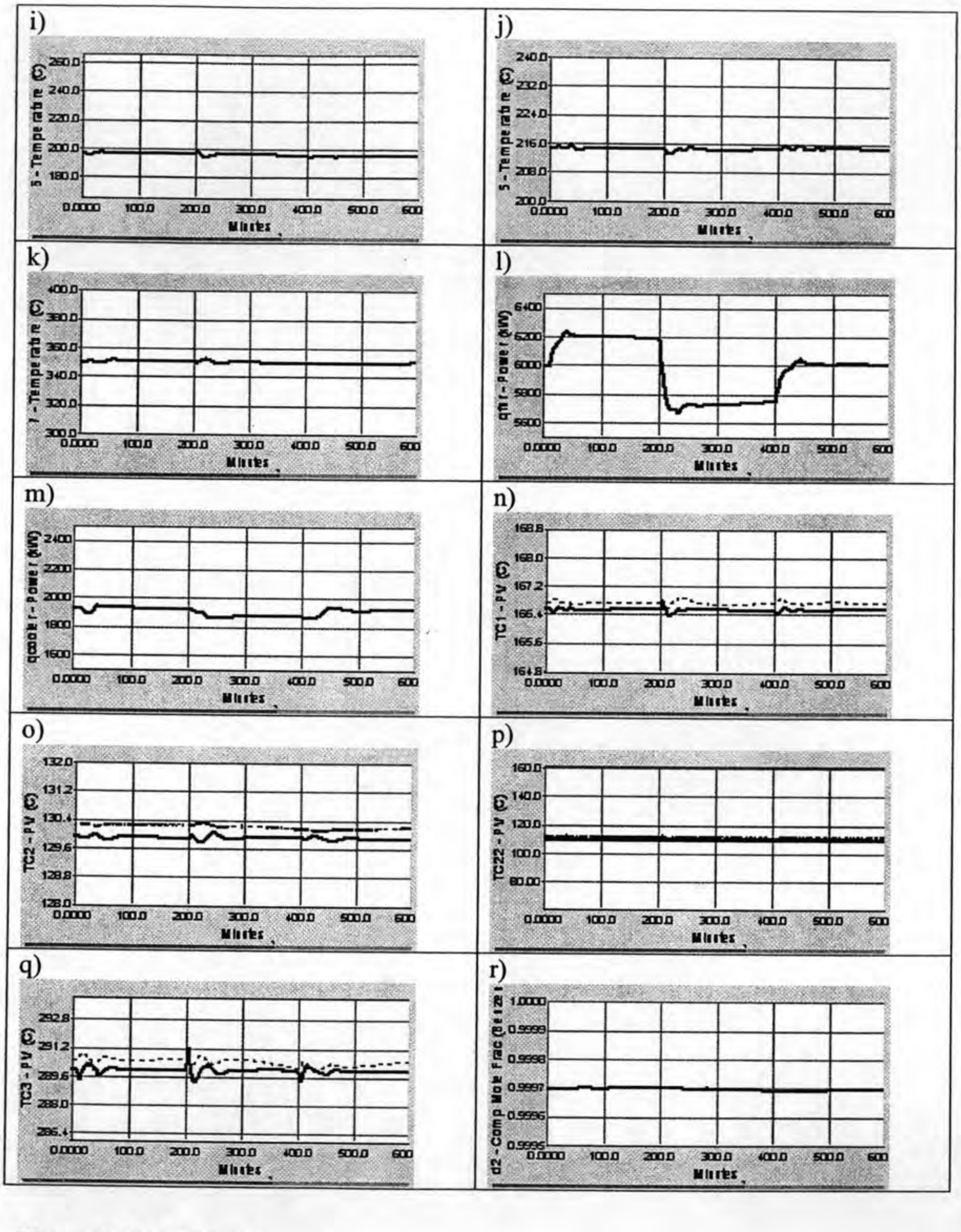

Figure 6.39 (continue)

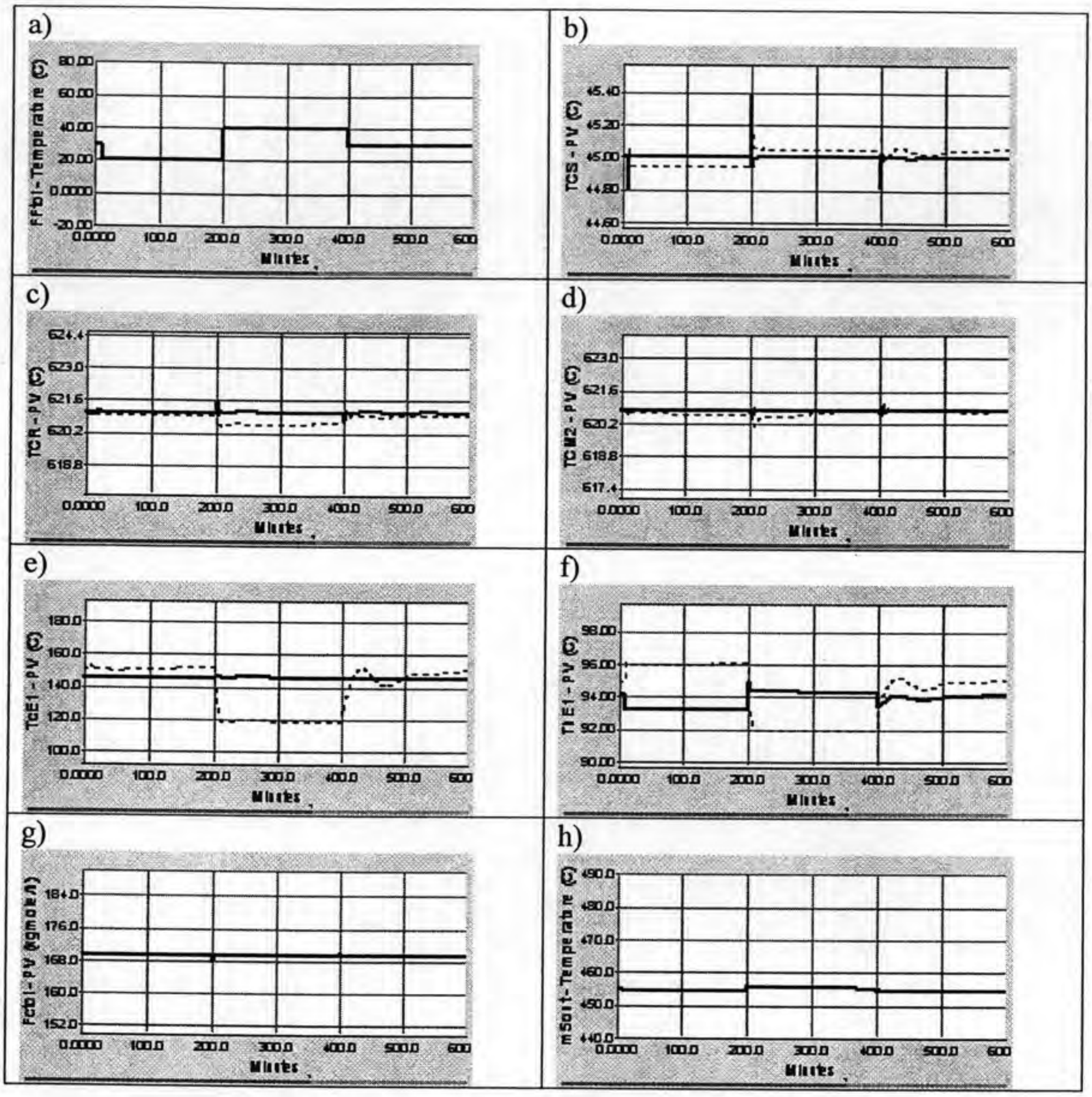

Figure 6.40 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS3, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ━━━ Process variable (PV) , ... Manipulated variable)

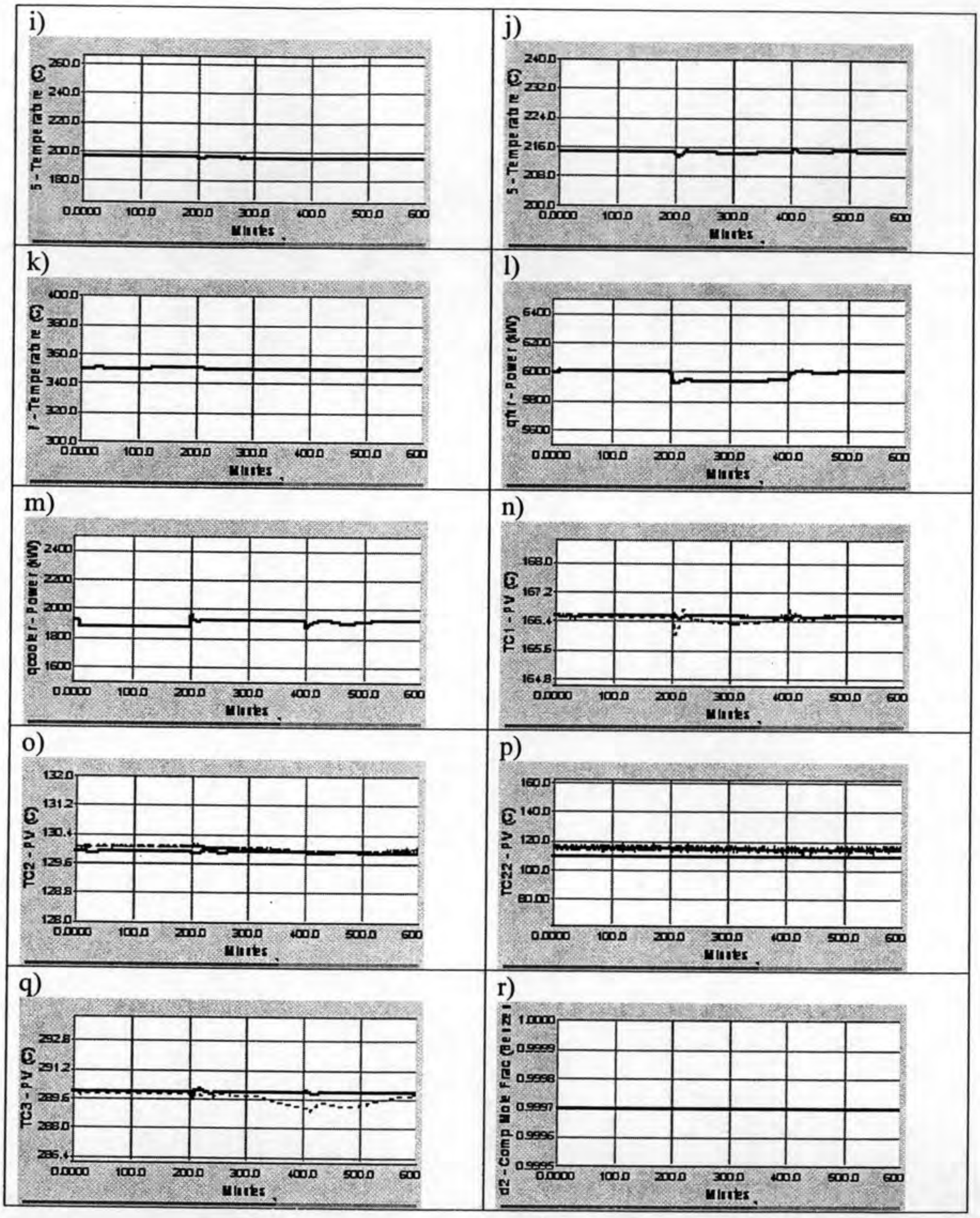

Figure 6.40 (continue)

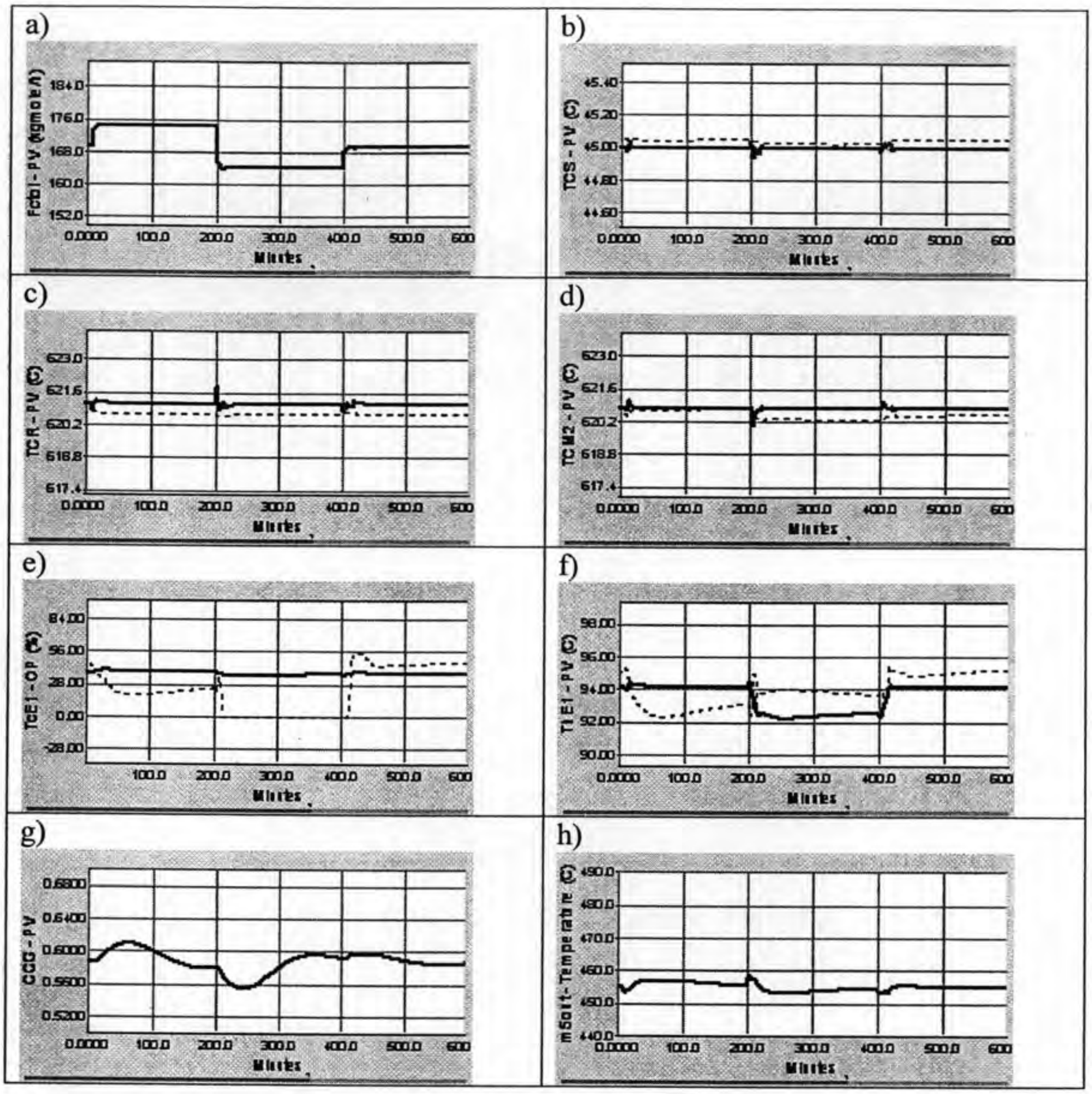

Figure 6.41 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS3, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ━━ Process variable (PV) , ⋯⋯ Manipulated variable)

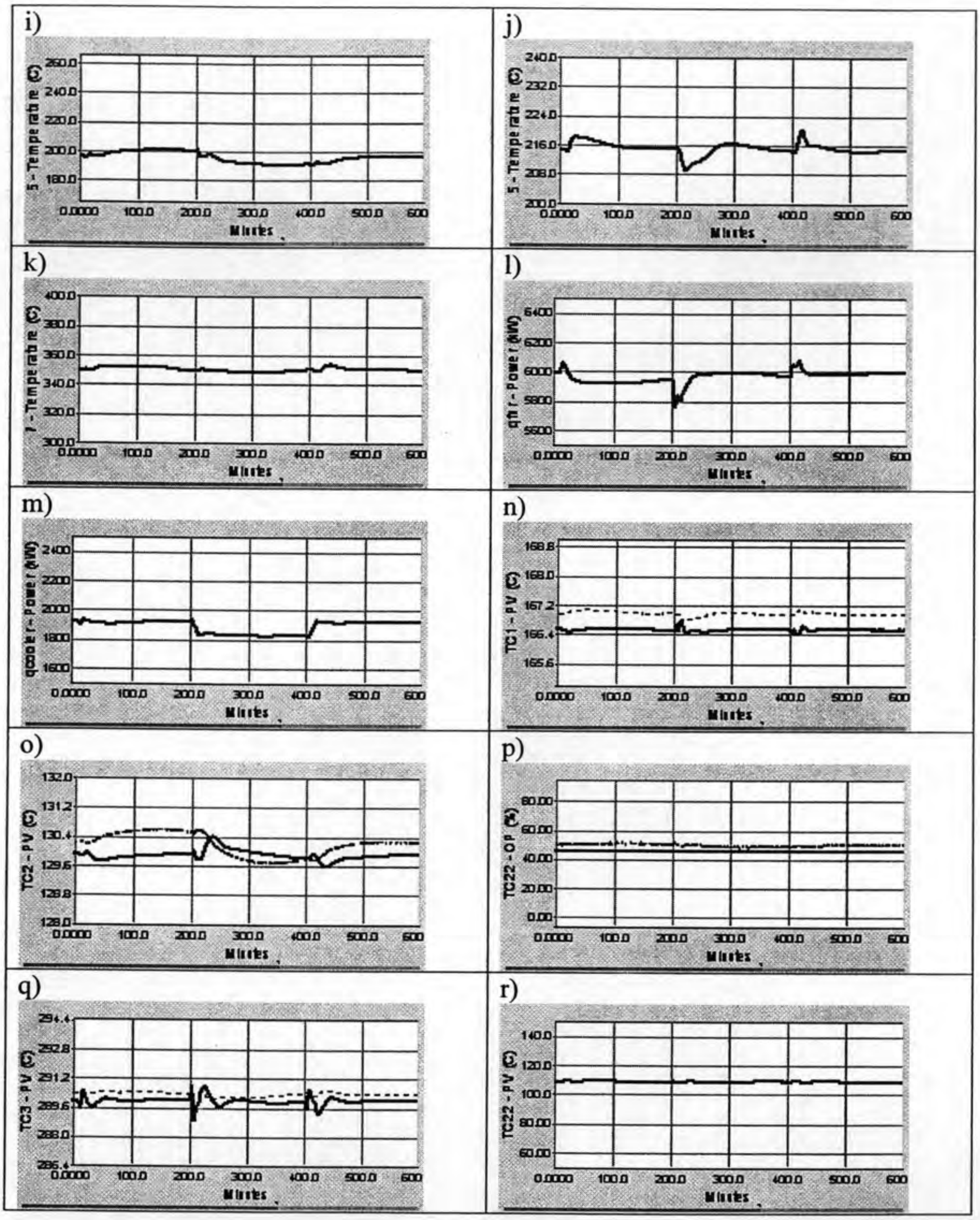

Figure 6.41 (continue)

6.9 Dynamic Simulation Results for HDA Process Alternative 6 (Basecase) with minimum Auxiliary Utility Units: CS4

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.42 to 6.44. Results for individual disturbance load changes are as follows:

6.9.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.30 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes

The dynamic responses of this control structure are worse than CS1. Particularly, the tray temperature control in the recycle column provides a poor performance (Figure 6.42.p) because the performance of the tray temperature controlling in distillation column by valve of bottom product is worse than the bypass valve. The separator temperature and the reactor inlet temperature are slightly well controlled (Figure 6.42.d and c), the oscillations occur in the tray temperature of the product column and stabilizer column (Figure 6.42.n and o).

6.9.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.43 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the cold stream occurs, since the performance of the tray temperature controlling in distillation column by valve by-pass is better than that by valve of bottom product. As this disturbance occurs, the effect of this change is reduced before entering to the downstream unit operation Thus, the performances of the tray temperature control in the product and recycle column of this control structure are worse than that of CS1. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.43.d and c). A deviation of 5°C happens in the tray temperature of the recycle column and it takes over 500 minutes to return to its nominal value of 290.3°C (Figure 6.43.p).

6.9.3 Change in the Total Toluene Feed Flow rate

Figure 6.44 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the total toluene occurs, since the performance of the tray temperature controlling in distillation column by valve by-pass is better than that by valve of bottom product. As this disturbance occurs, the effect of this change is reduced before entering to the downstream unit operation Thus, the performances of the tray temperature control in the product and recycle column of this control structure are worse than that of CS1. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.44.d and c). A deviation of 18 °C happens in the tray temperature of the recycle column and it takes over 800 minutes to return to its nominal value of 290.3°C (Figure 6.44.p). A variation of 5 °C happens in the tray temperature of the stabilizer column (Figure 6.44.n) the oscillations occur in the tray temperature of the product column (Figure 6.44.o).

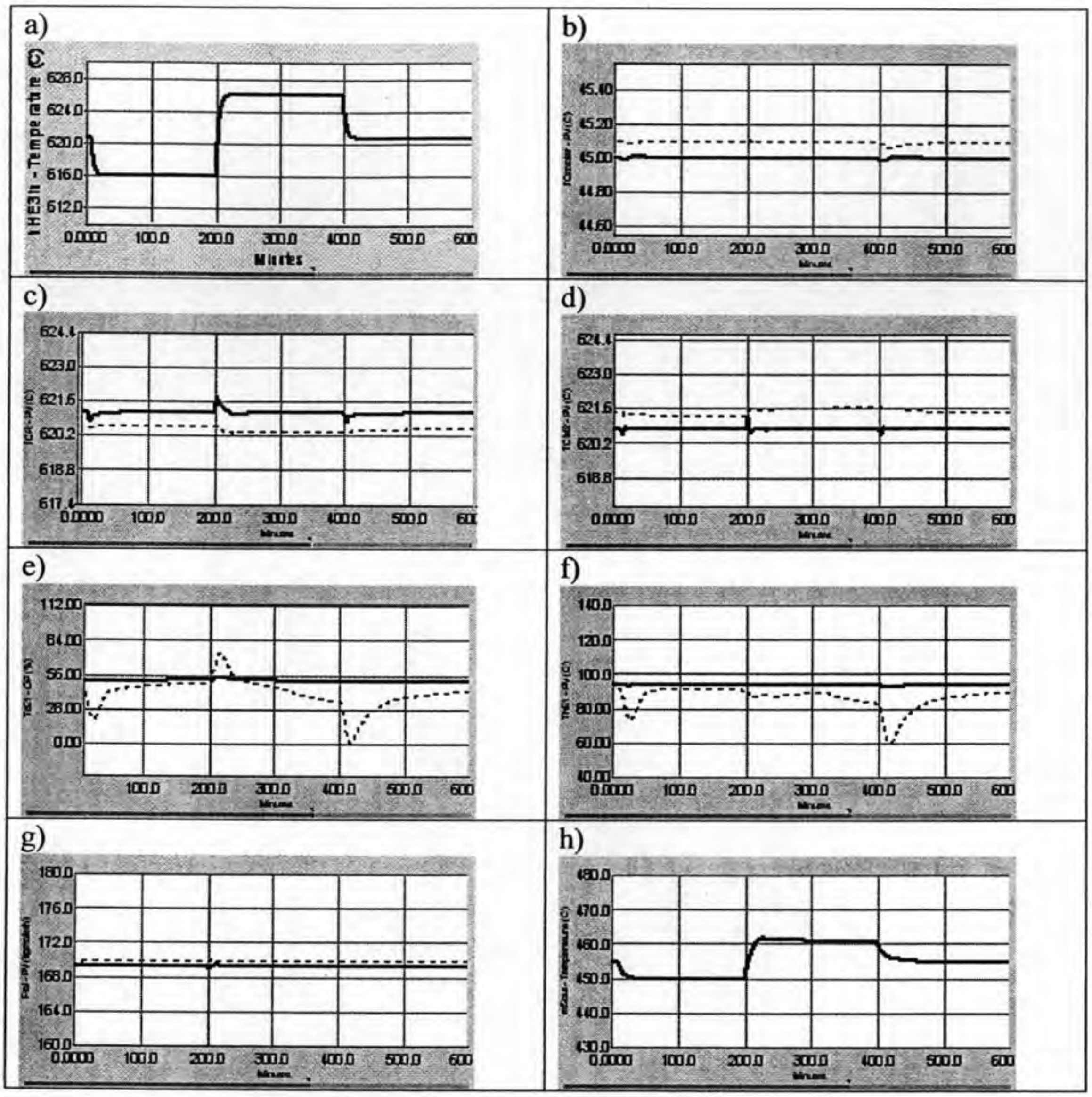

Figure 6.42 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS4, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

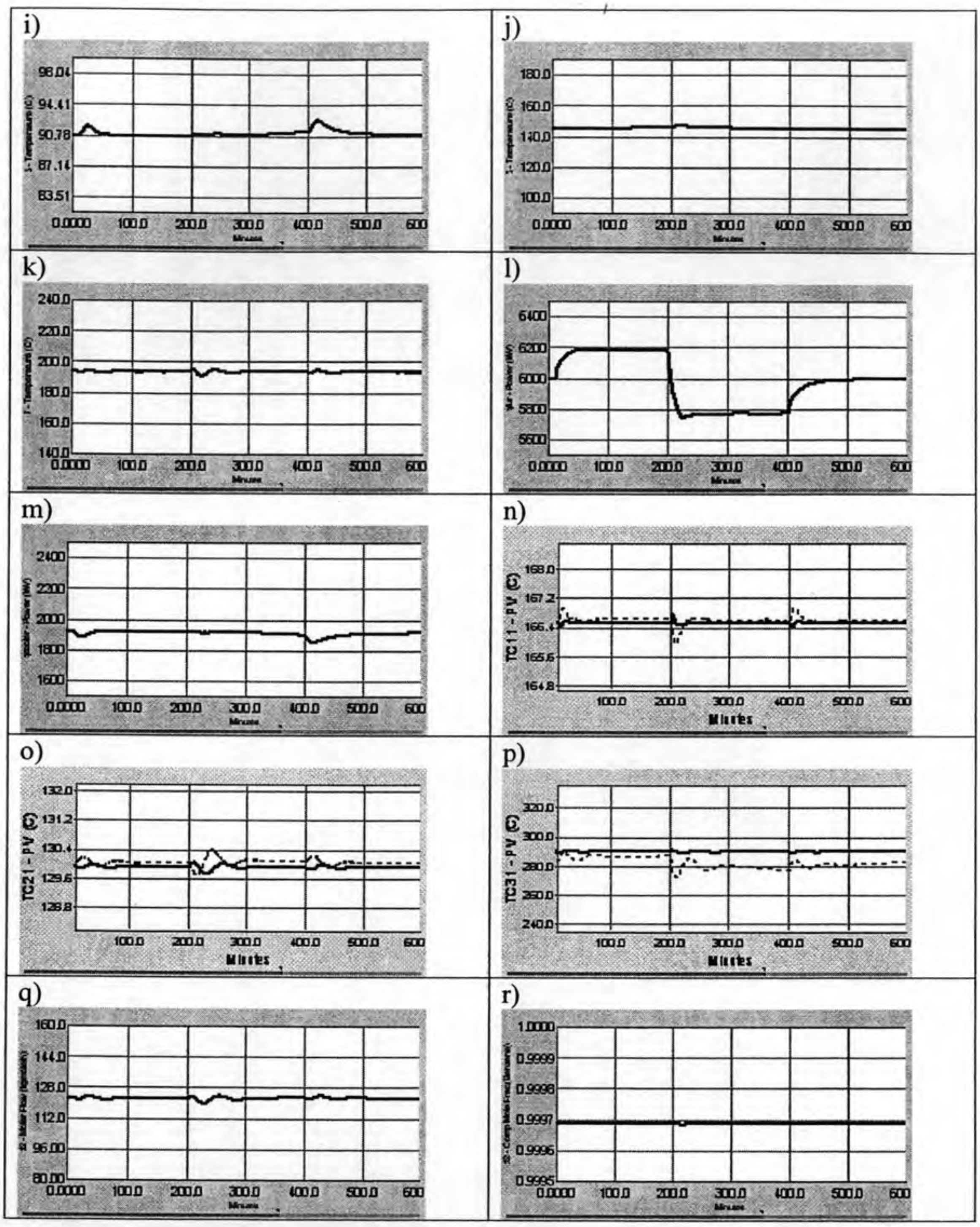

Figure 6.42 (continue)

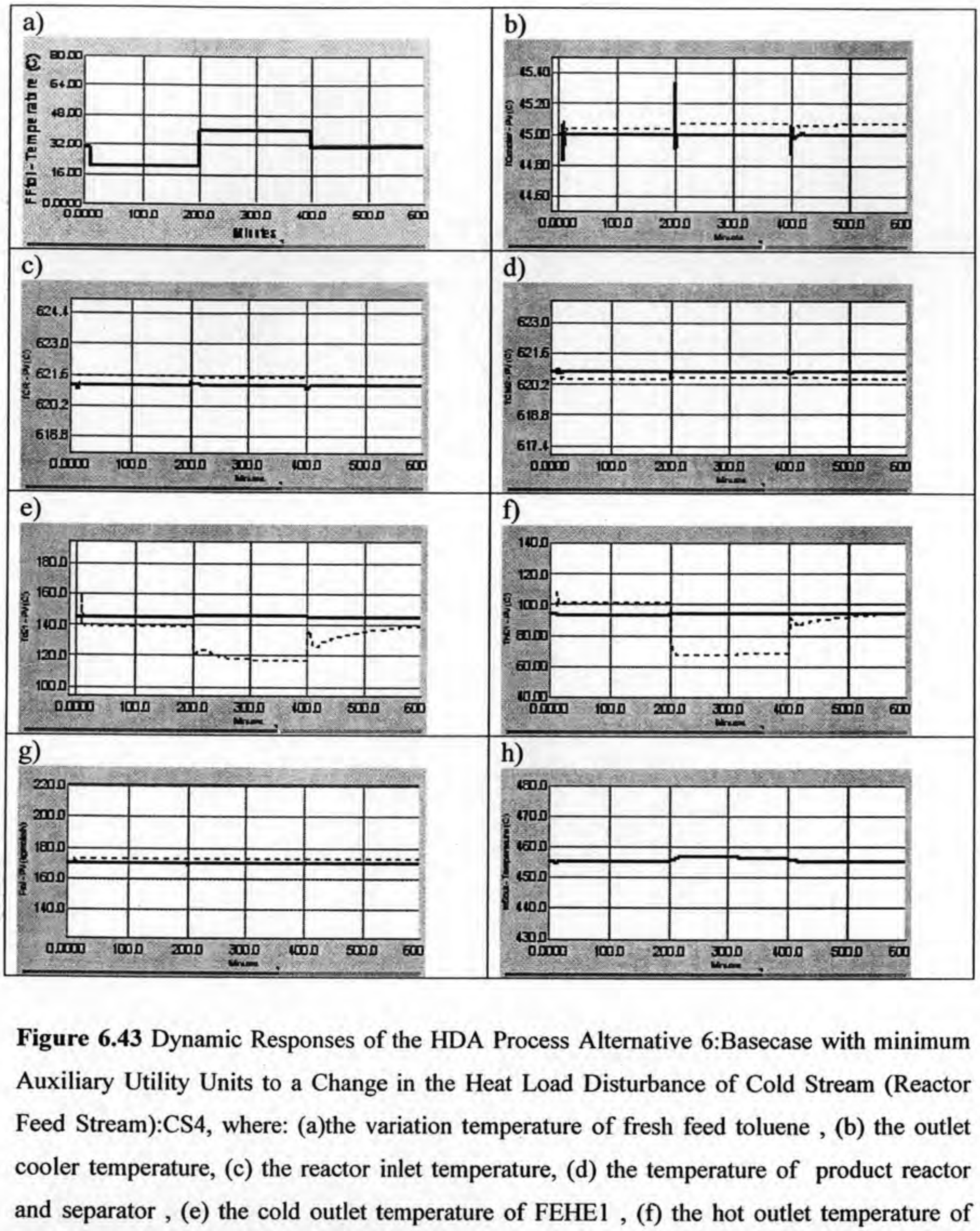

Figure 6.43 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS4, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ⋯⋯ Manipulated variable)

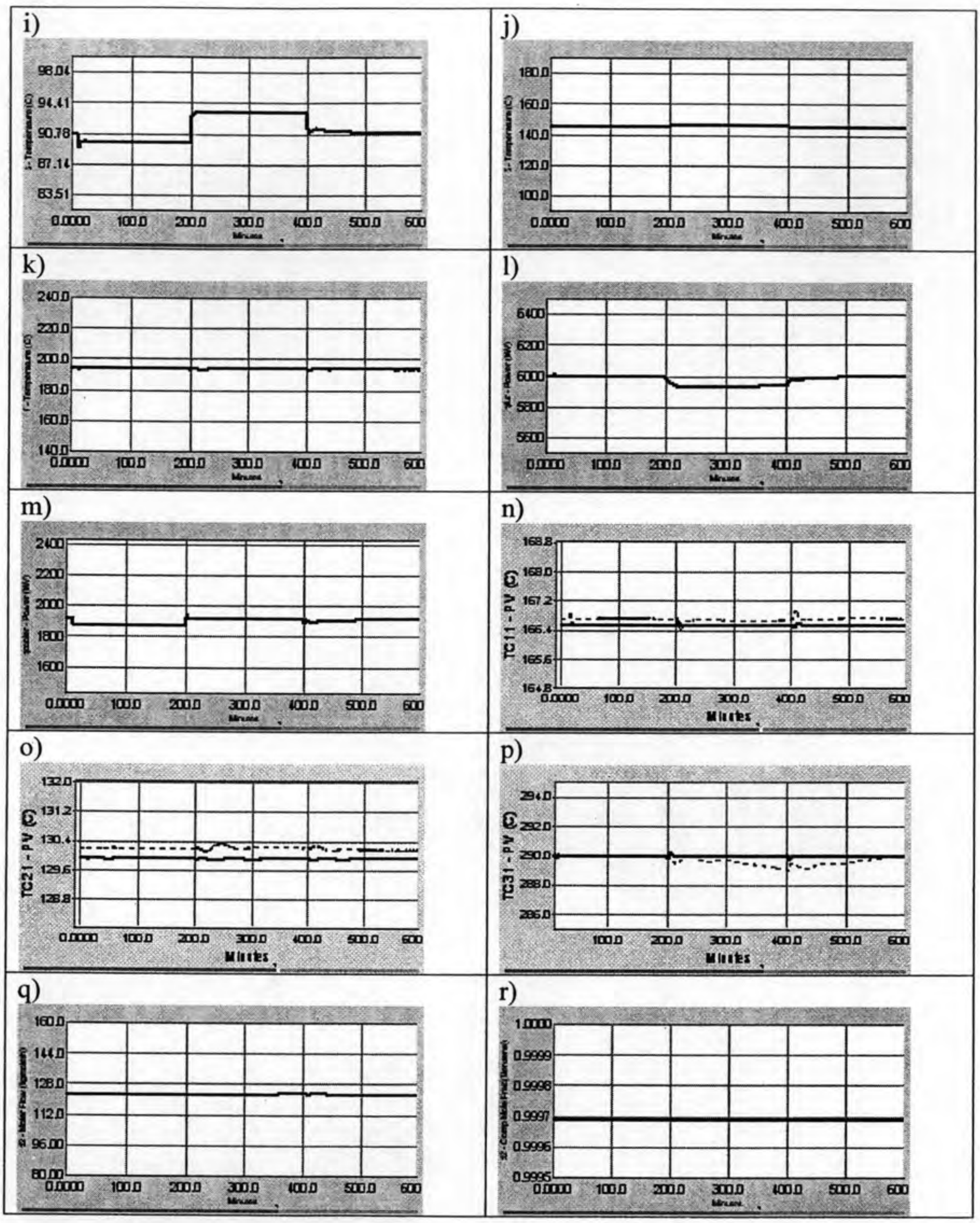

Figure 6.43 (continue)

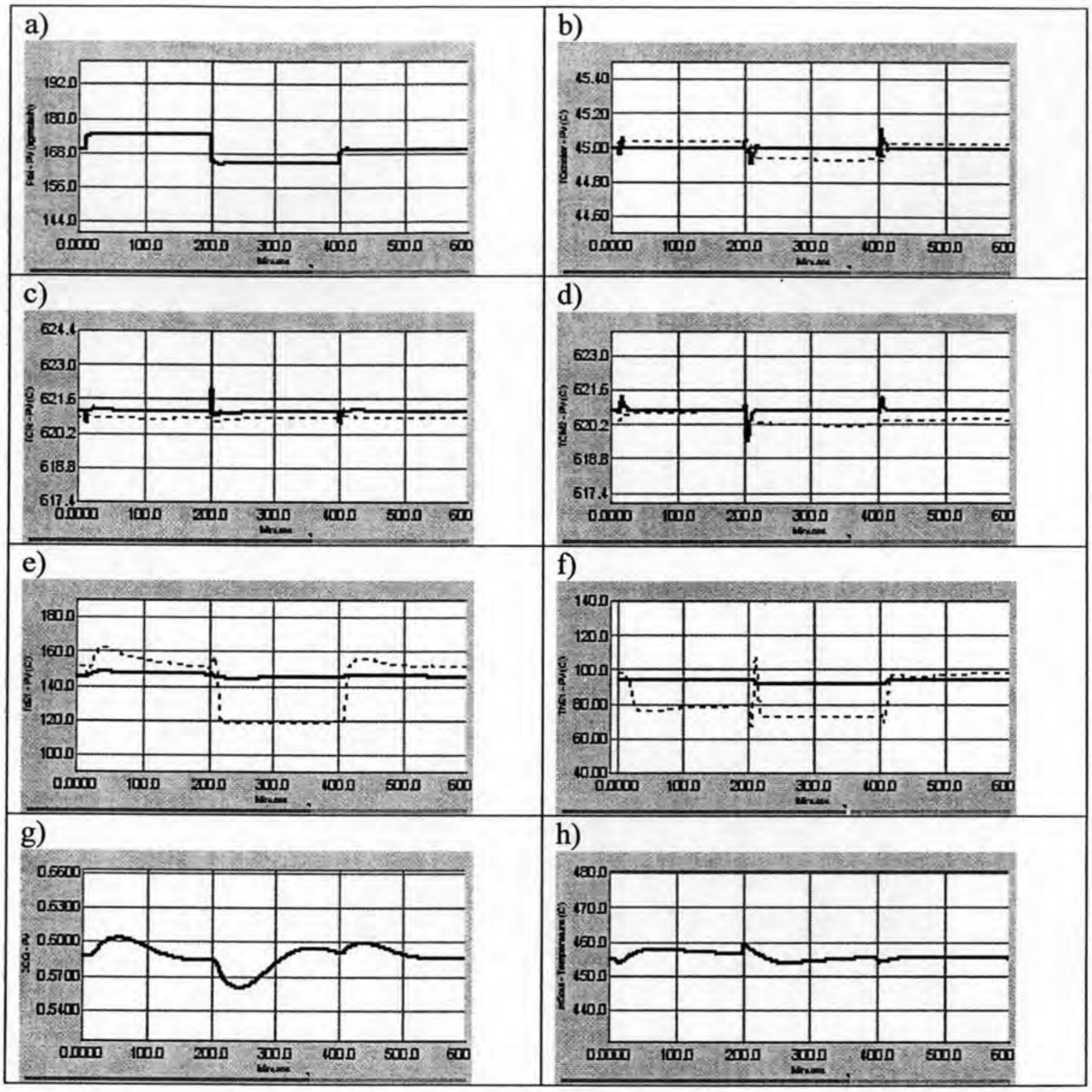

Figure 6.44 Dynamic Responses of the HDA Process Alternative 6:Basecase with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS4, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

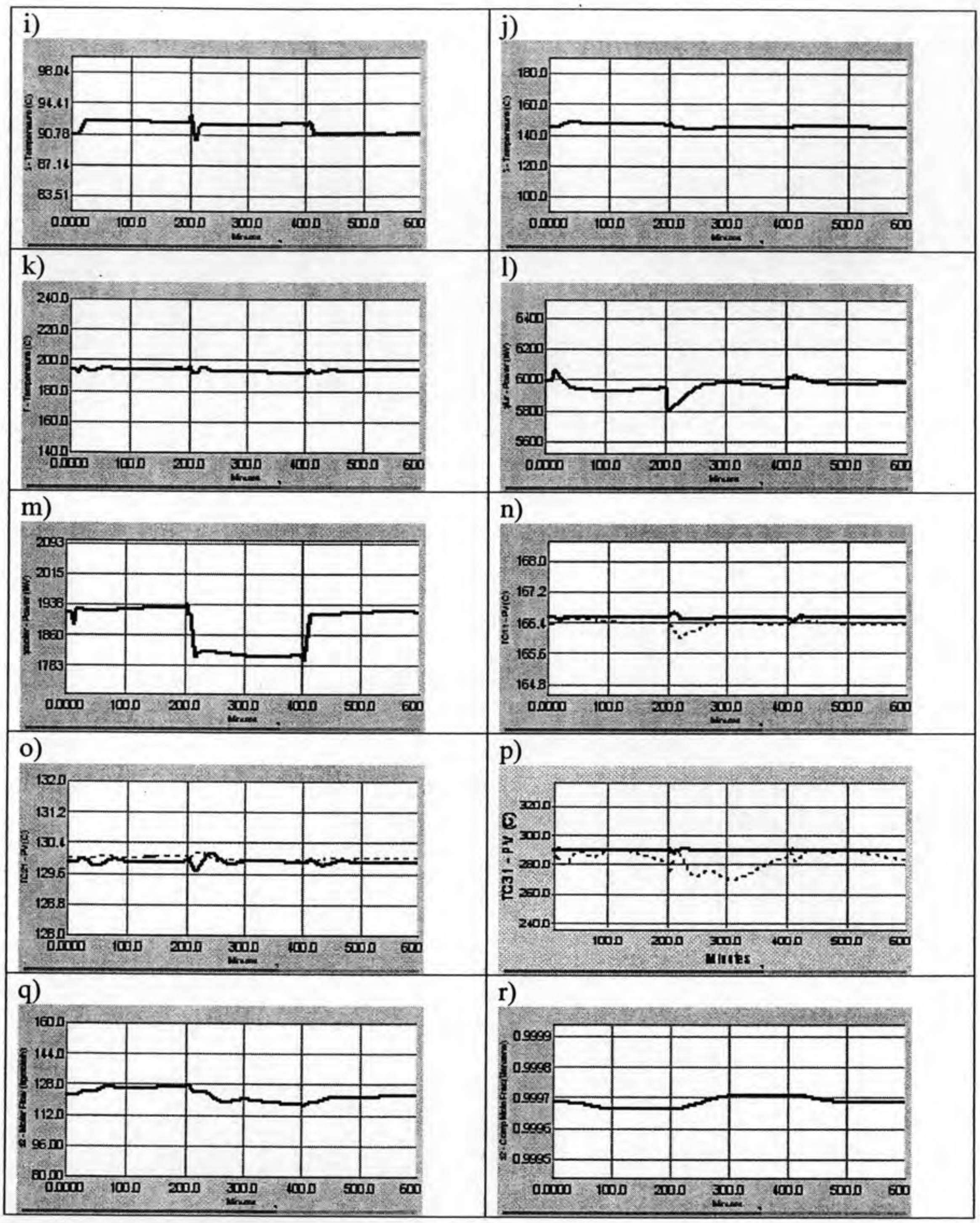

Figure 6.44 (continue)

6.10 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN1) with minimum Auxiliary Utility Units: CS1

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.45 to 6.47. Results for individual disturbance load changes are as follows:

6.10.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.45 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS1 are similar to the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.45.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.45.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.45.p).

6.10.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.46 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN1 with CS1 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.46.n and o).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.46.c,d and p).

6.10.3 Change in the Total Toluene Feed Flow rate

Figure 6.47 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.47.d).A small oscillation of 3°C happens in the product column (Figure6.47.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.47.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.47.p).

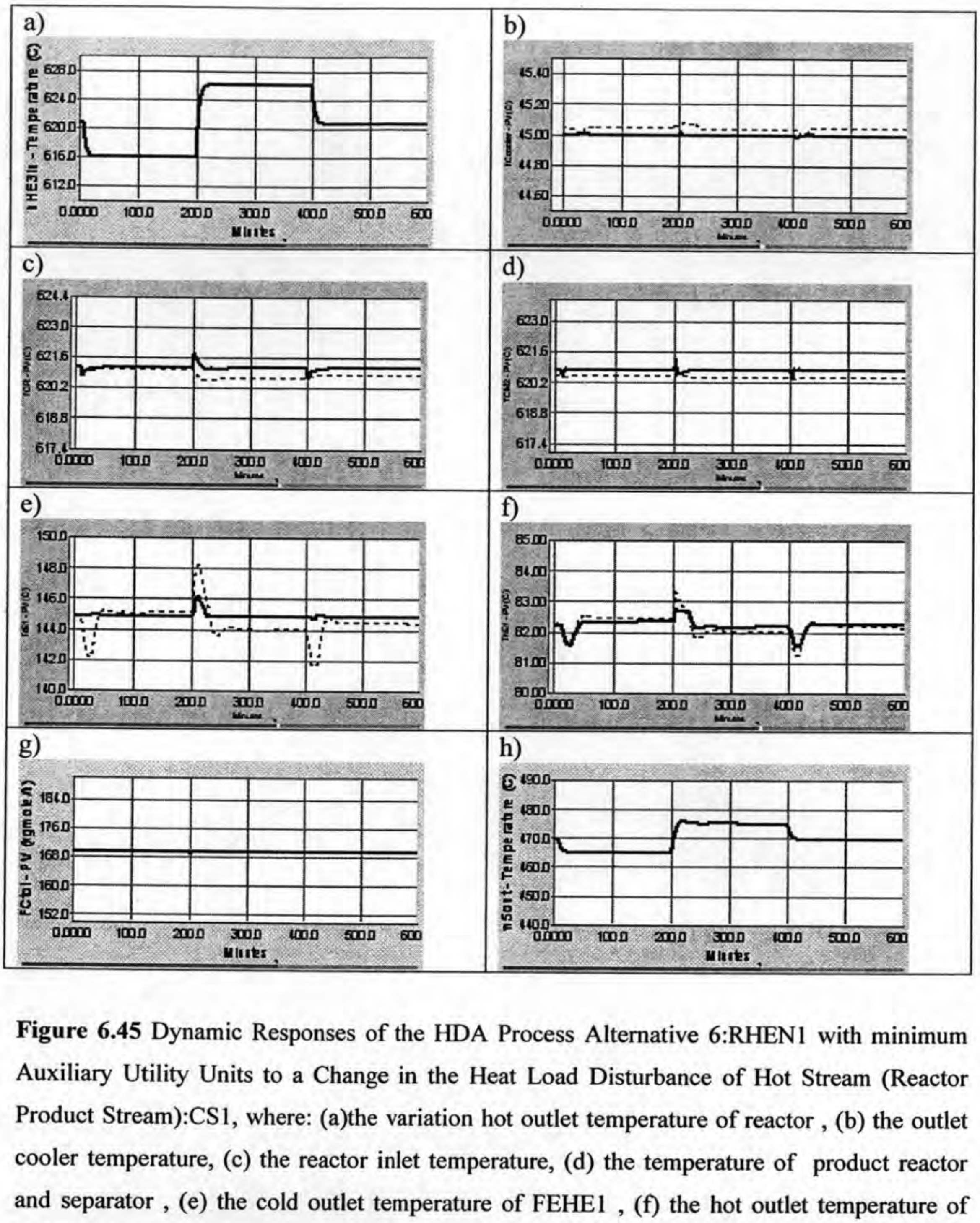

Figure 6.45 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS1, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

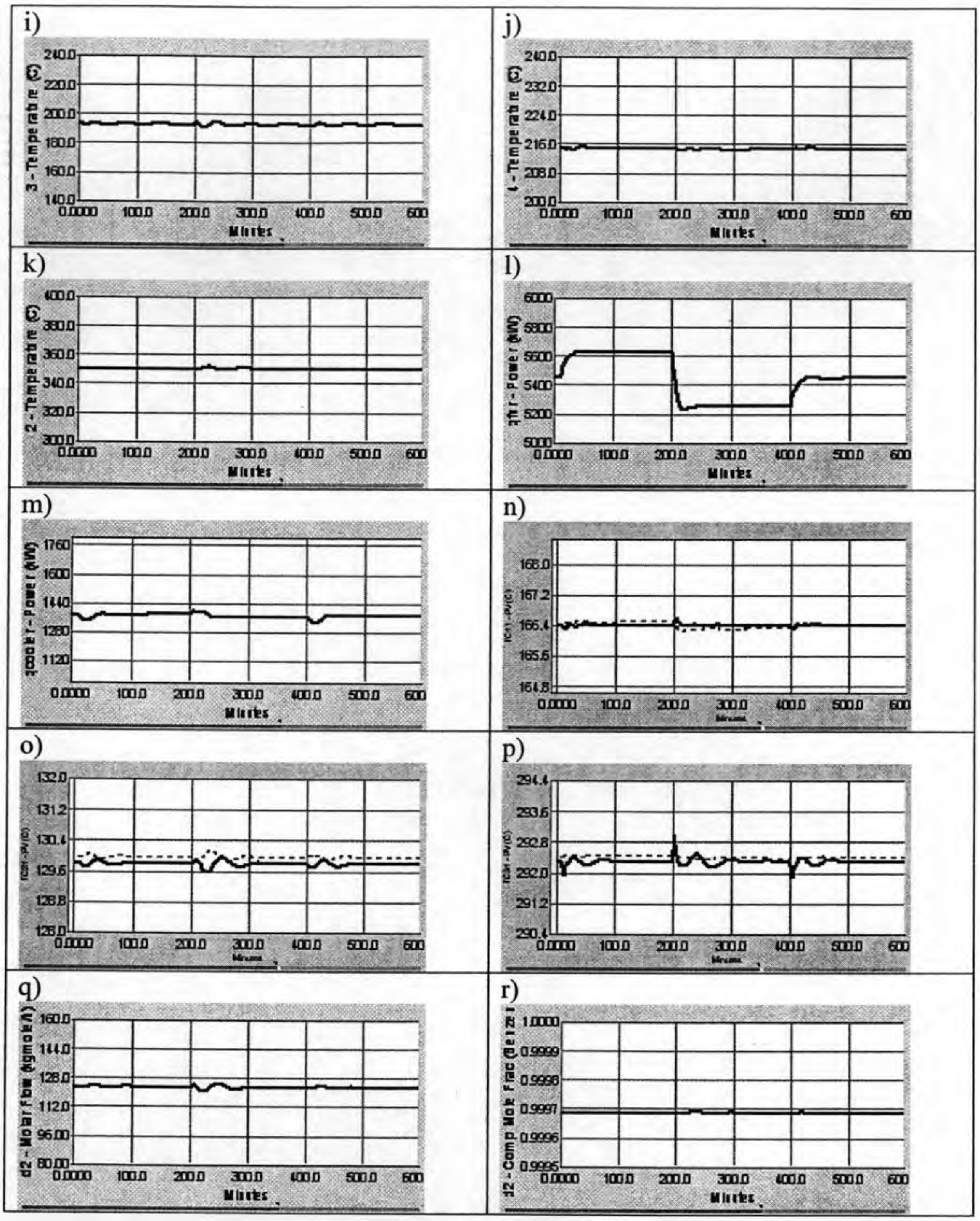

Figure 6.45 (continue)

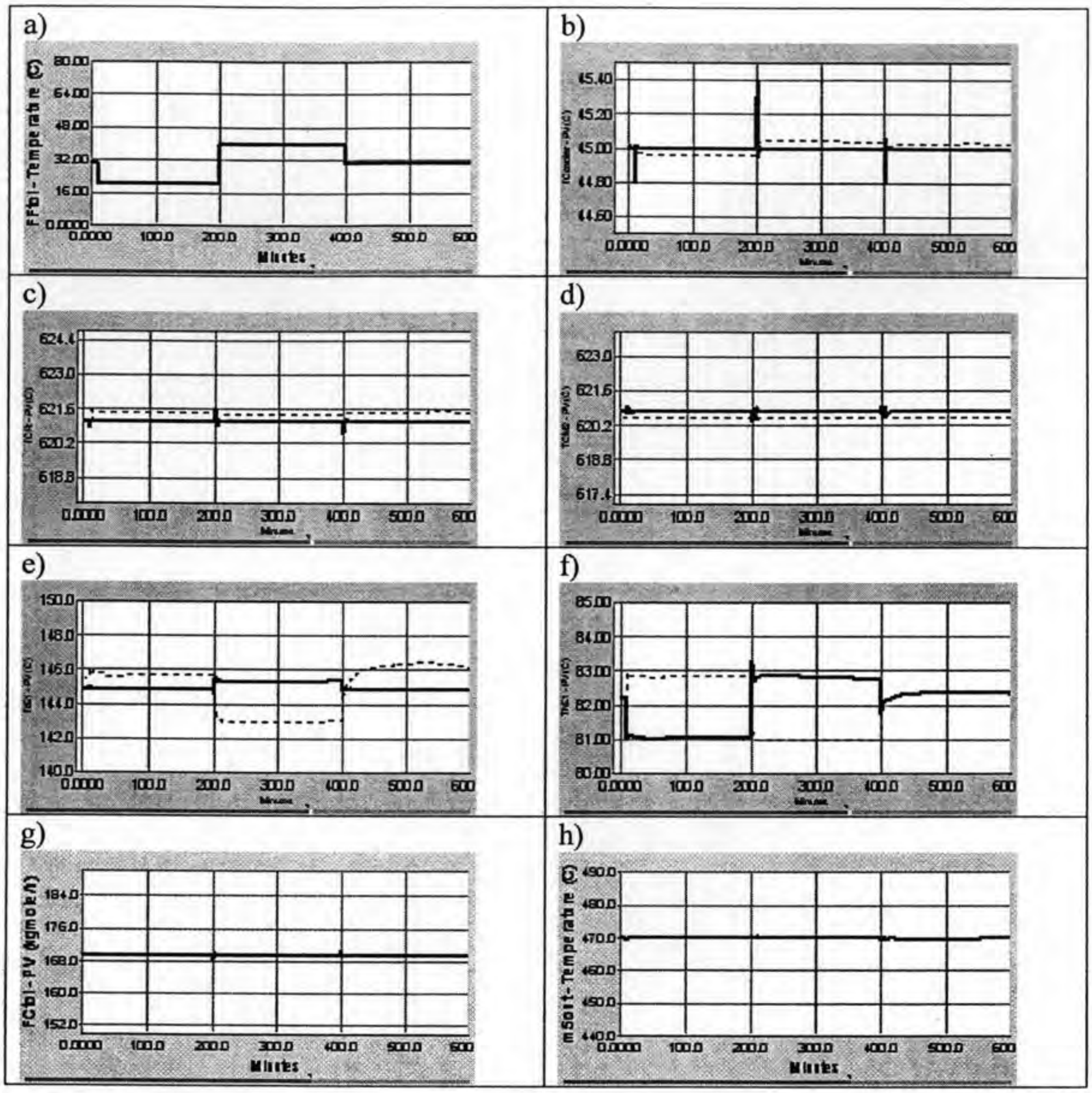

Figure 6.46 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS1, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━━ Process variable (PV) , •••••• Manipulated variable)

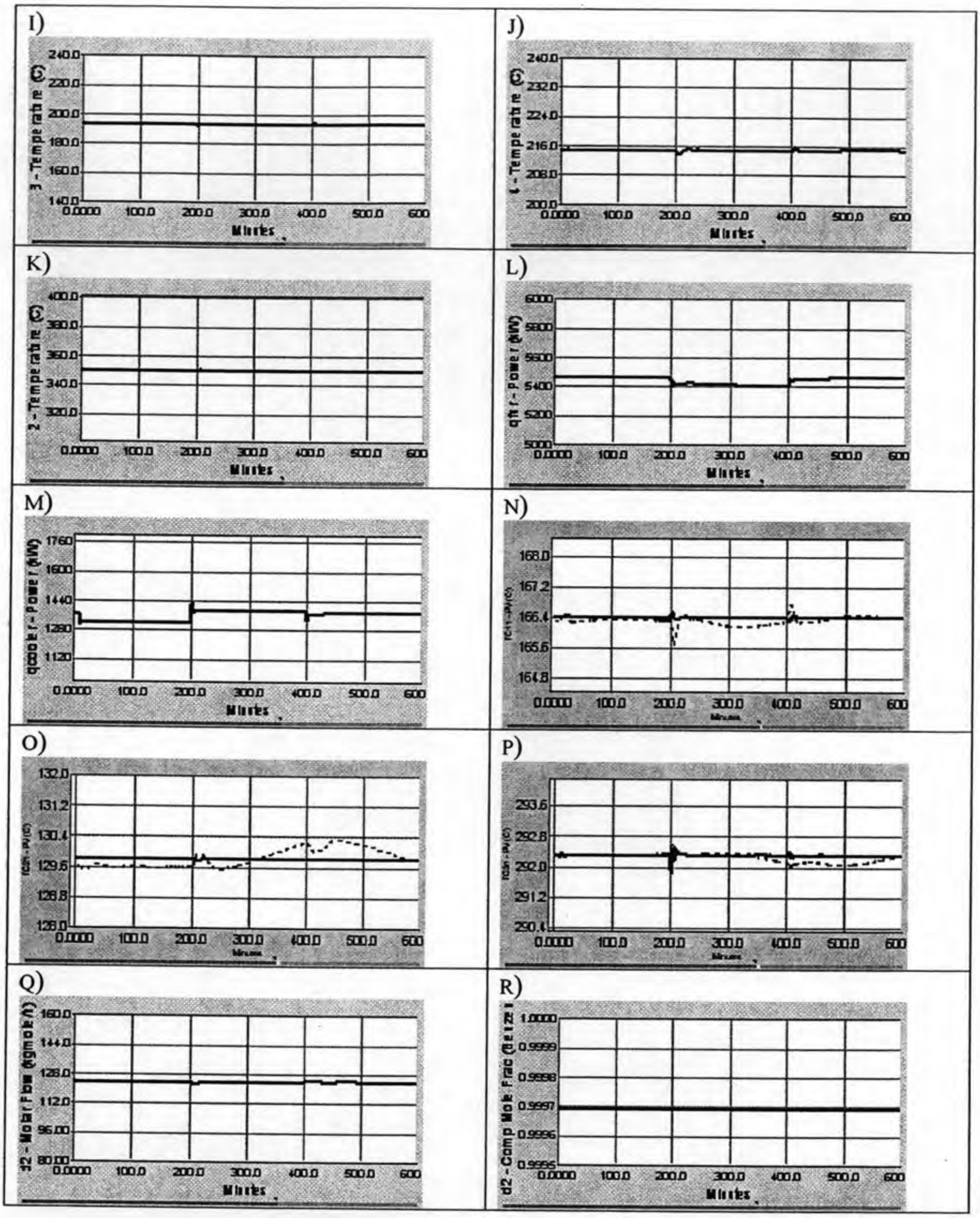

Figure 6.46 (continue)

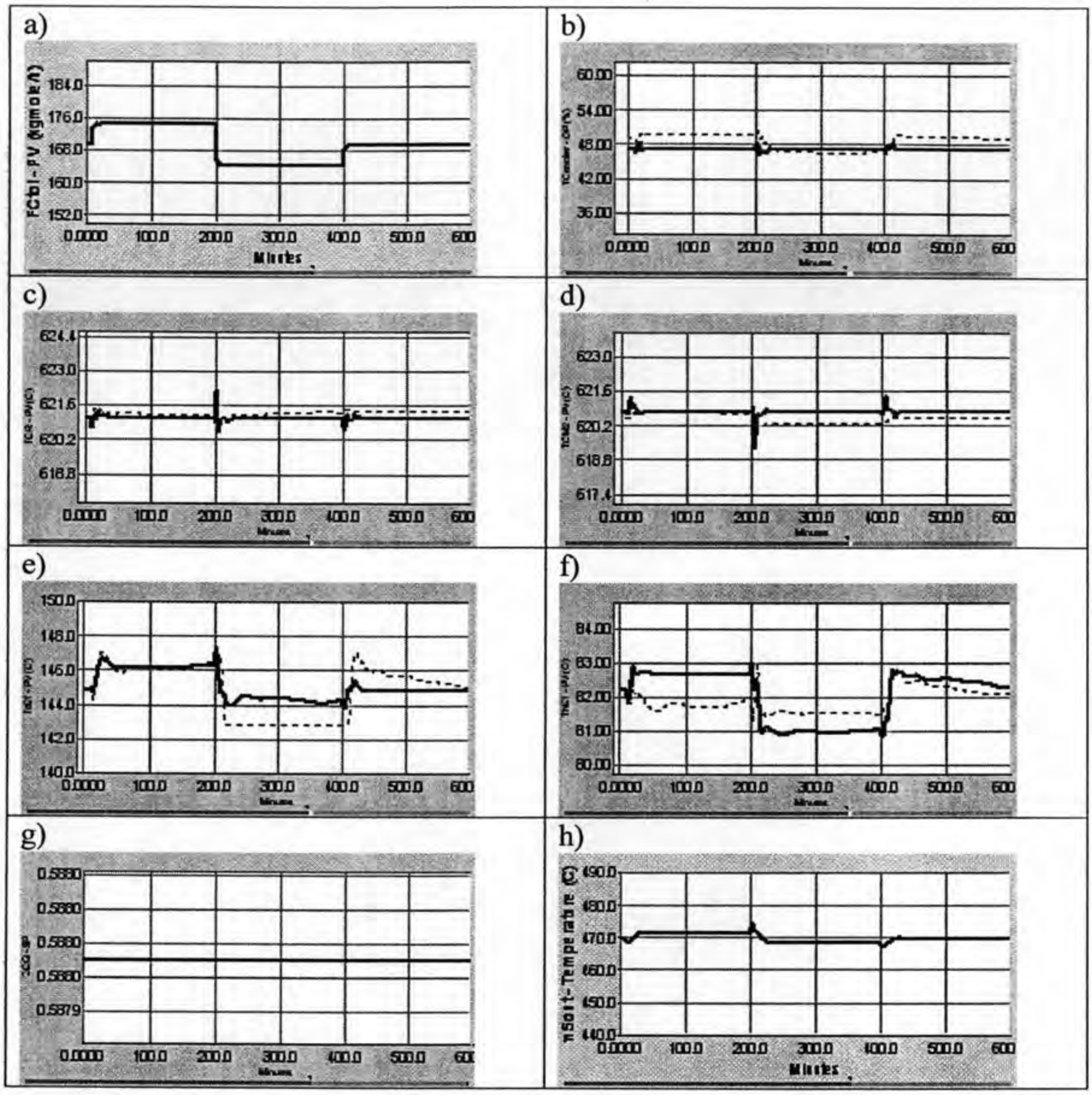

Figure 6.47 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS1, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ······ Manipulated variable)

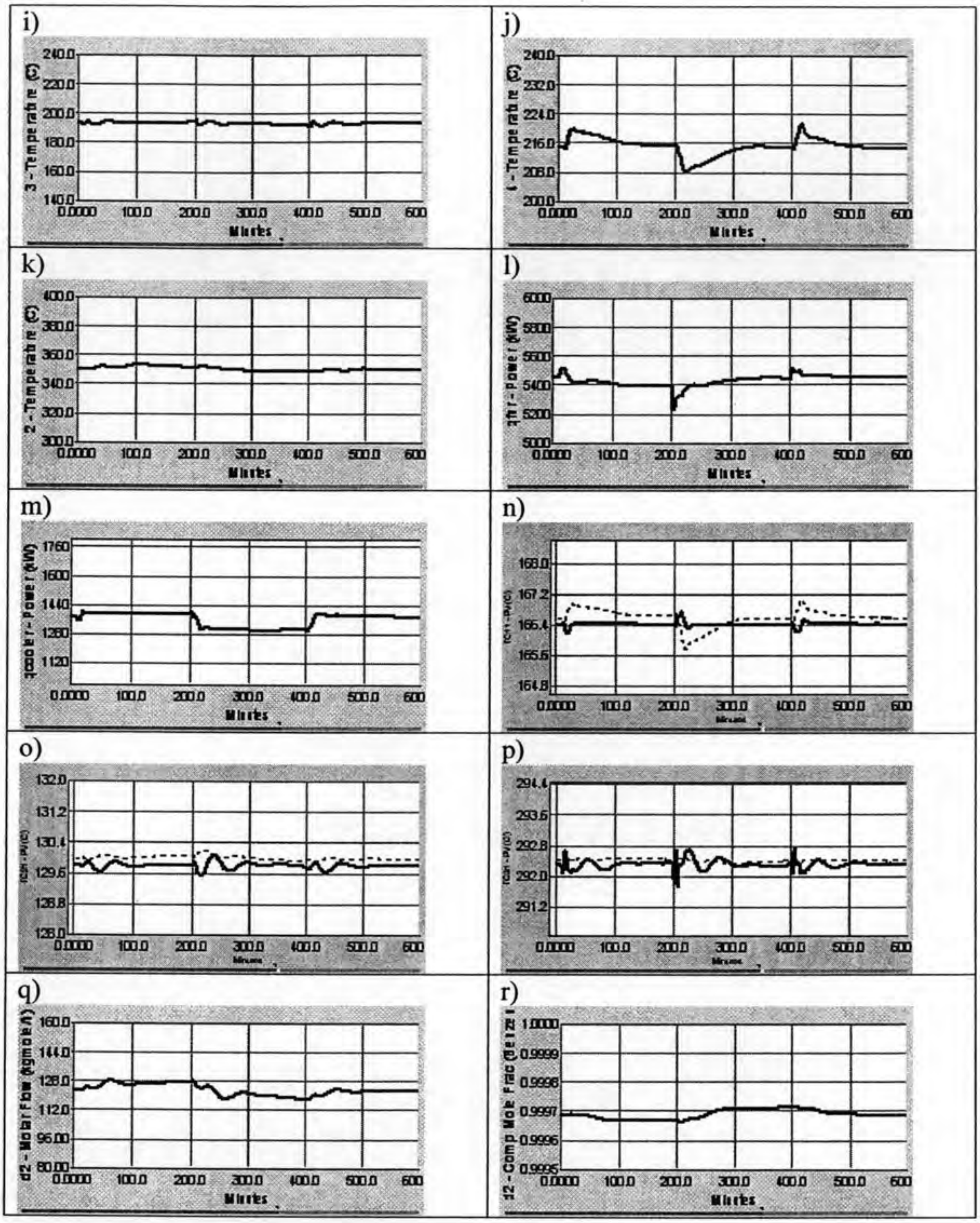

Figure 6.47 (continue)

6.11 Dynamic Simulation Results for HDA Process Alternative6 (RHEN1) with minimum Auxiliary Utility Units: CS2

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.48 to 6.50. Results for individual disturbance load changes are as follows

6.11.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.48 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS2 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.48.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.48.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.48.p). The oscillations occur in the molar flow of the benzene (Figure 6.48.q).

6.11.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.49 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS2 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.49.d and c). A deviation of 5°C happens in the tray temperature of the recycle column and it takes over 500 minutes to return to its nominal value of 290.3°C (Figure 6.49.p) and the oscillations occur in the molar flow of the benzene (Figure 6.49.q).

6.11.3 Change in the Total Toluene Feed Flow rate

Figure 6.50 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.50.d).A small oscillation of 3°C happens in the product column (Figure6.50.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.50.n). The tray temperature of the recycle column has a small deviation about 2°C and it takes over 500 minutes to return to its nominal value (Figure6.50.p). The oscillations occur in the molar flow of the benzene (Figure 6.50.q).

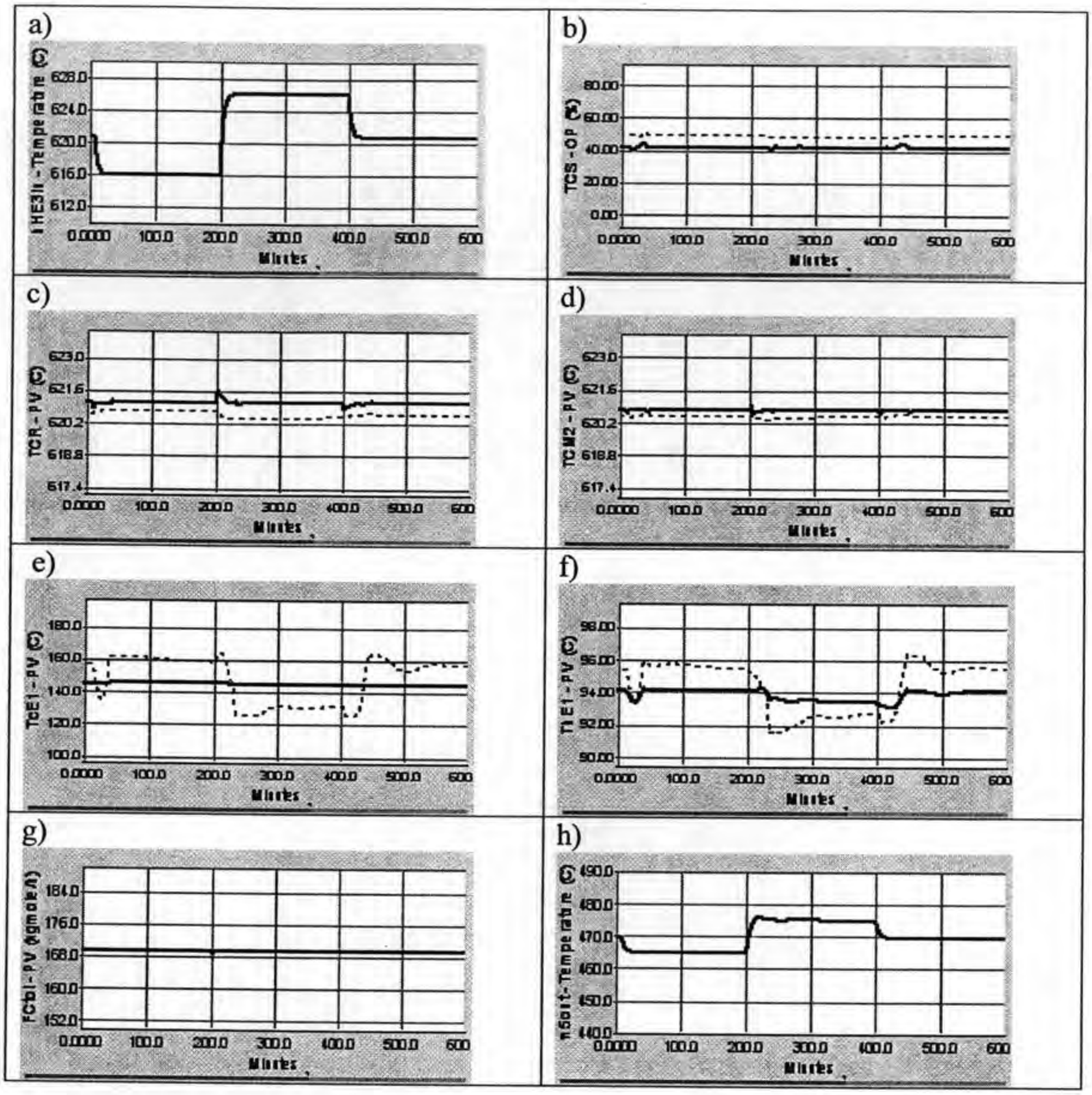

Figure 6.48 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS2, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ▬▬ Process variable (PV) , ▪▪▪▪▪▪ Manipulated variable)

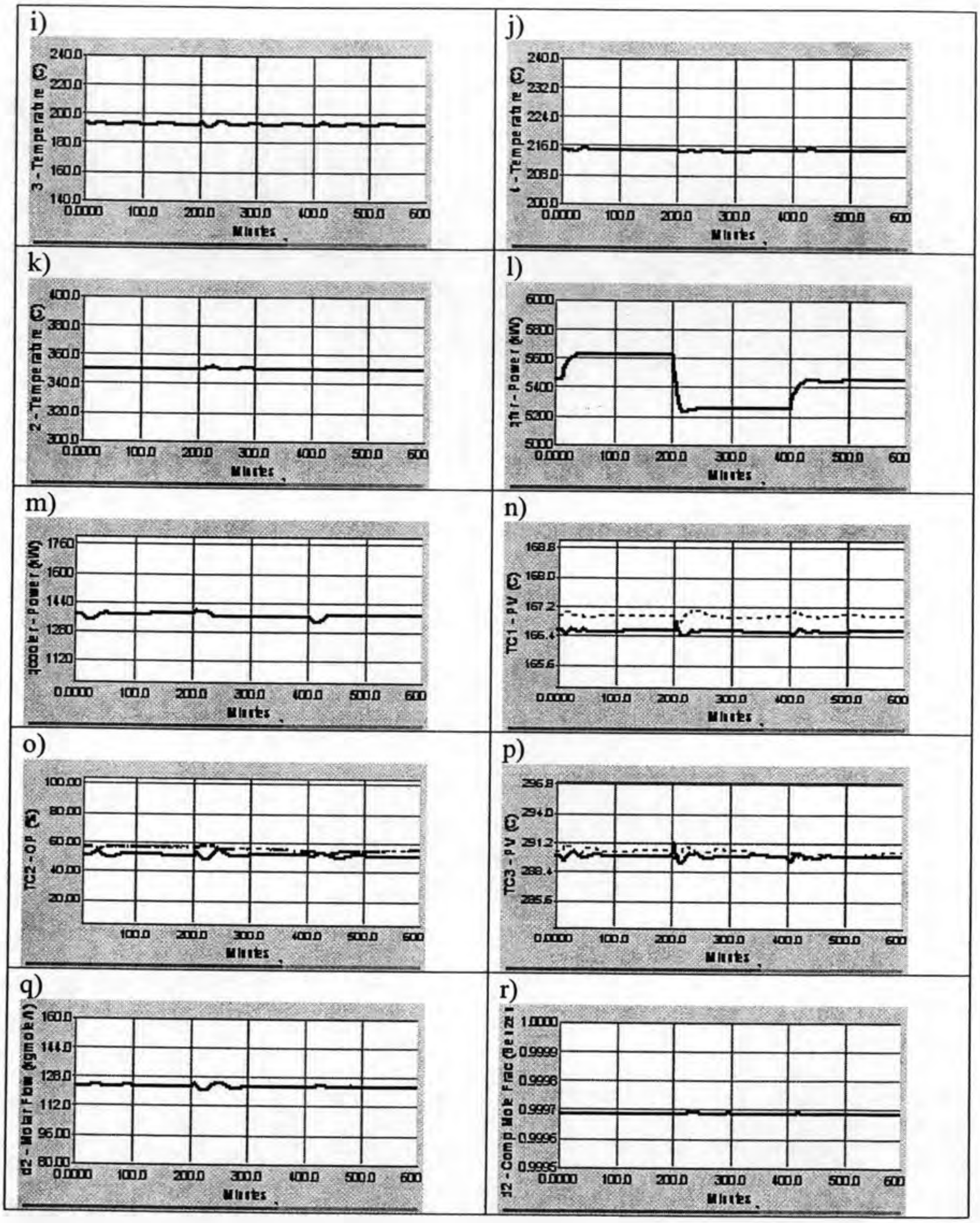

Figure 6.48 (continue)

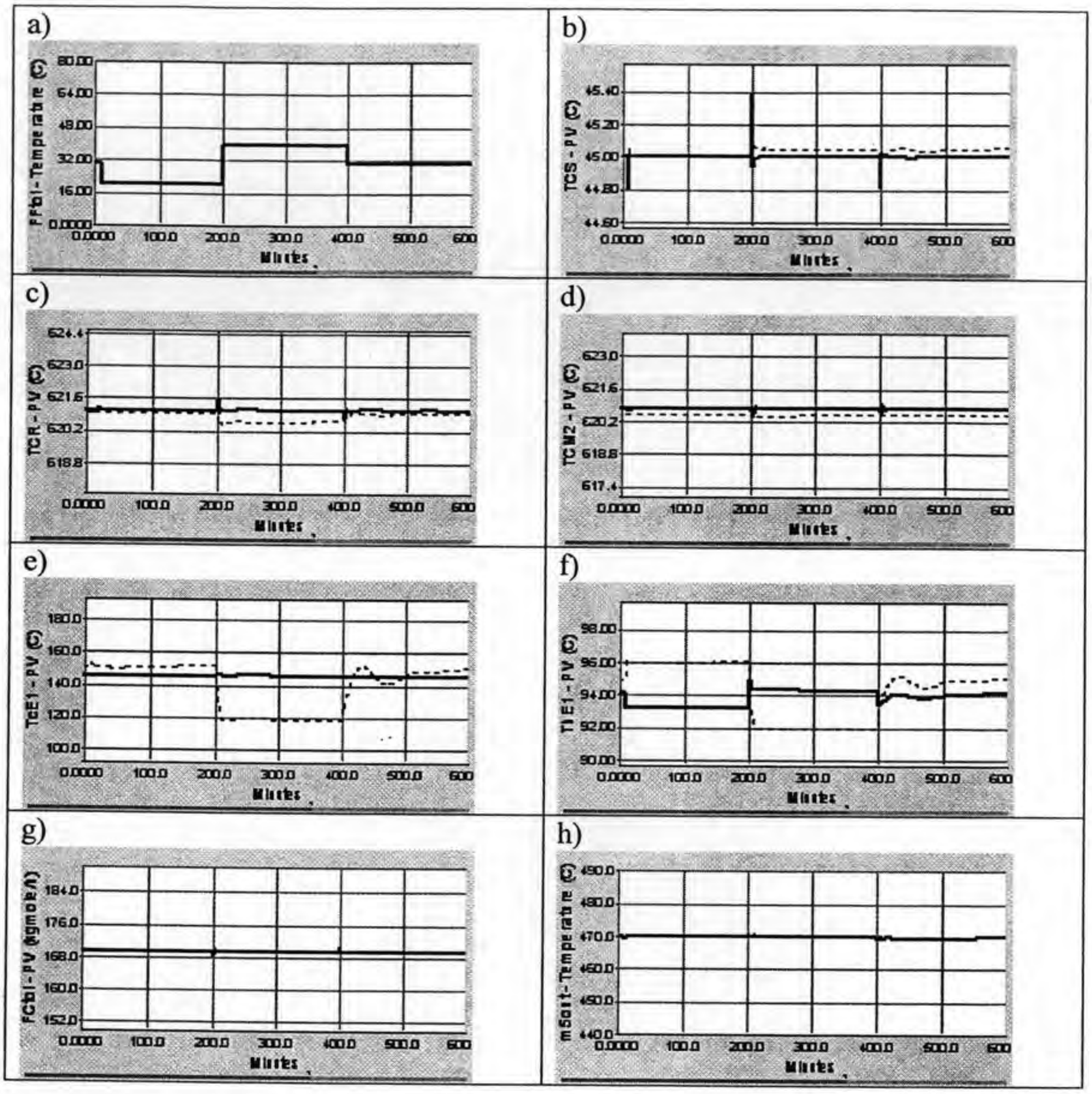

Figure 6.49 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS2, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ▬▬ Process variable (PV) , ▪▪▪▪▪▪ Manipulated variable)

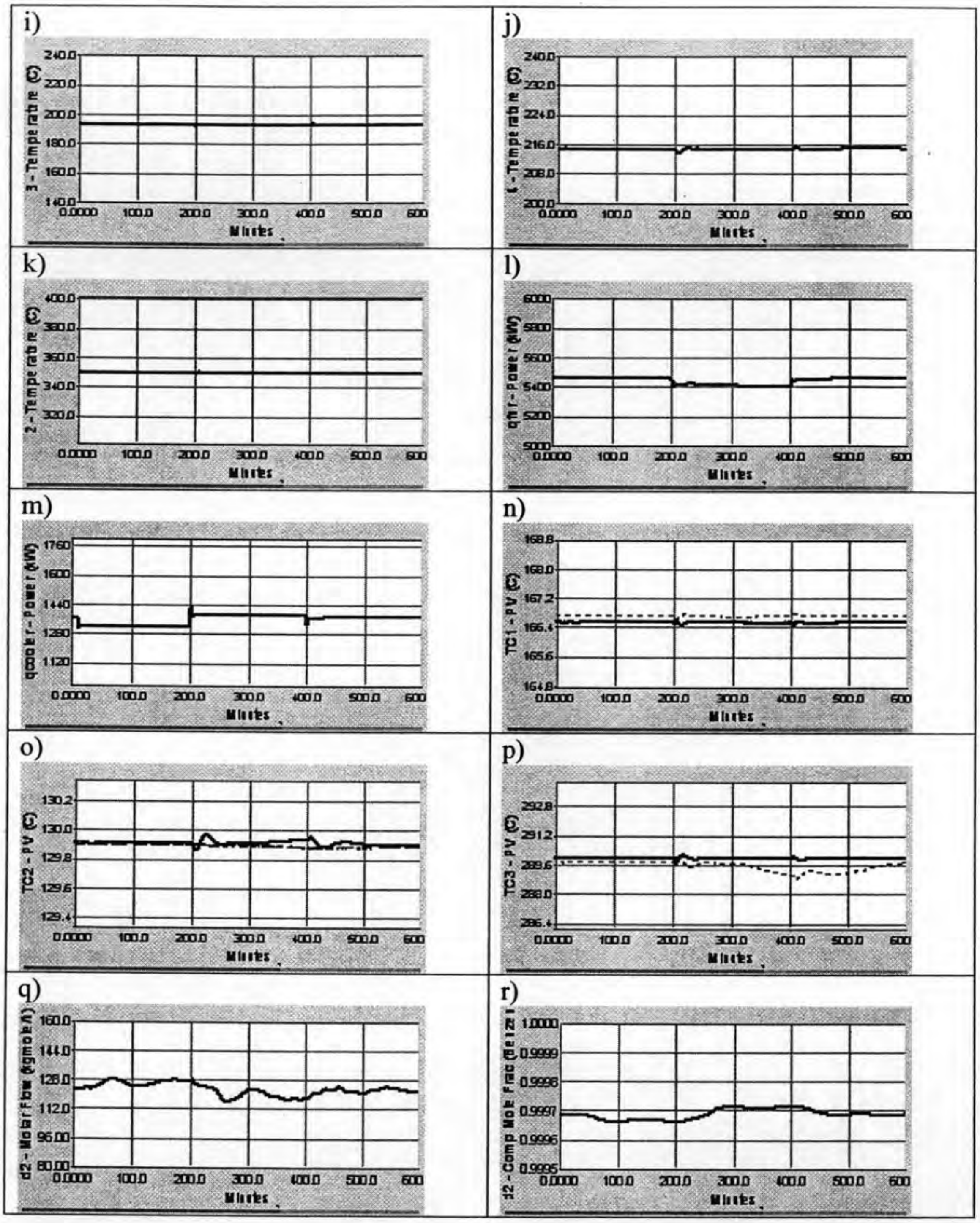

Figure 6.49 (continue)

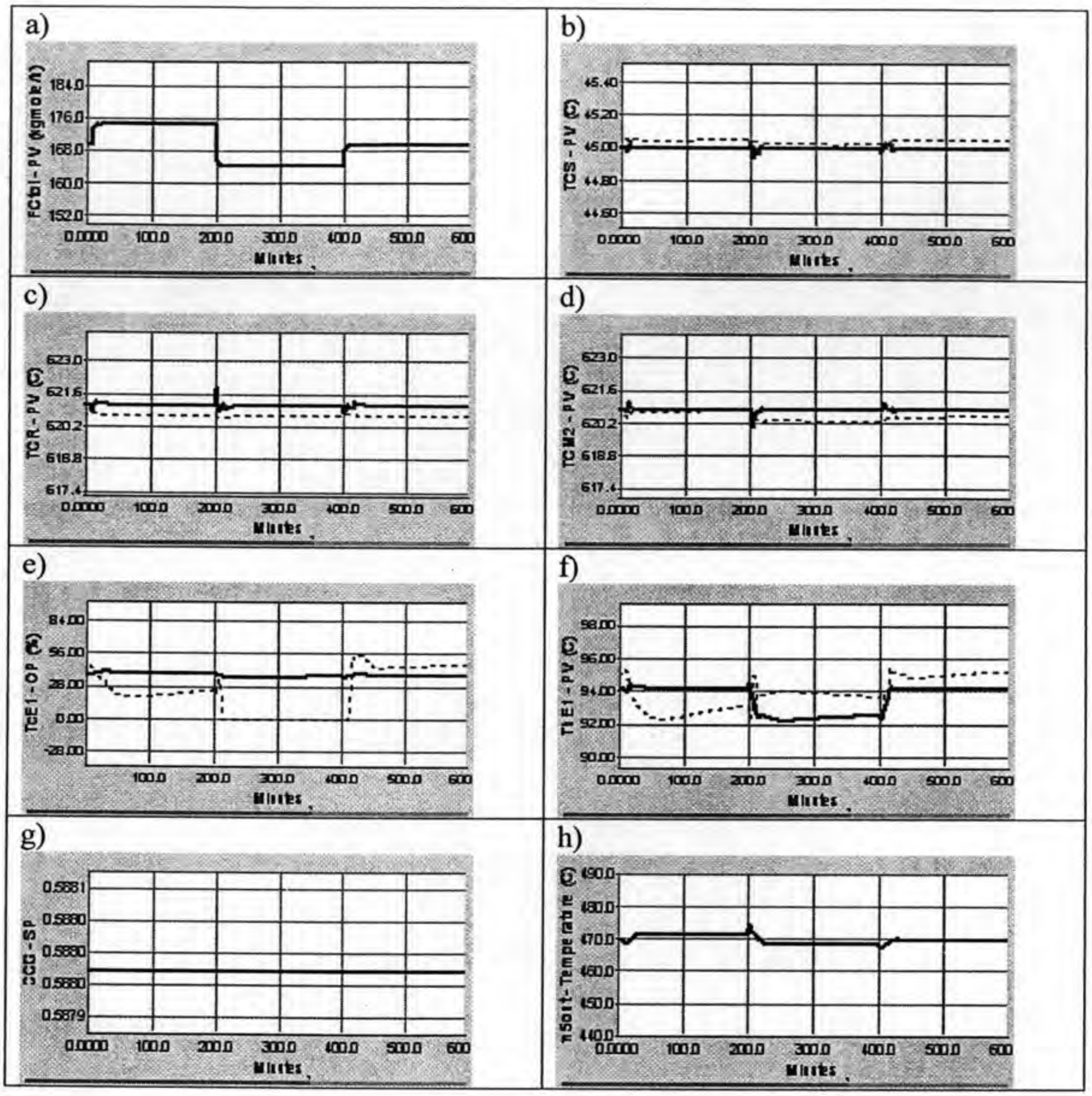

Figure 6.50 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS2, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ─── Process variable (PV) , ⋯⋯ Manipulated variable)

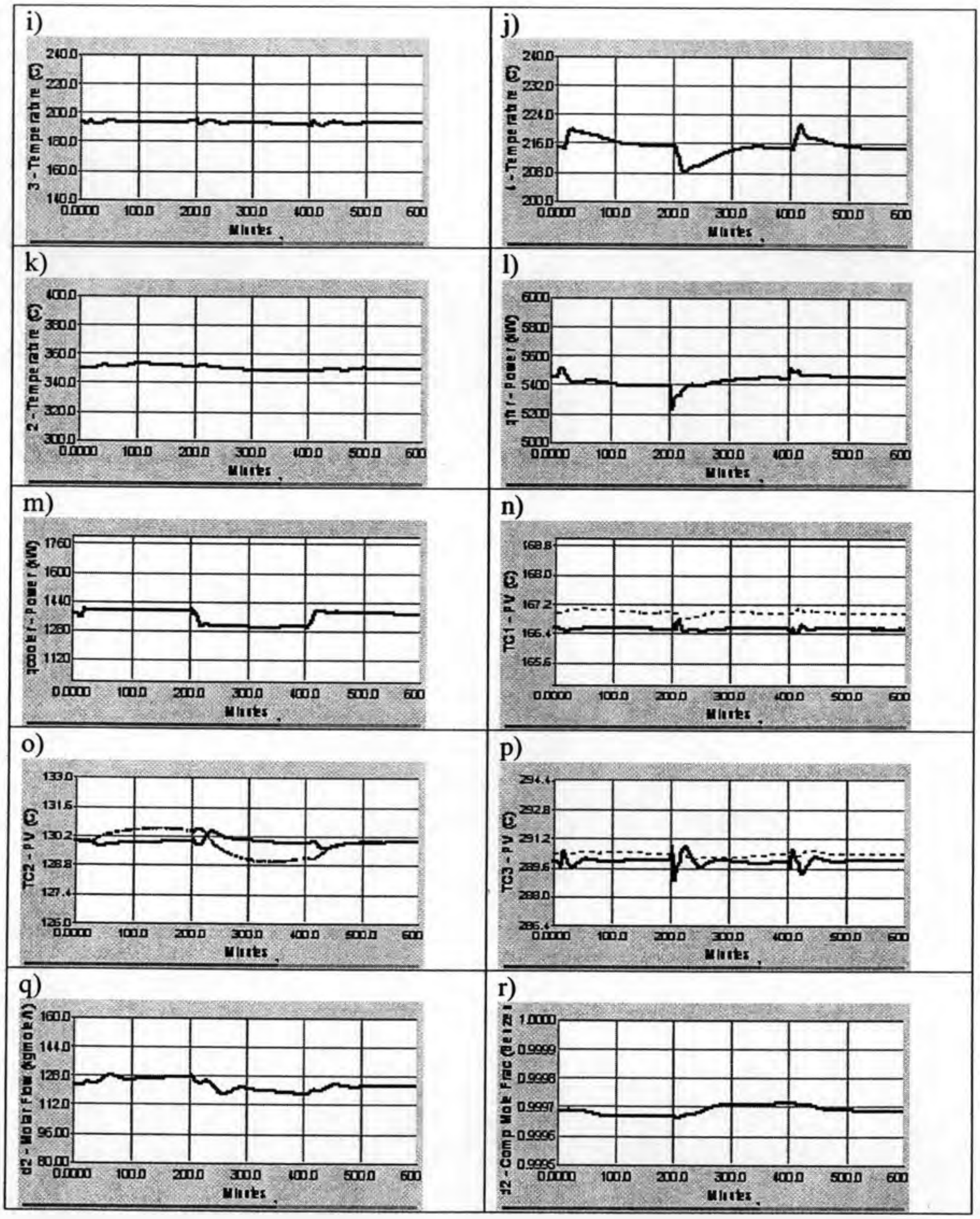

Figure 6.50 (continue)

6.12 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN1) with minimum Auxiliary Utility Units: CS3

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.51 to 6.53. Results for individual disturbance load changes are as follows:

6.12.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.51 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS3 are better than the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.51.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.51.n, o and p).Its advantages is that it provides higher performance of the tray temperature control in the product column, since there are two point controls in the product column. The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.51.q).

6.12.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.52 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh

toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN1 with CS3 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.52.n, o and p), since there are two tray temperature controls in the product column (One is the tray-12 temperature control and the other is tray-18 temperature control).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.52.c,d and q).

6.12.3 Change in the Total Toluene Feed Flow rate

Figure 6.53 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.53.d).A small oscillation of 3°C happens in the product column (Figure6.53.o and p) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.53.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.53.q).

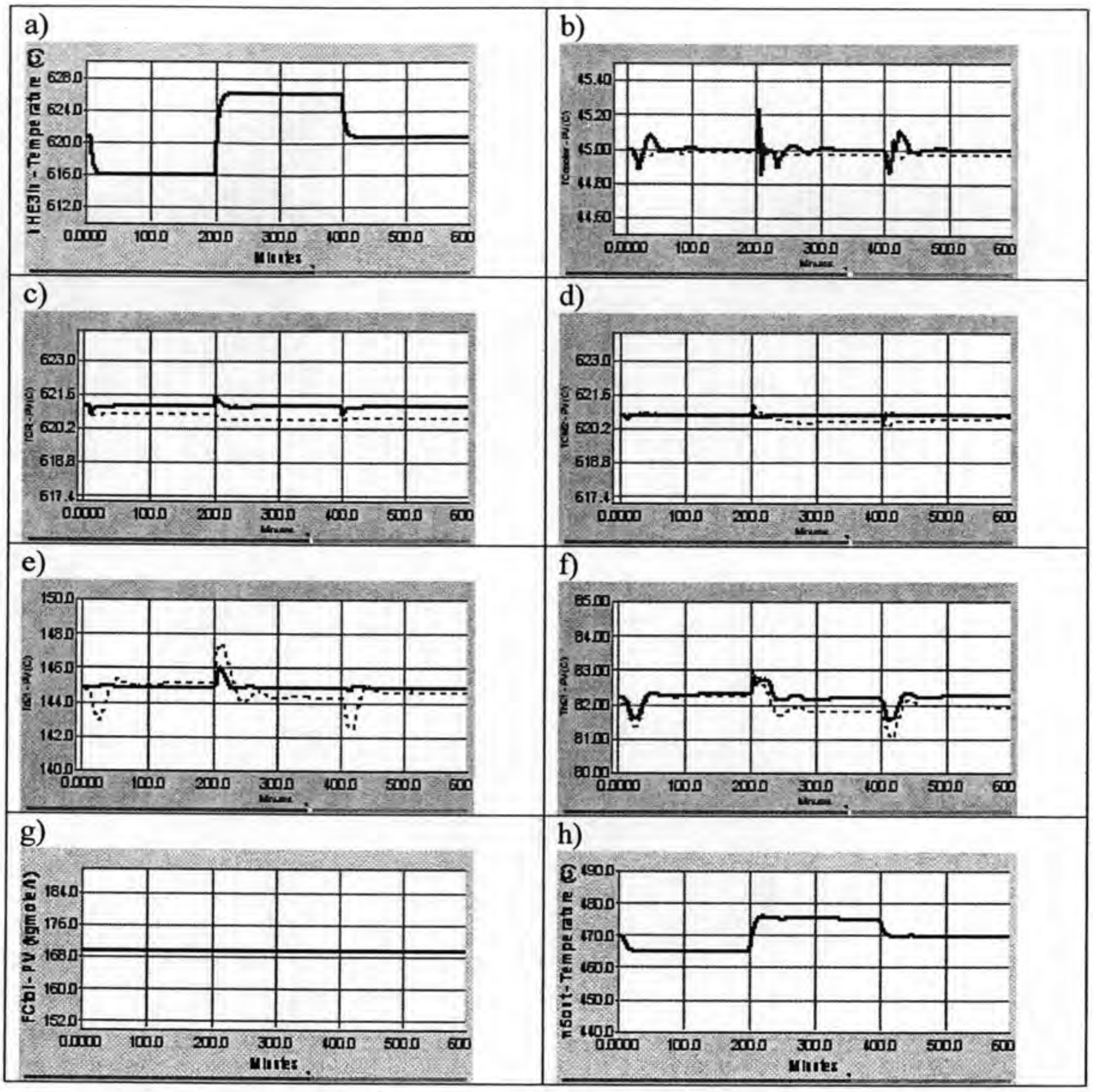

Figure 6.51 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS3, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene of product column (Note. ——— Process variable (PV) , ······ Manipulated variable)

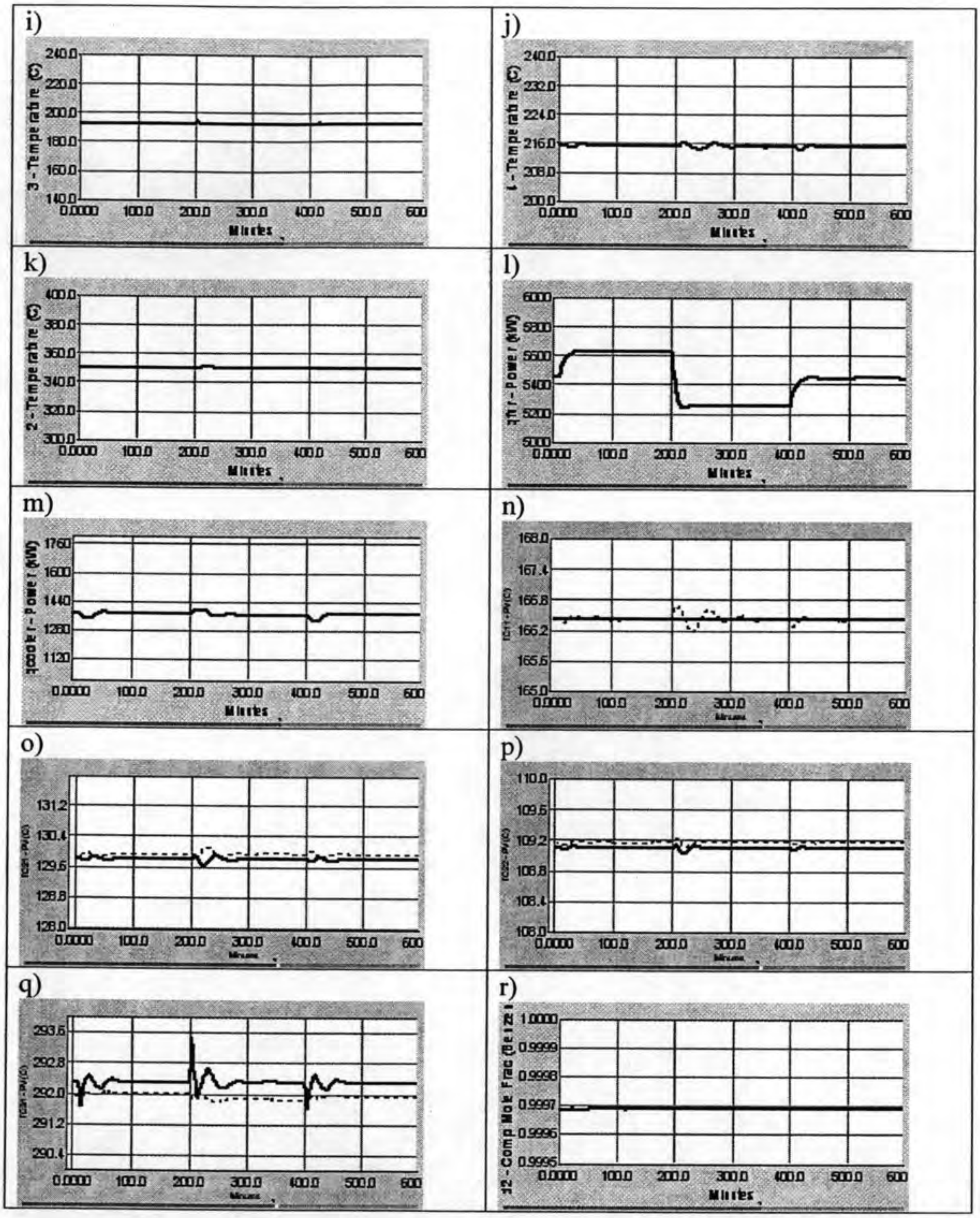

Figure 6.51 (continue)

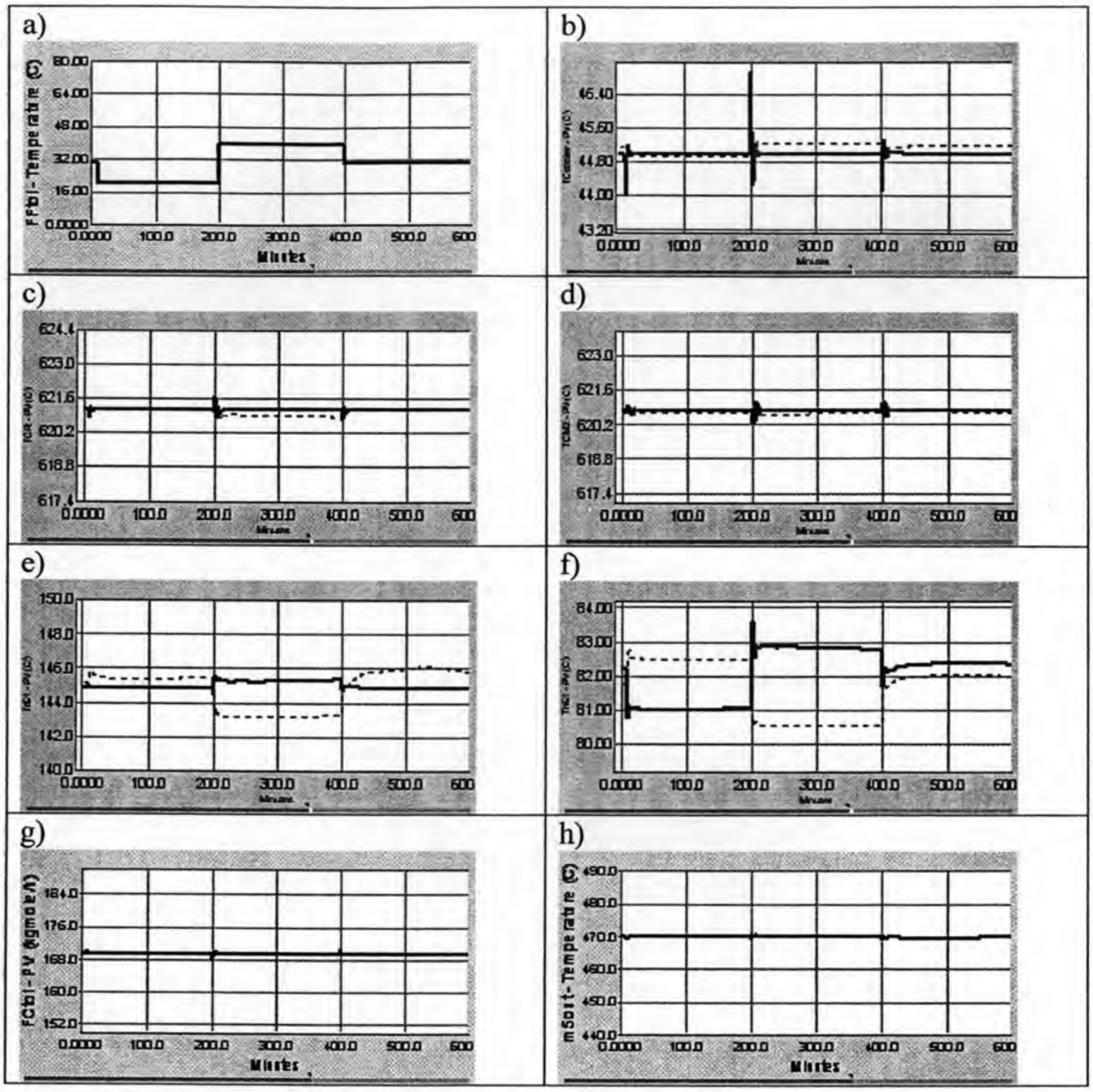

Figure 6.52 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS3, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ━━━ Process variable (PV) , ⋯⋯ Manipulated variable)

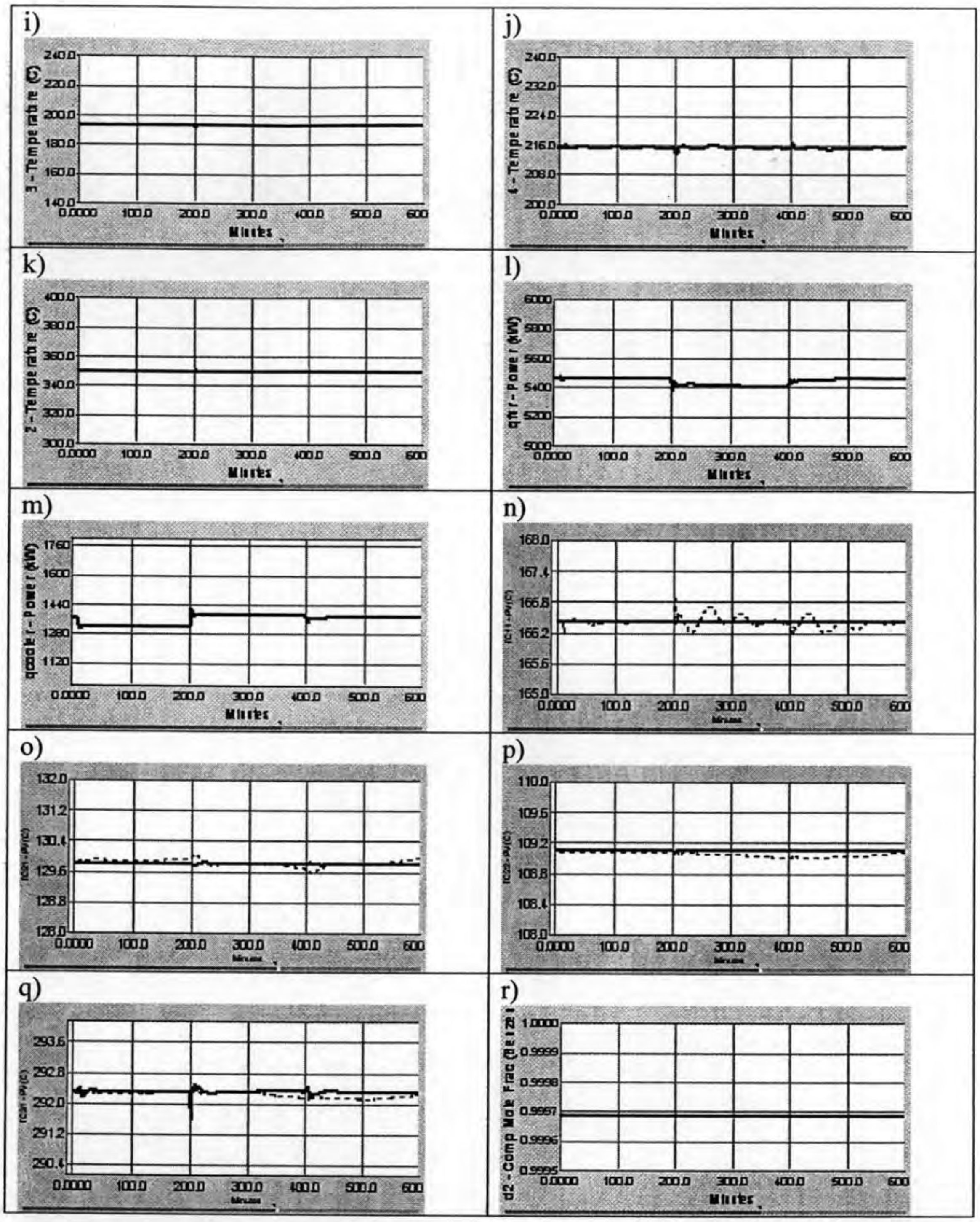

Figure 6.52 (continue)

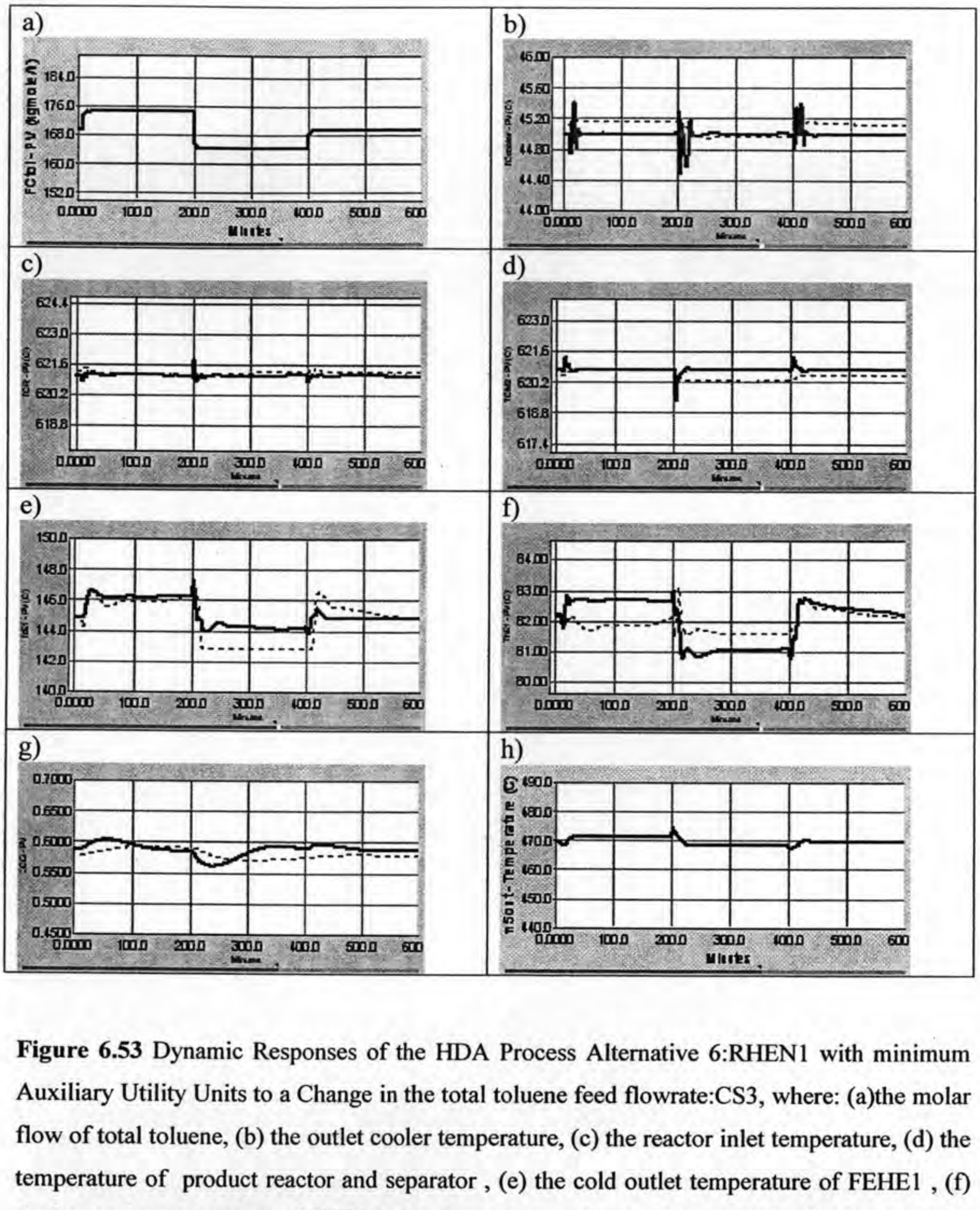

Figure 6.53 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS3, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ——— Process variable (PV) , ······ Manipulated variable)

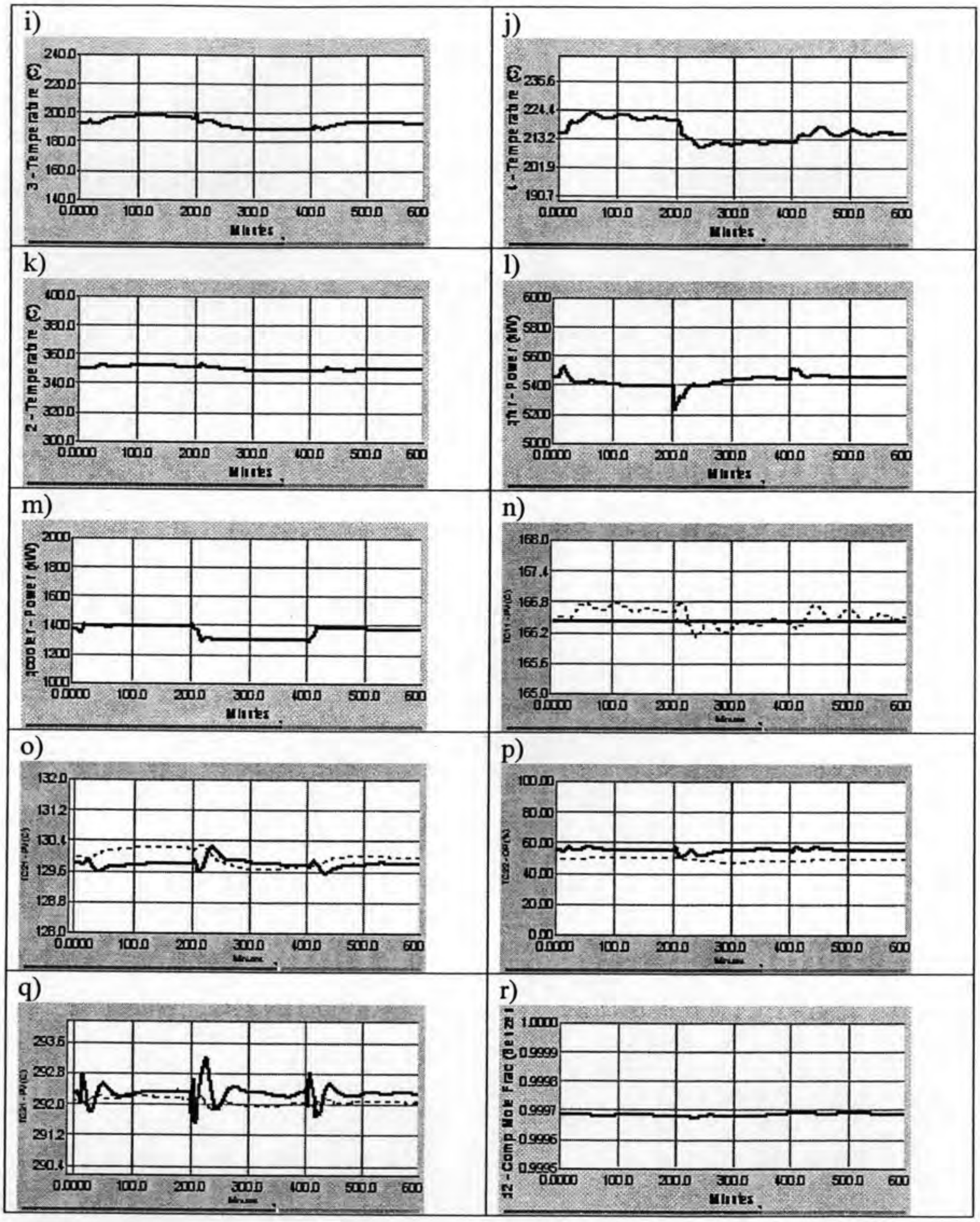

Figure 6.53 (continue)

6.13 Dynamic Simulation Results for HDA Process Alternative6 (RHEN1) with minimum Auxiliary Utility Units: CS4

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.54 to 6.56. Results for individual disturbance load changes are as follows

6.13.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.54 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS3 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.54.c and d), the oscillations occur about 5°C in the tray temperature of the stabilizer and the product column (Figure 6.54.n and o). The tray temperature in the recycle column has a large oscillation and it takes more than 800 minutes to come back to setpoint (Figure6.54.p). The oscillations occur in the molar flow of the benzene (Figure 6.54.q).

6.13.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.55 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS3 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.55.d and c). A deviation of 6°C happens in the tray temperature of the recycle column and it takes over 800 minutes to return to its nominal value of 290.3°C (Figure 6.55.p) and the oscillations occur in the molar flow of the benzene (Figure 6.55.q).

6.11.3 Change in the Total Toluene Feed Flow rate

Figure 6.56 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.56.d).A small oscillation of 3°C happens in the product column (Figure6.56.o), Also a slightly worse controlled occurs in the tray temperature of the stabilizer column (Figure6.56.n). The tray temperature of the recycle column has a large deviation about 20°C and it takes over 900 minutes to return to its nominal value (Figure6.56.p). The oscillations occur in the molar flow of the benzene (Figure 6.56.q).

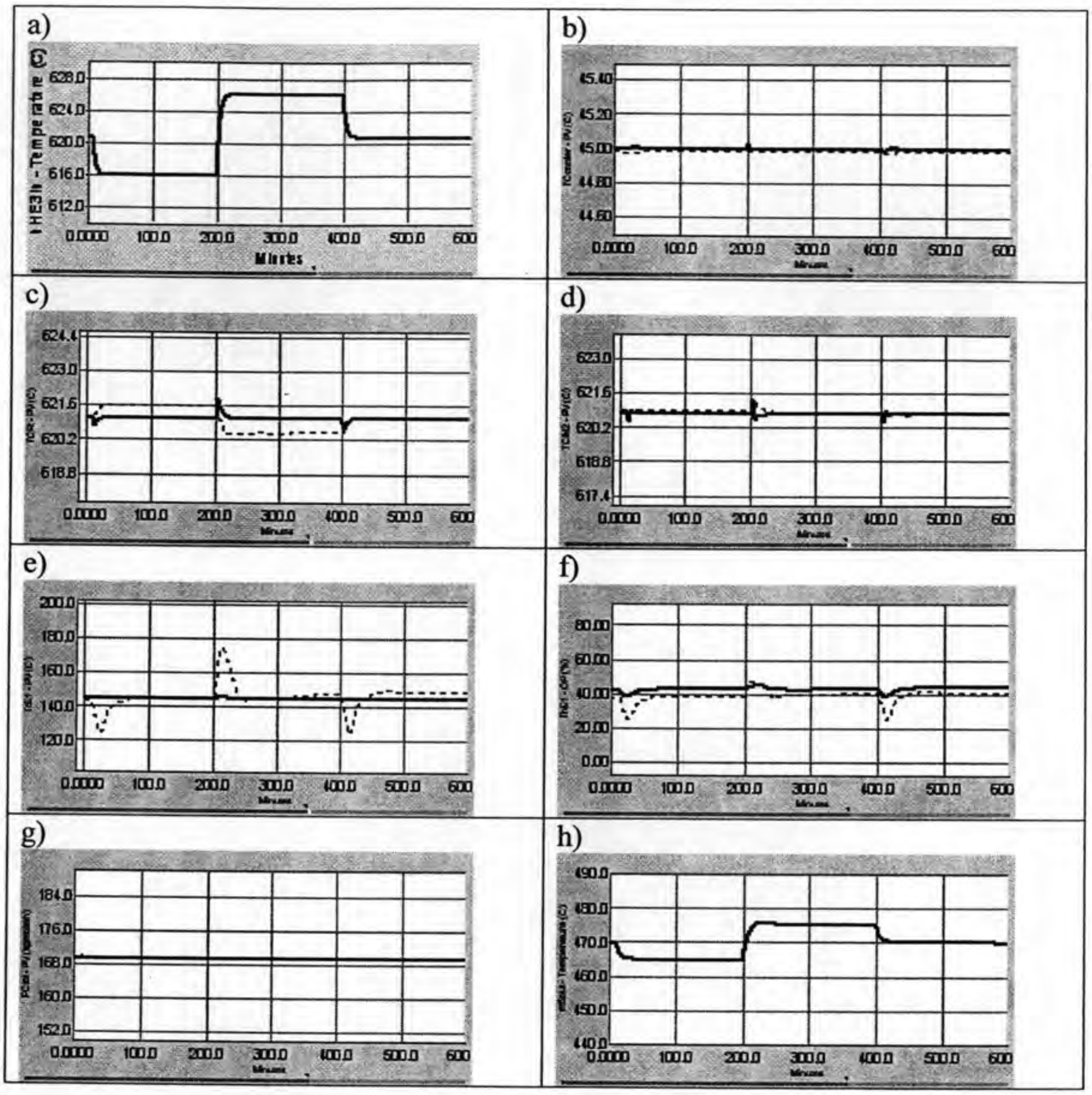

Figure 6.54 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS4, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

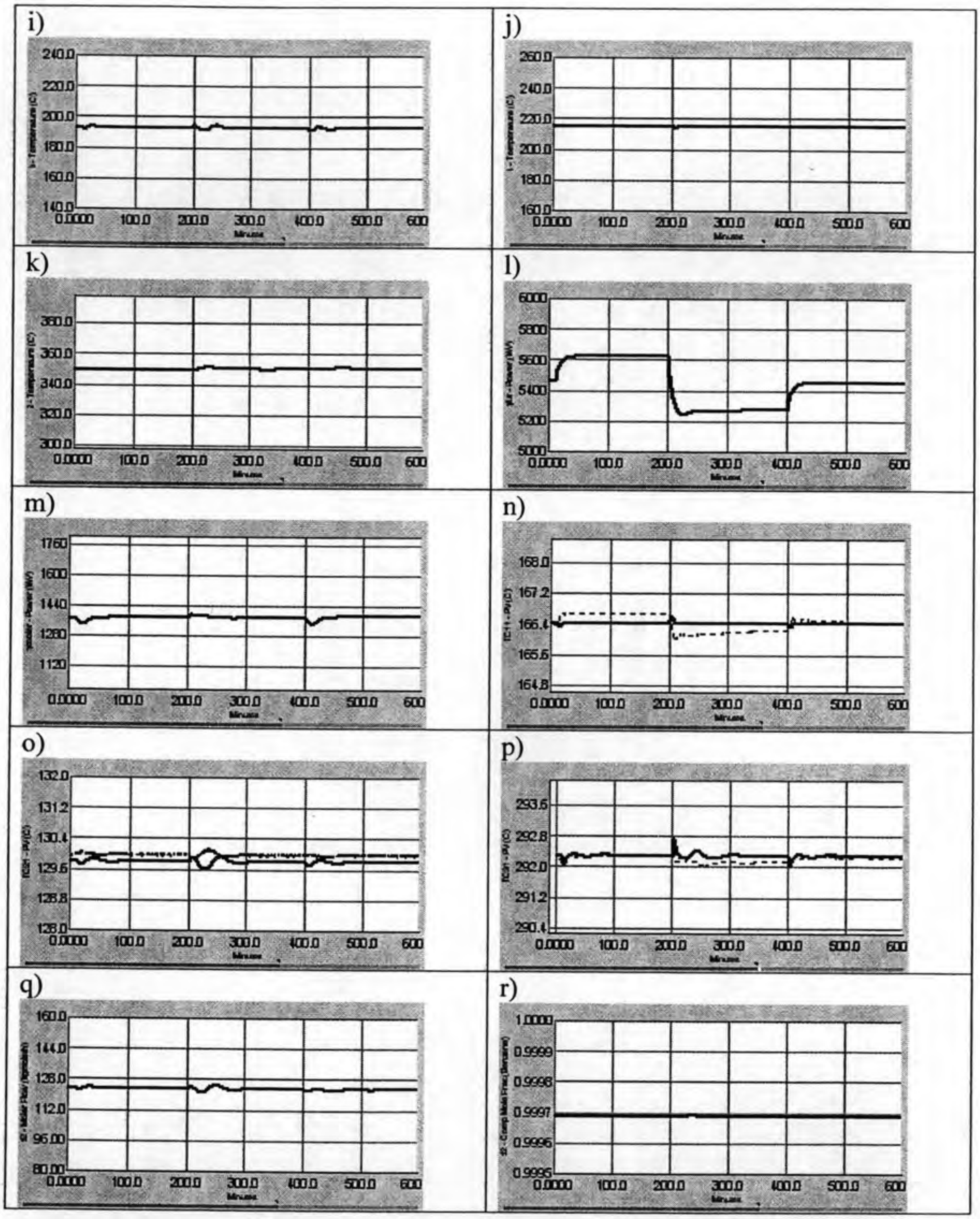

Figure 6.54 (continue)

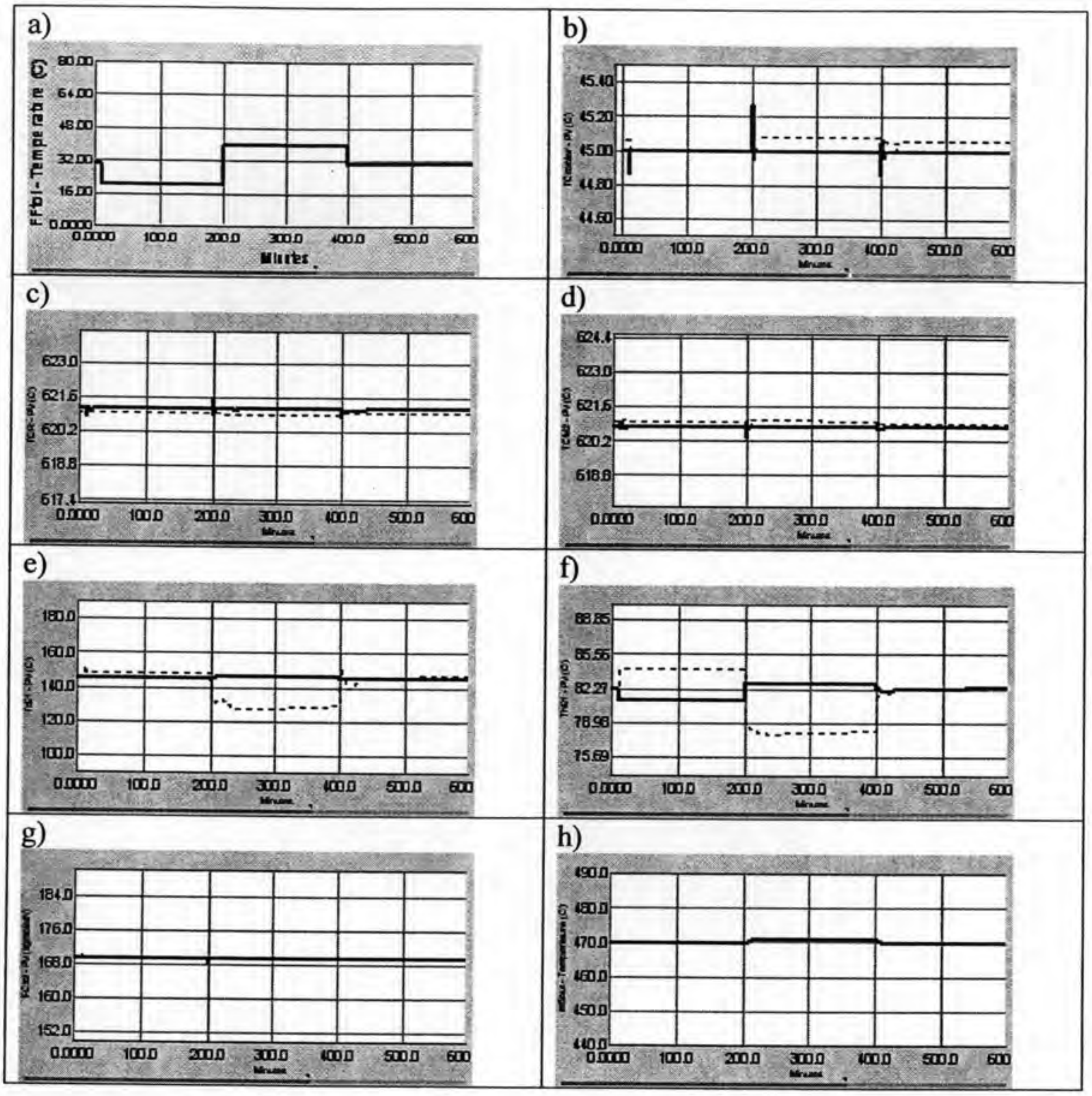

Figure 6.55 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS4, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ―― Process variable (PV) , ⋯⋯ Manipulated variable)

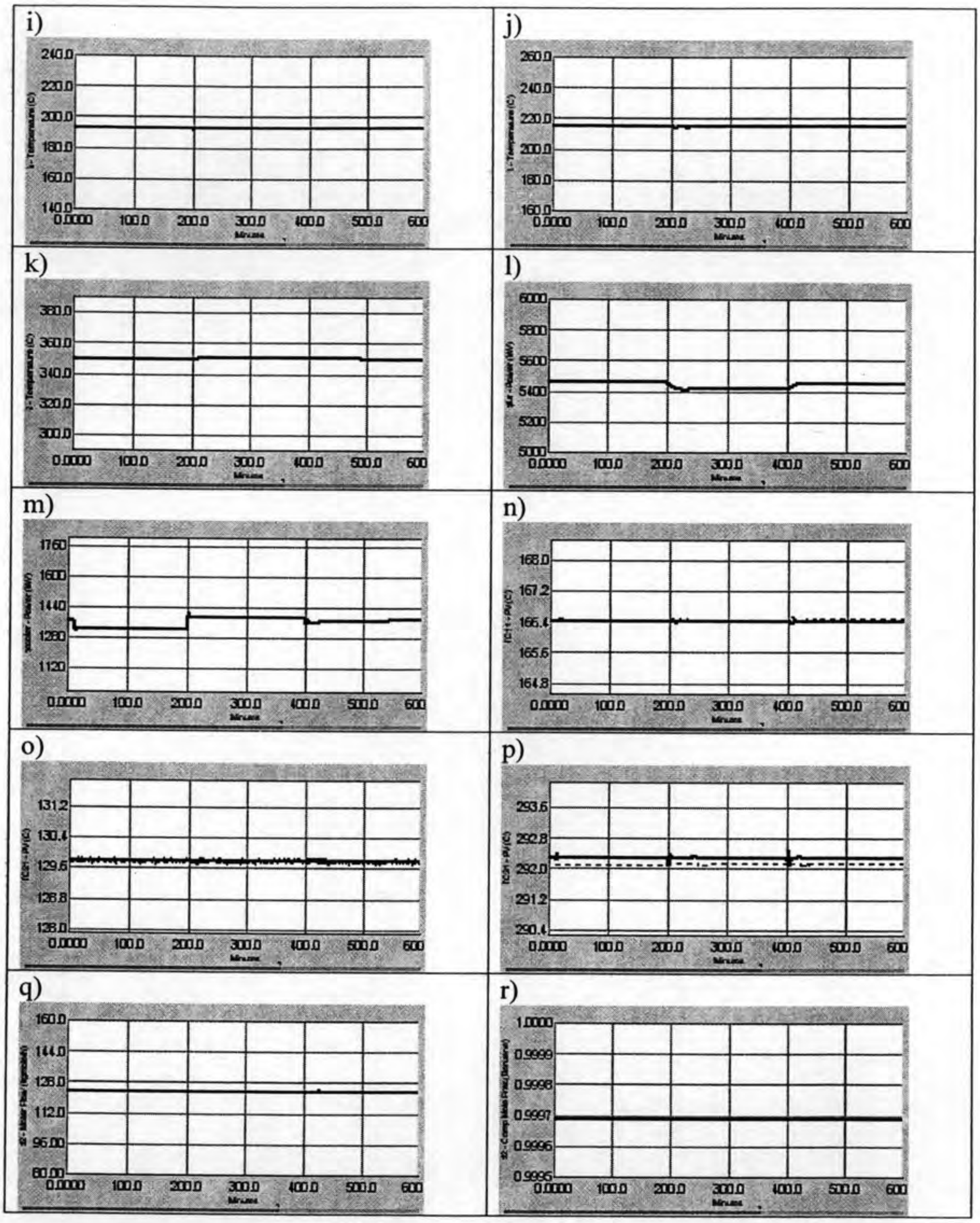

Figure 6.55 (continue)

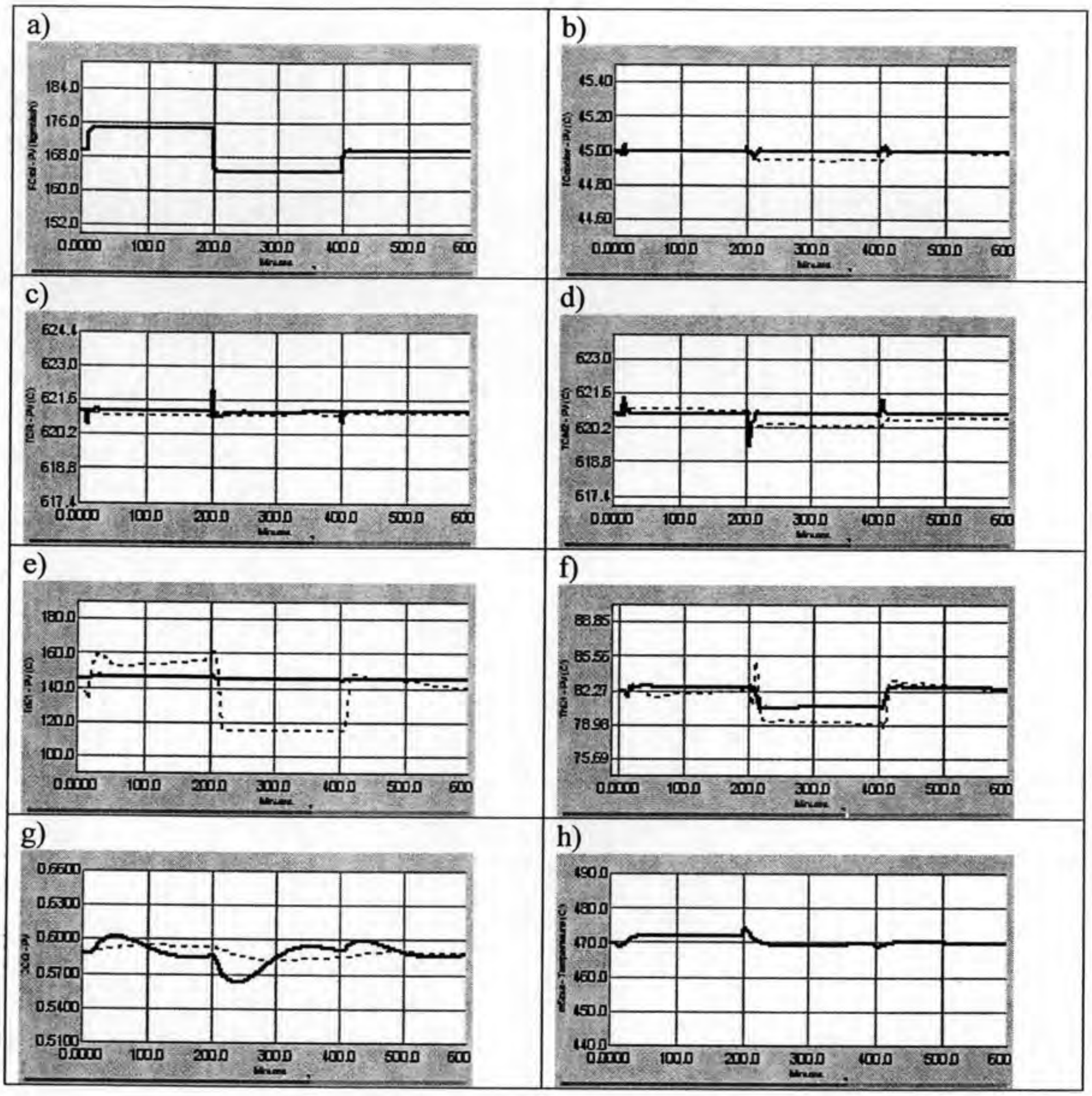

Figure 6.56 Dynamic Responses of the HDA Process Alternative 6:RHEN1 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS4, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

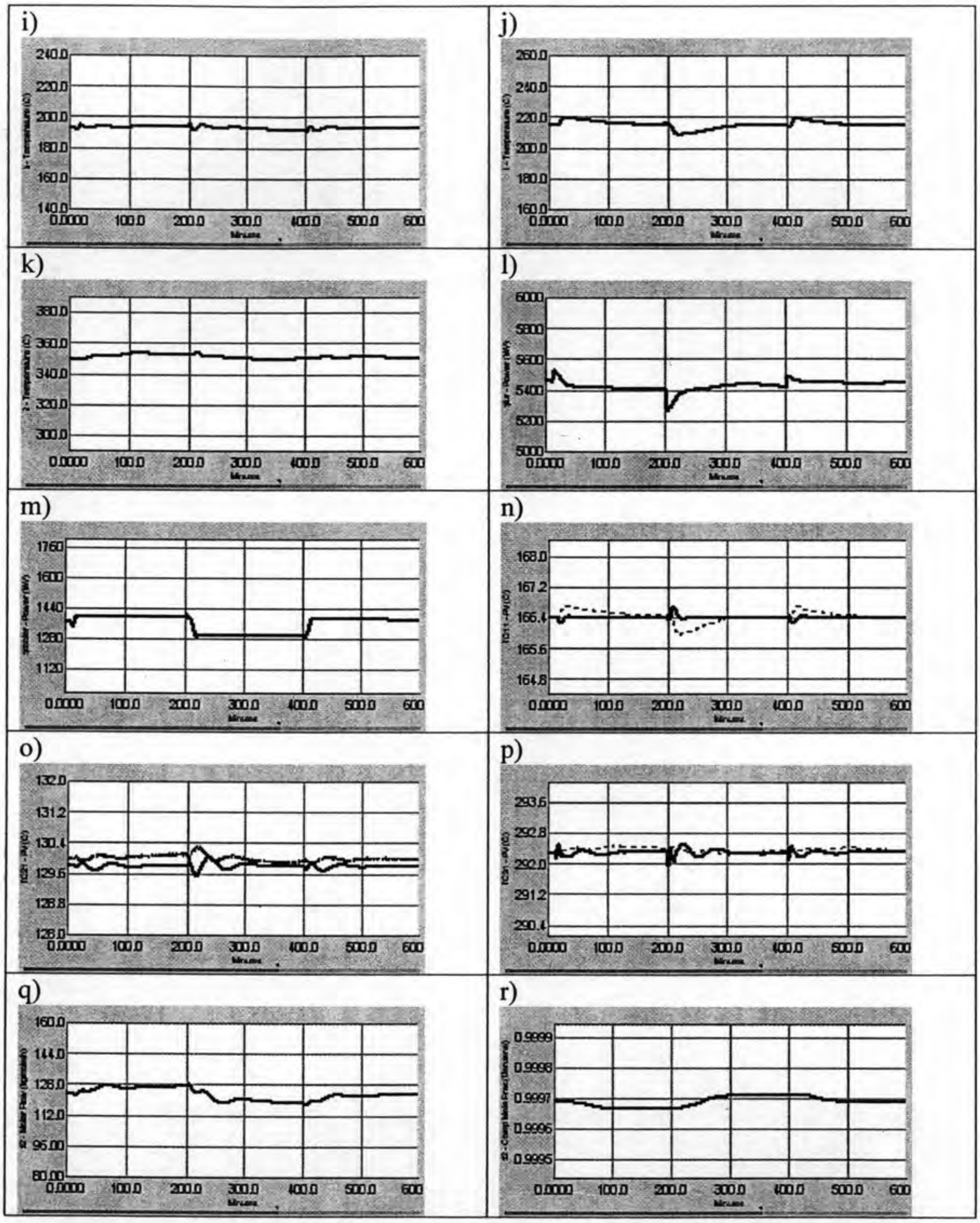

Figure 6.56 (continue)

6.14 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN2) with minimum Auxiliary Utility Units: CS1

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.57 to 6.59. Results for individual disturbance load changes are as follows:

6.14.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.57 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS1 are similar to the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.57.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.57.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.57.p).

6.14.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.58 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN2 with CS1 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.58.n and o).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.58.c,d and p).

6.14.3 Change in the Total Toluene Feed Flow rate

Figure 6.59 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.59.d).A small oscillation of 3°C happens in the product column (Figure6.59.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.59.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.59.p).

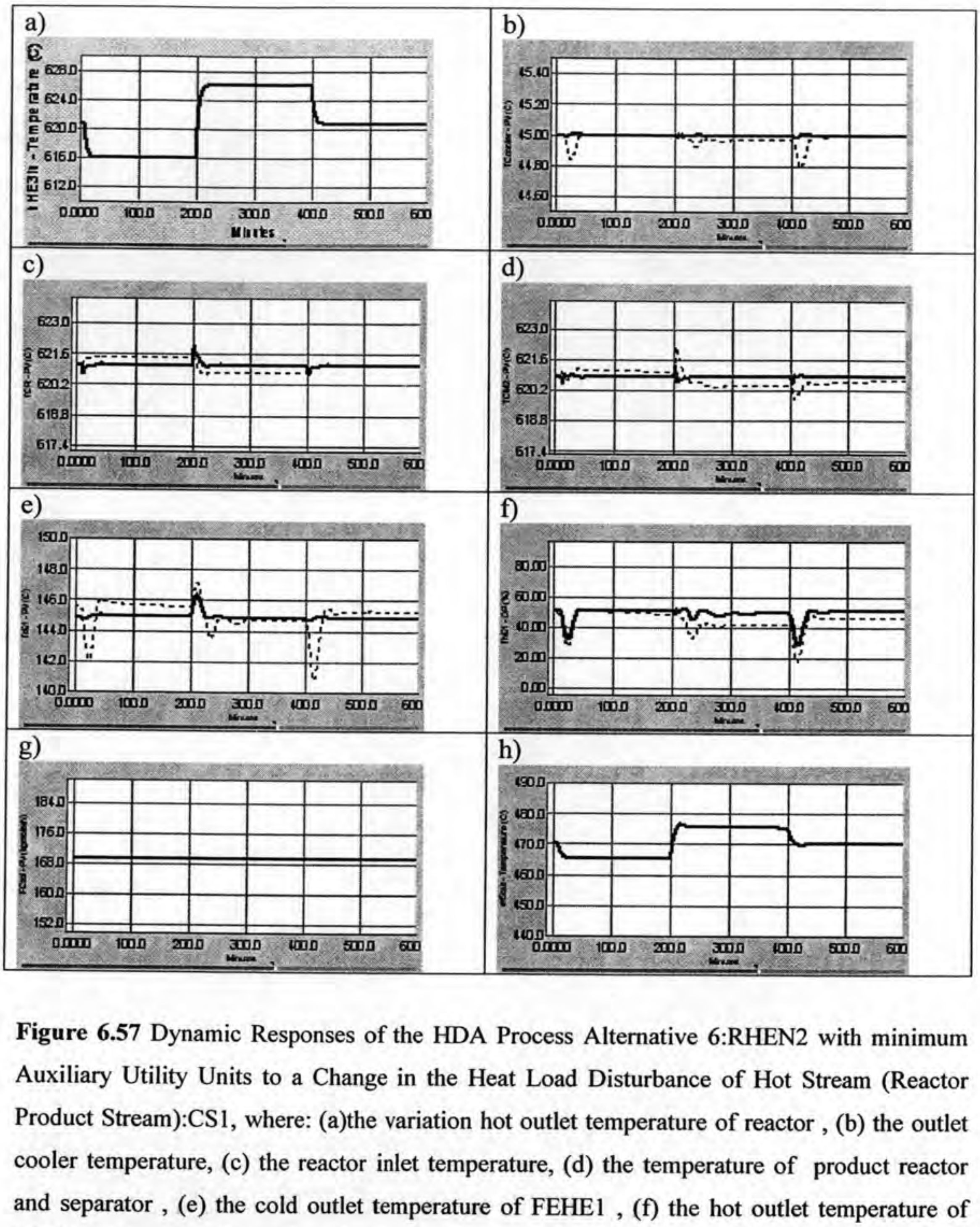

Figure 6.57 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS1, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ······ Manipulated variable)

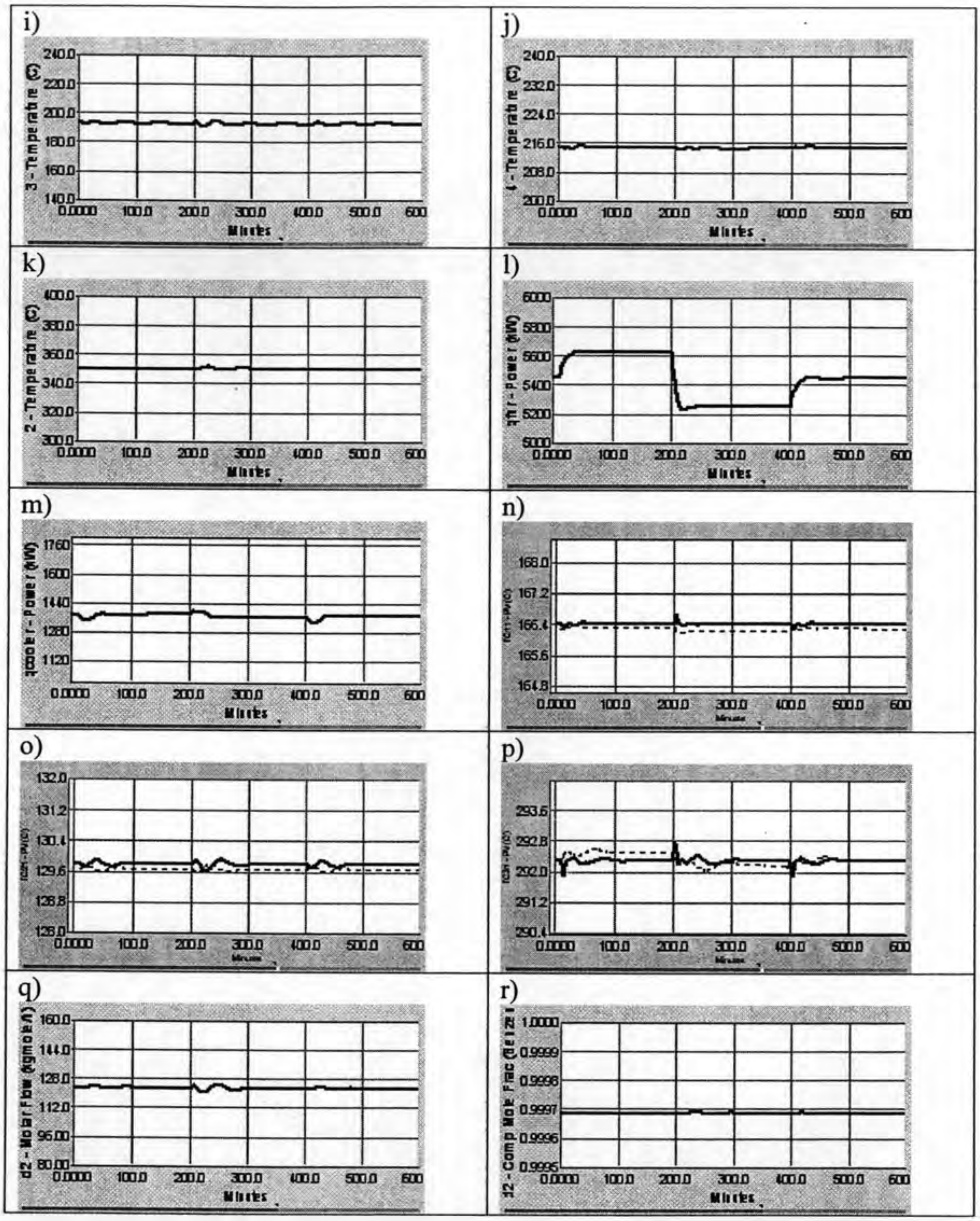

Figure 6.57 (continue)

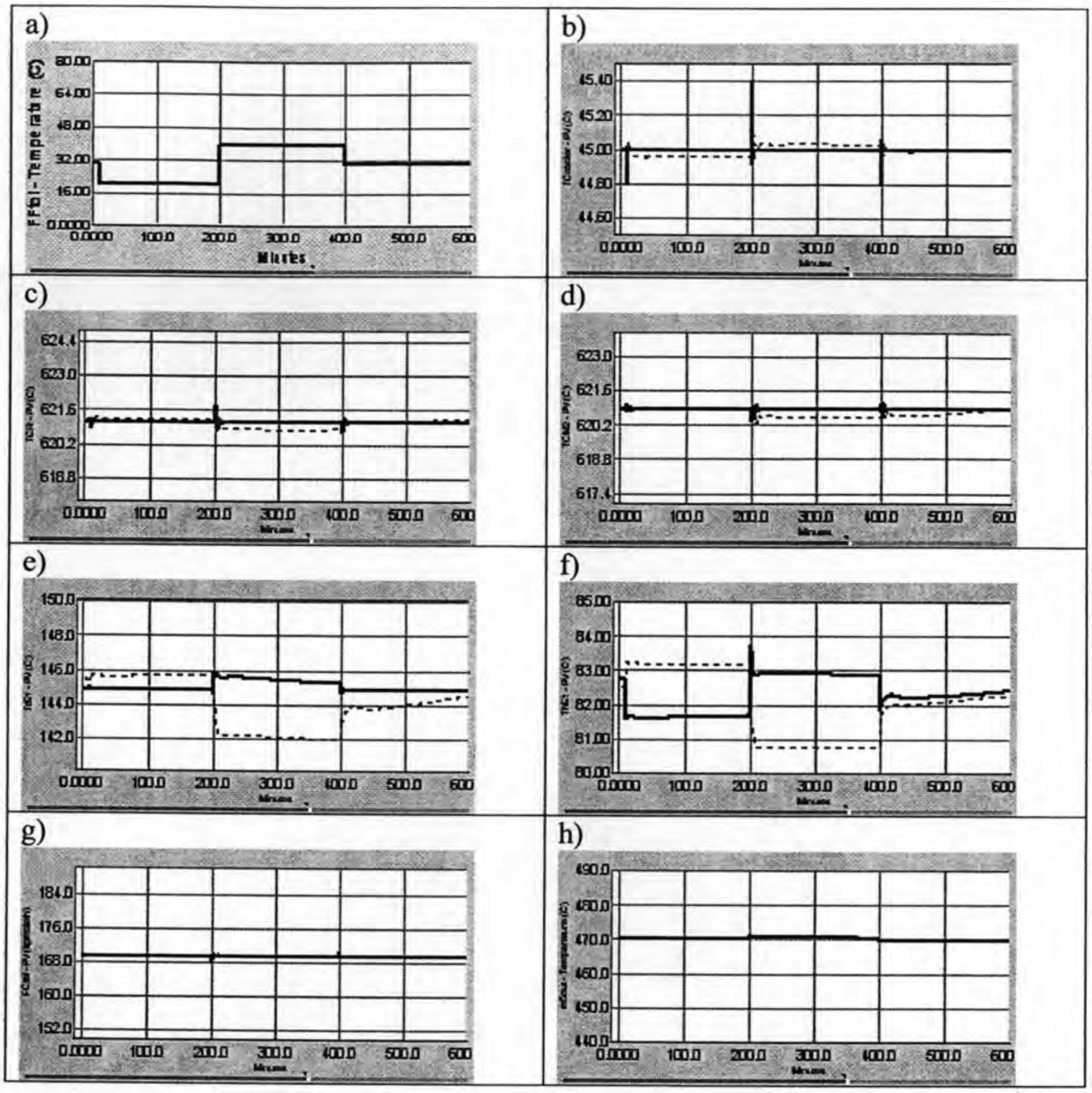

Figure 6.58 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS1, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

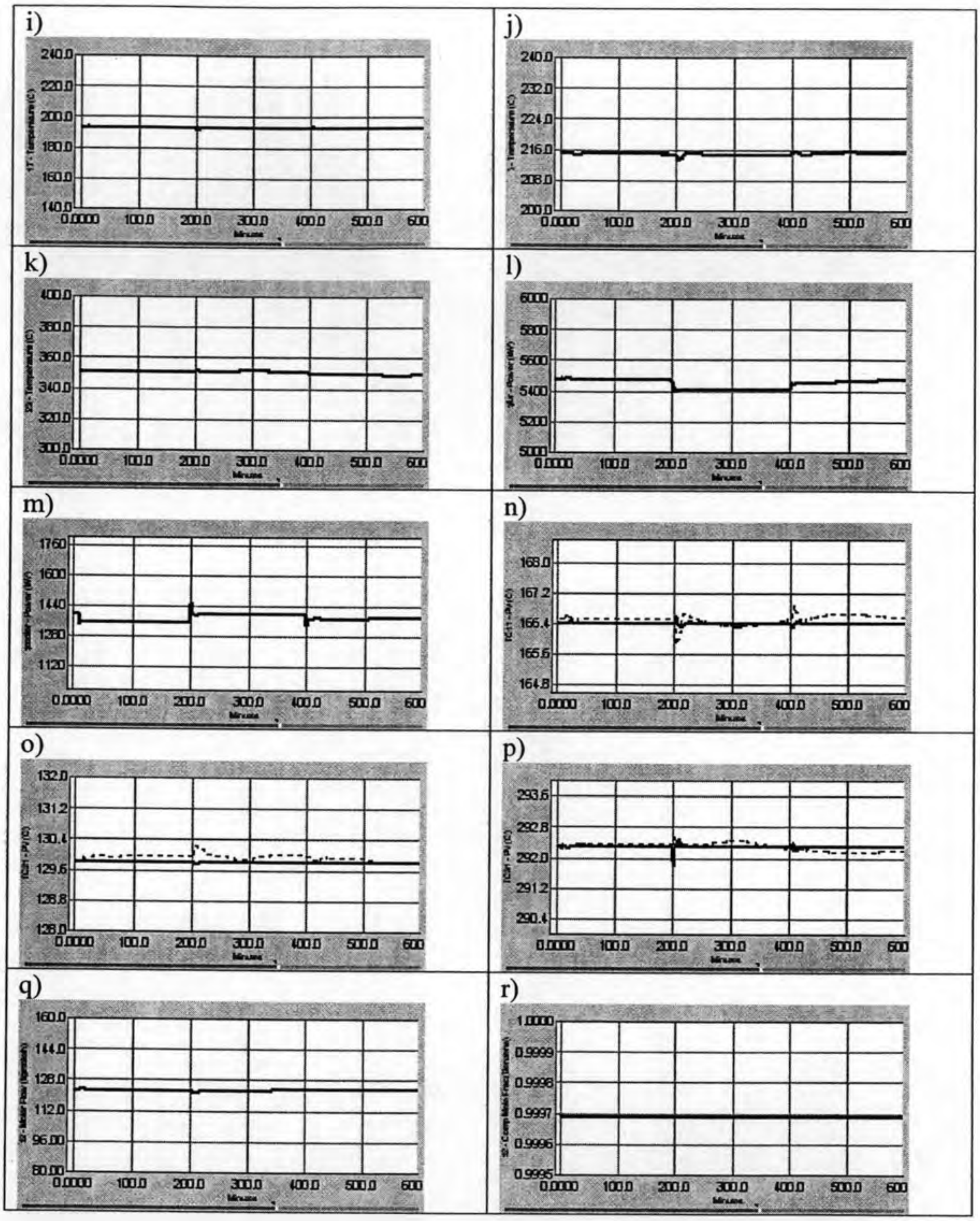

Figure 6.58 (continue)

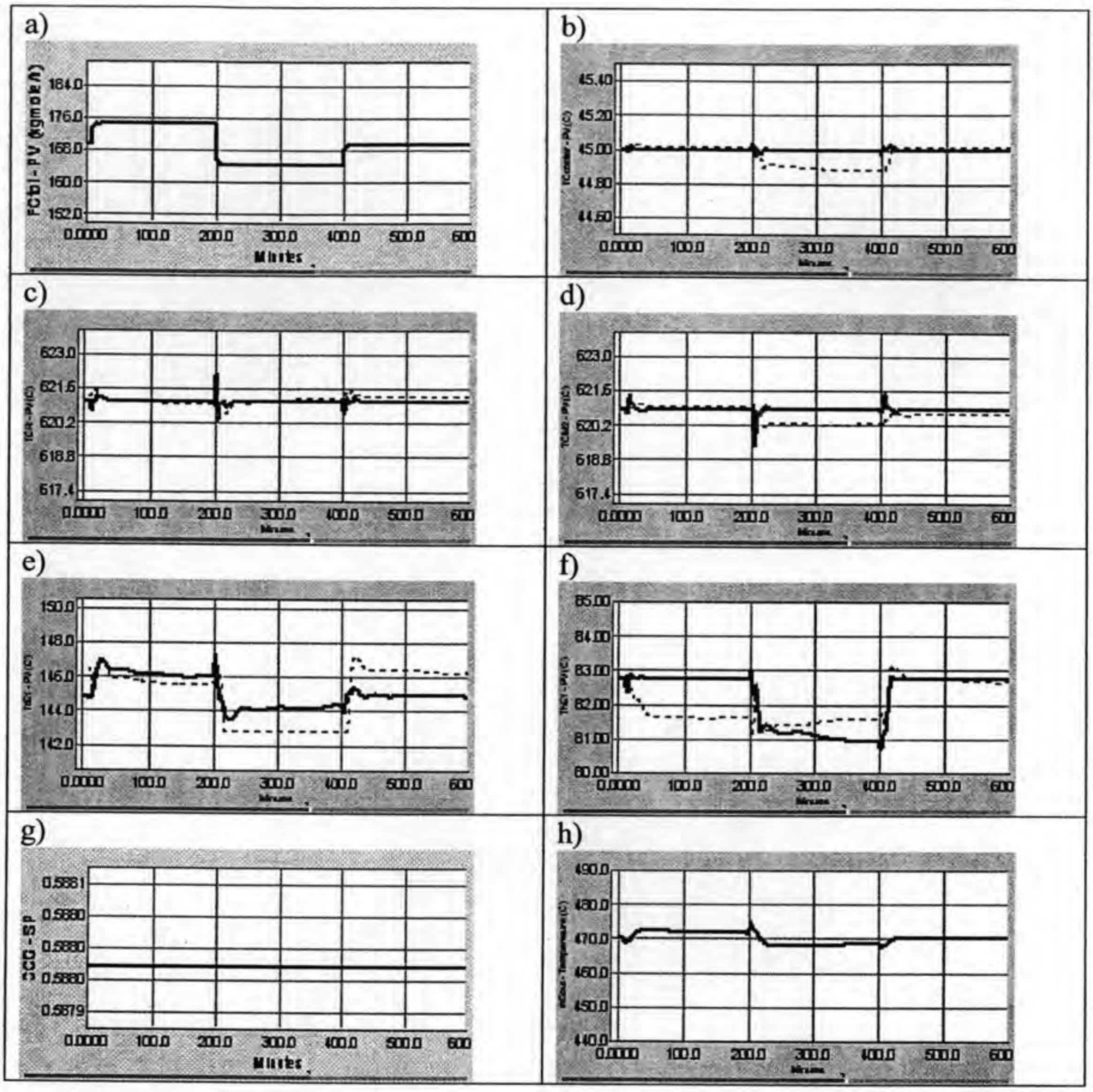

Figure 6.59 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS1, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ―― Process variable (PV) , ······ Manipulated variable)

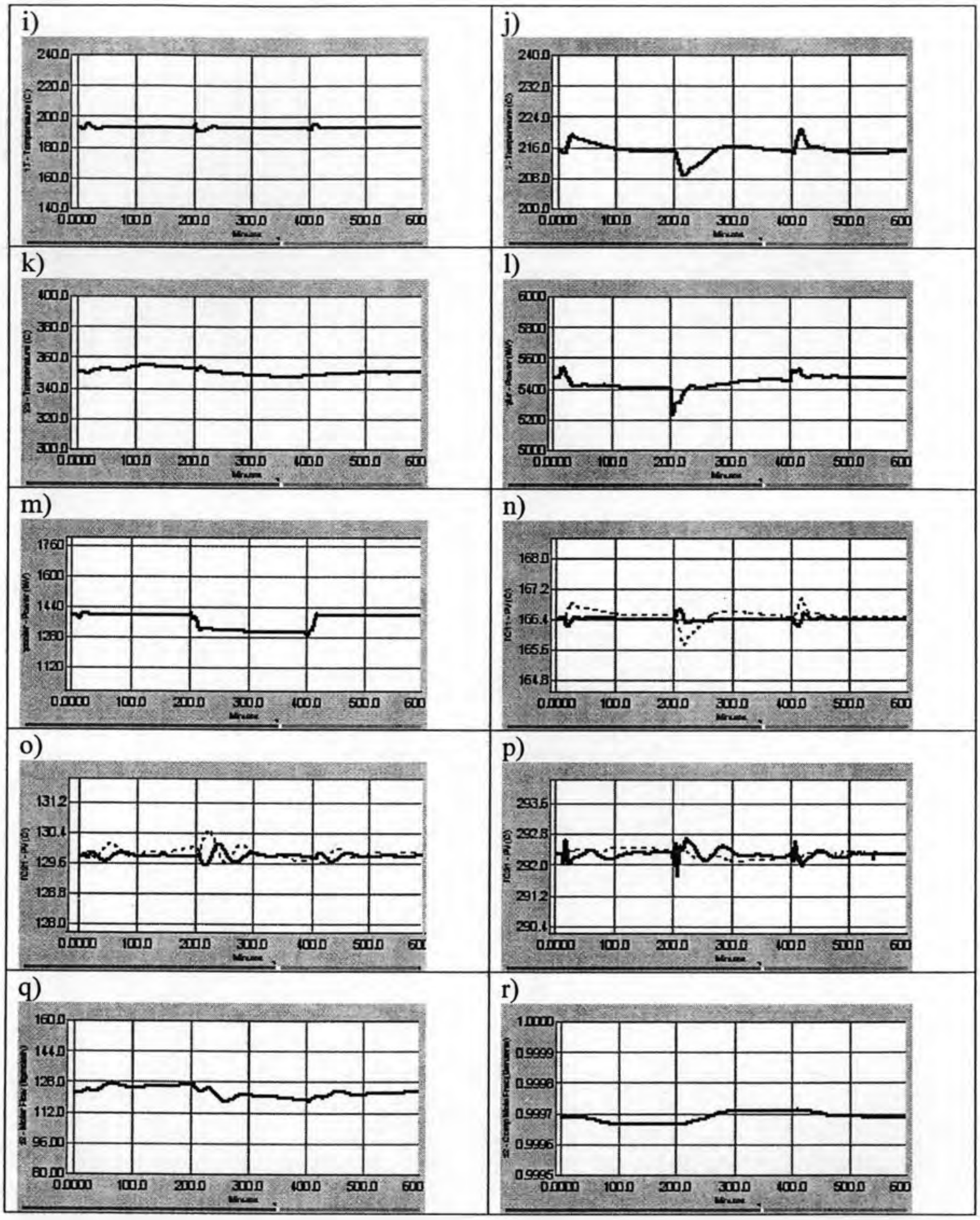

Figure 6.59 (continue)

6.15 Dynamic Simulation Results for HDA Process Alternative6 (RHEN2) with minimum Auxiliary Utility Units: CS2

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.60 to 6.62. Results for individual disturbance load changes are as follows

6.15.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.60 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS2 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.60.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.60.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.60.p). The oscillations occur in the molar flow of the benzene (Figure 6.60.q).

6.15.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.61 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS2 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.61.d and c). A deviation of 5°C happens in the tray temperature of the recycle column and it takes over 500 minutes to return to its nominal value of 290.3°C (Figure 6.61.p) and the oscillations occur in the molar flow of the benzene (Figure 6.61.q).

6.15.3 Change in the Total Toluene Feed Flow rate

Figure 6.62 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.62.d).A small oscillation of 3°C happens in the product column (Figure6.62.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.62.n). The tray temperature of the recycle column has a small deviation about 2°C and it takes over 500 minutes to return to its nominal value (Figure6.62.p). The oscillations occur in the molar flow of the benzene (Figure 6.62.q).

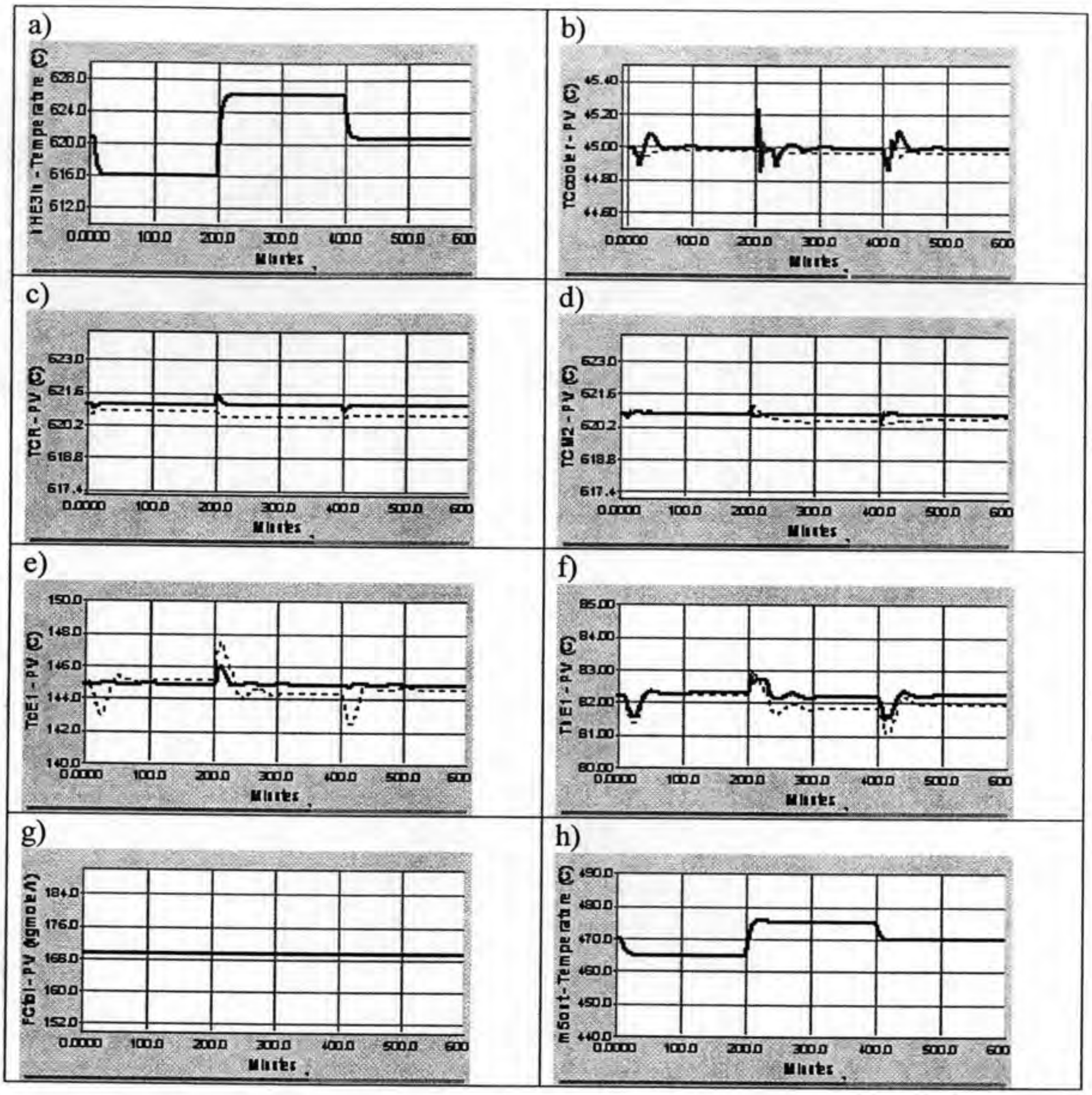

Figure 6.60 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS2, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

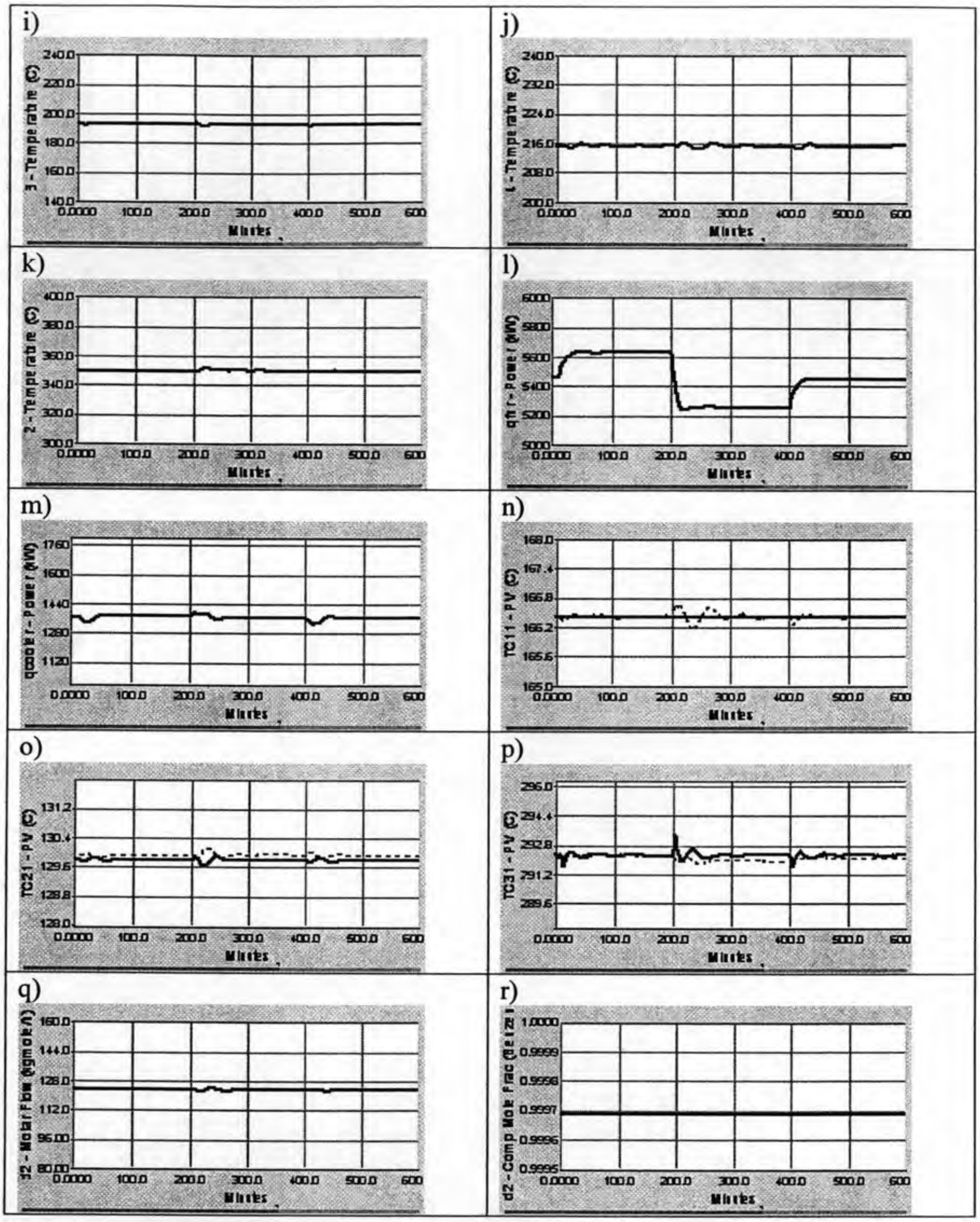

Figure 6.60 (continue)

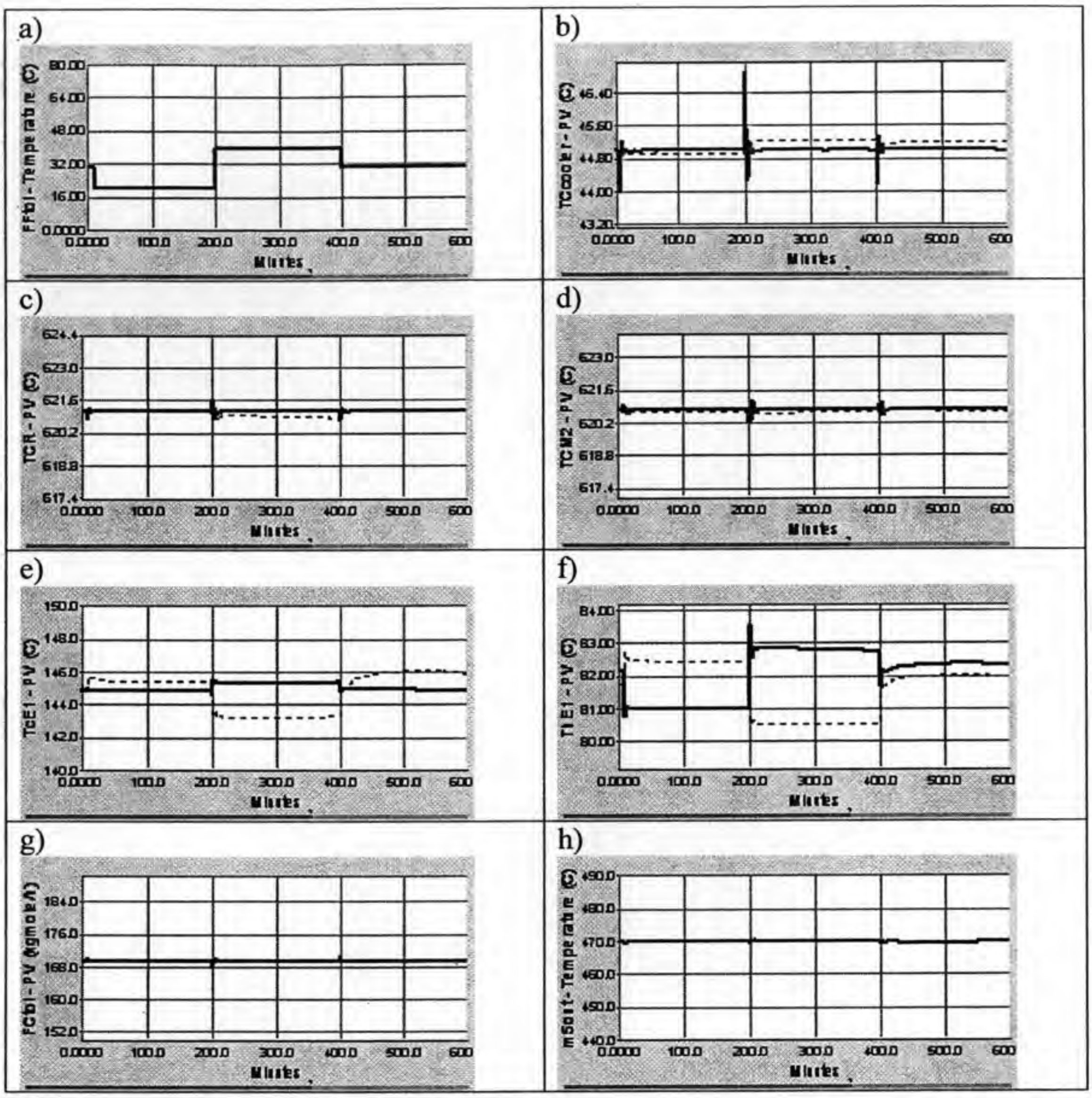

Figure 6.61 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS2, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

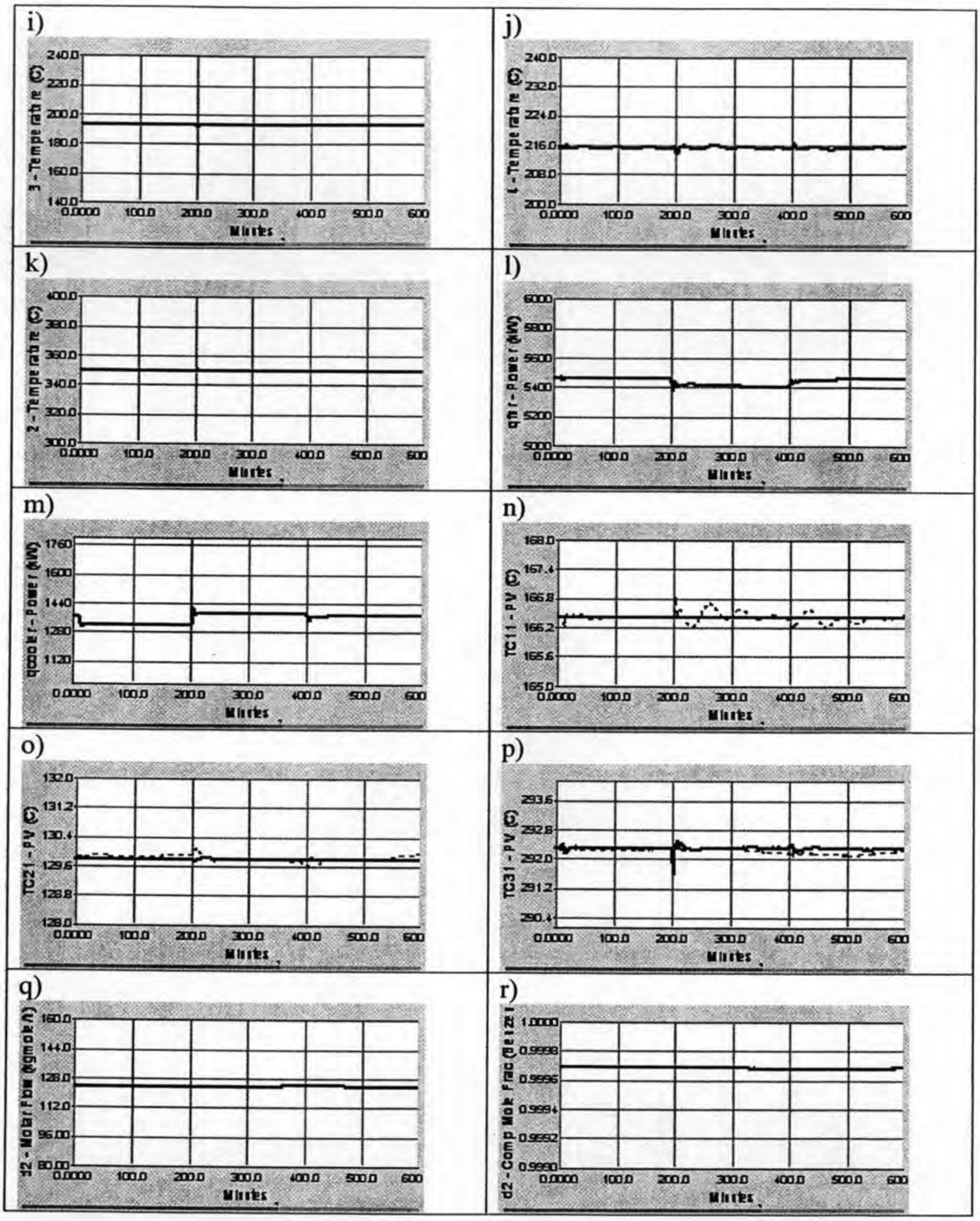

Figure 6.61 (continue)

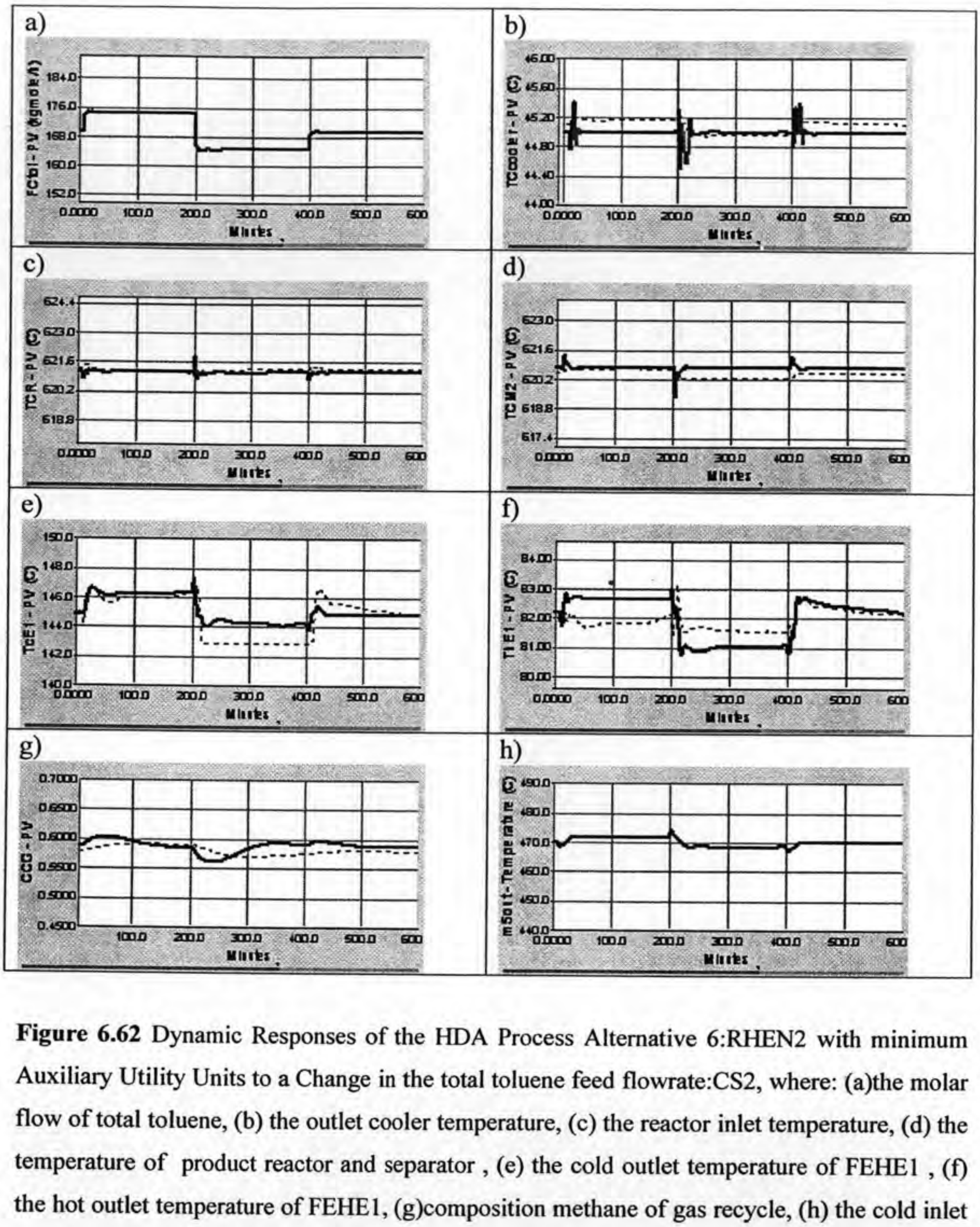

Figure 6.62 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS2, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

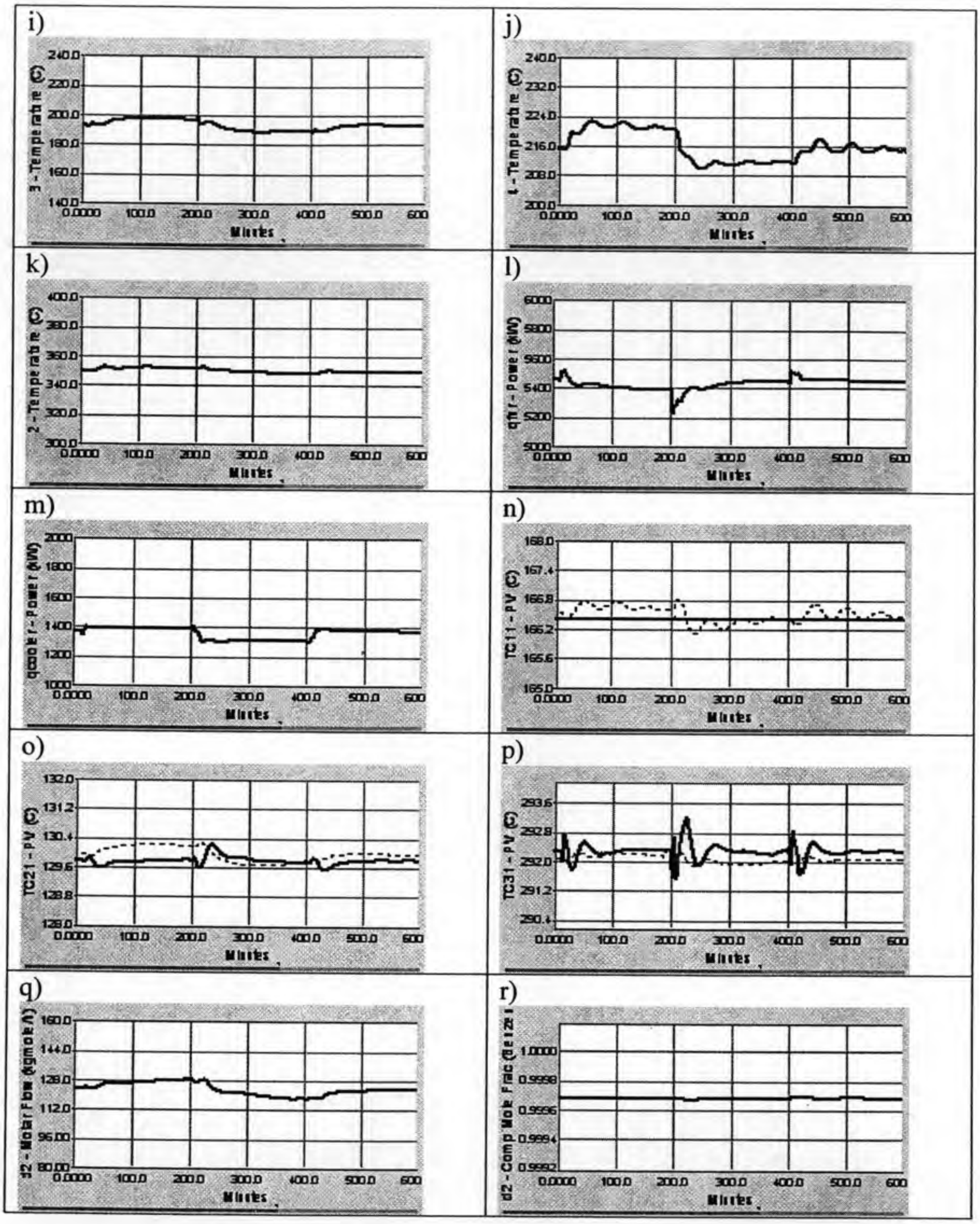

Figure 6.62 (continue)

6.16 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN2) with minimum Auxiliary Utility Units: CS3

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.63 to 6.65. Results for individual disturbance load changes are as follows:

6.16.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.63 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS3 are better than the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.63.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.63.n, o and p).Its advantages is that it provides higher performance of the tray temperature control in the product column, since there are two point controls in the product column. The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.63.q).

6.16.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.64 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh

toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN1 with CS3 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.64.n, o and p), since there are two tray temperature controls in the product column (One is the tray-12 temperature control and the other is tray-18 temperature control).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.64.c,d and q).

6.16.3 Change in the Total Toluene Feed Flow rate

Figure 6.65 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.65.d).A small oscillation of 3°C happens in the product column (Figure6.65.o and p) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.65.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.65.q).

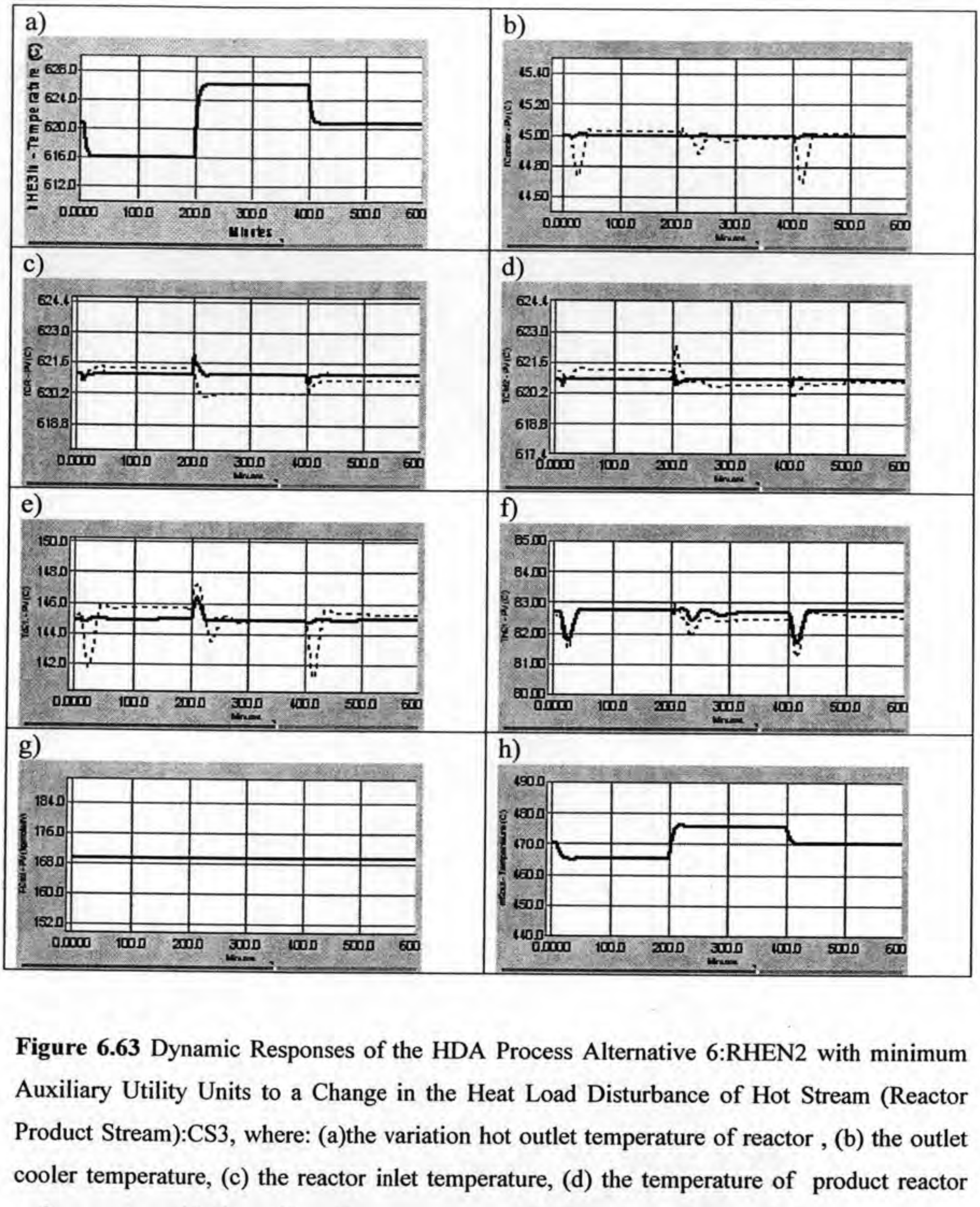

Figure 6.63 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS3, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene of product column (Note. ——— Process variable (PV) , ‧‧‧‧‧‧ Manipulated variable)

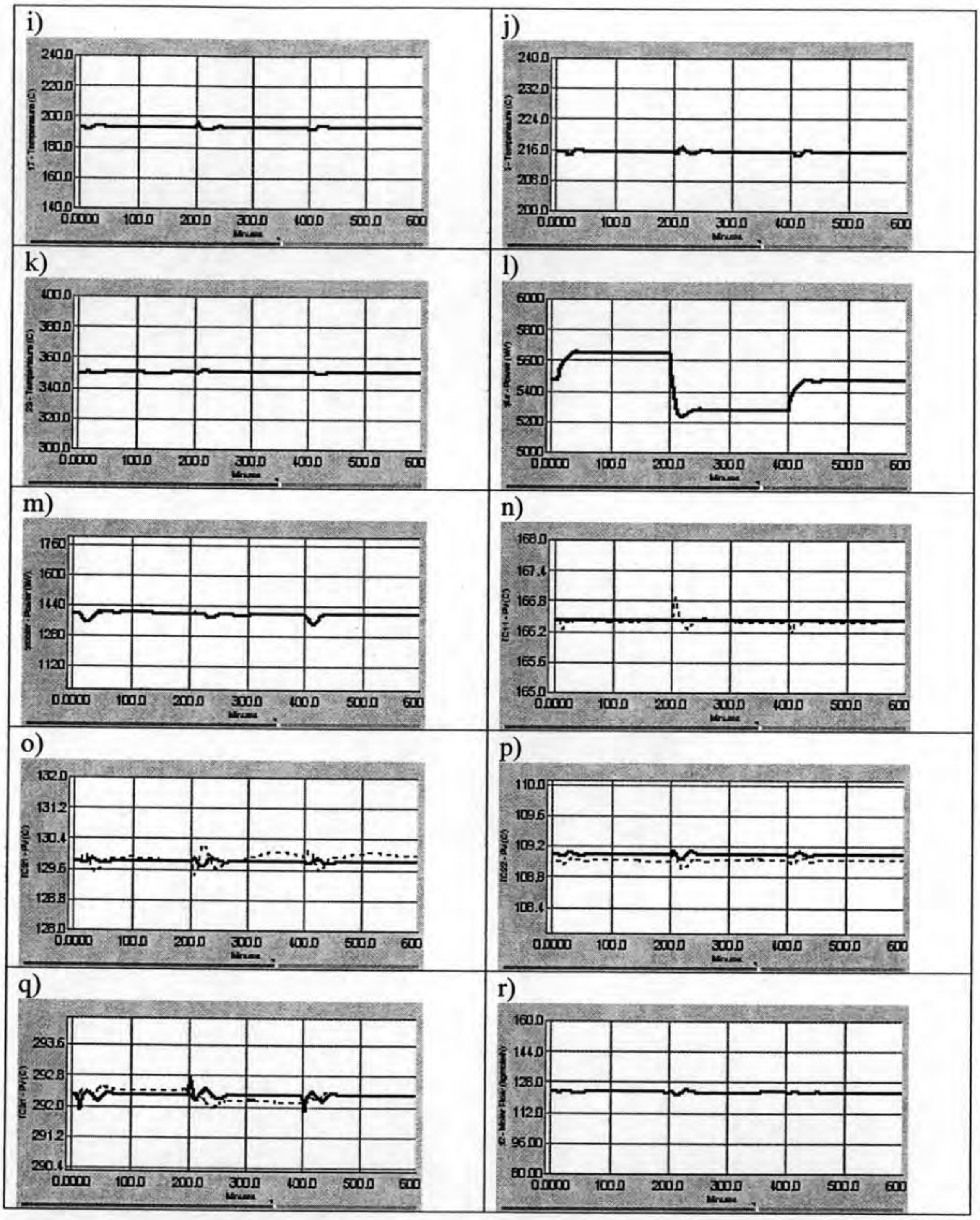

Figure 6.63 (continue)

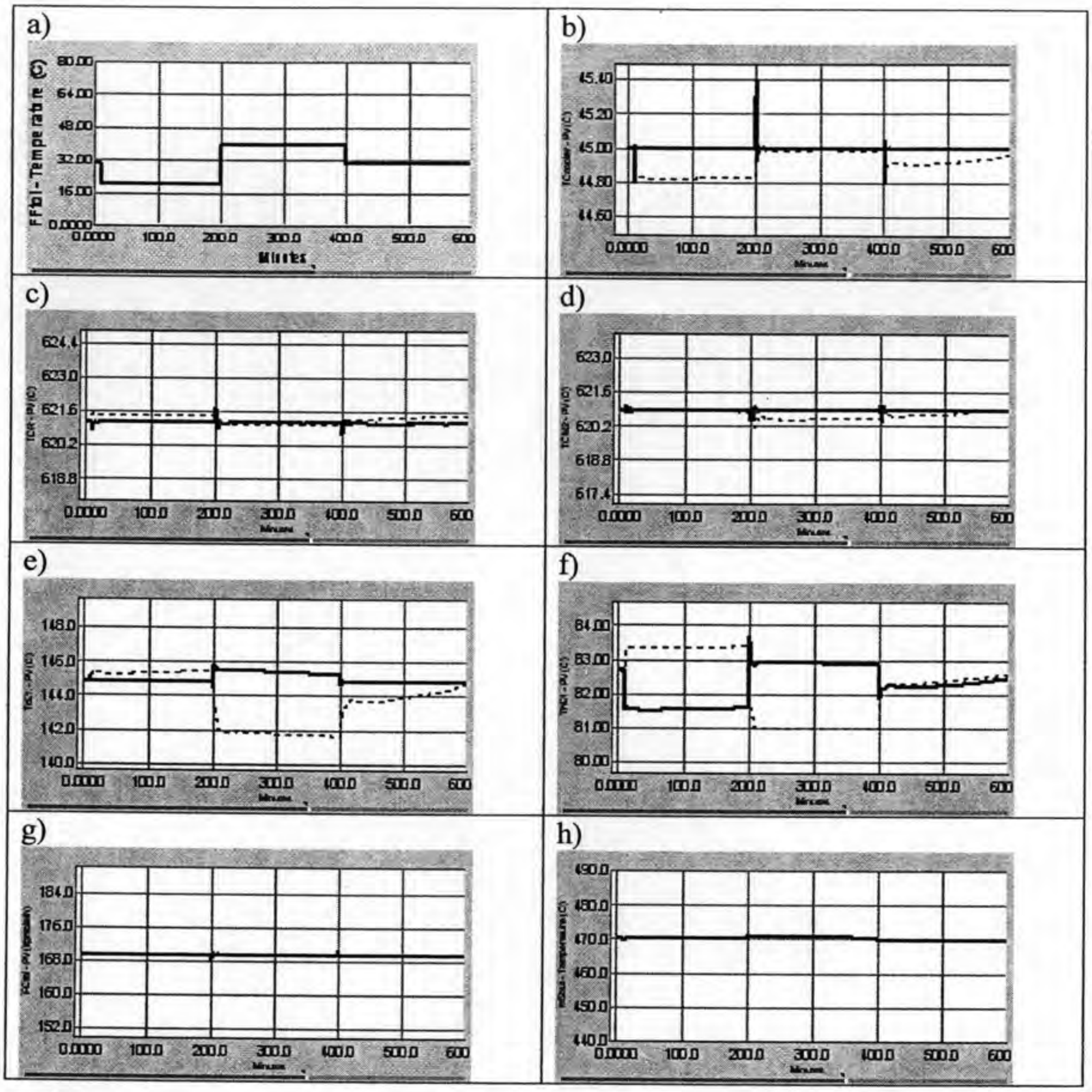

Figure 6.64 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS3, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ——— Process variable (PV) , ······ Manipulated variable)

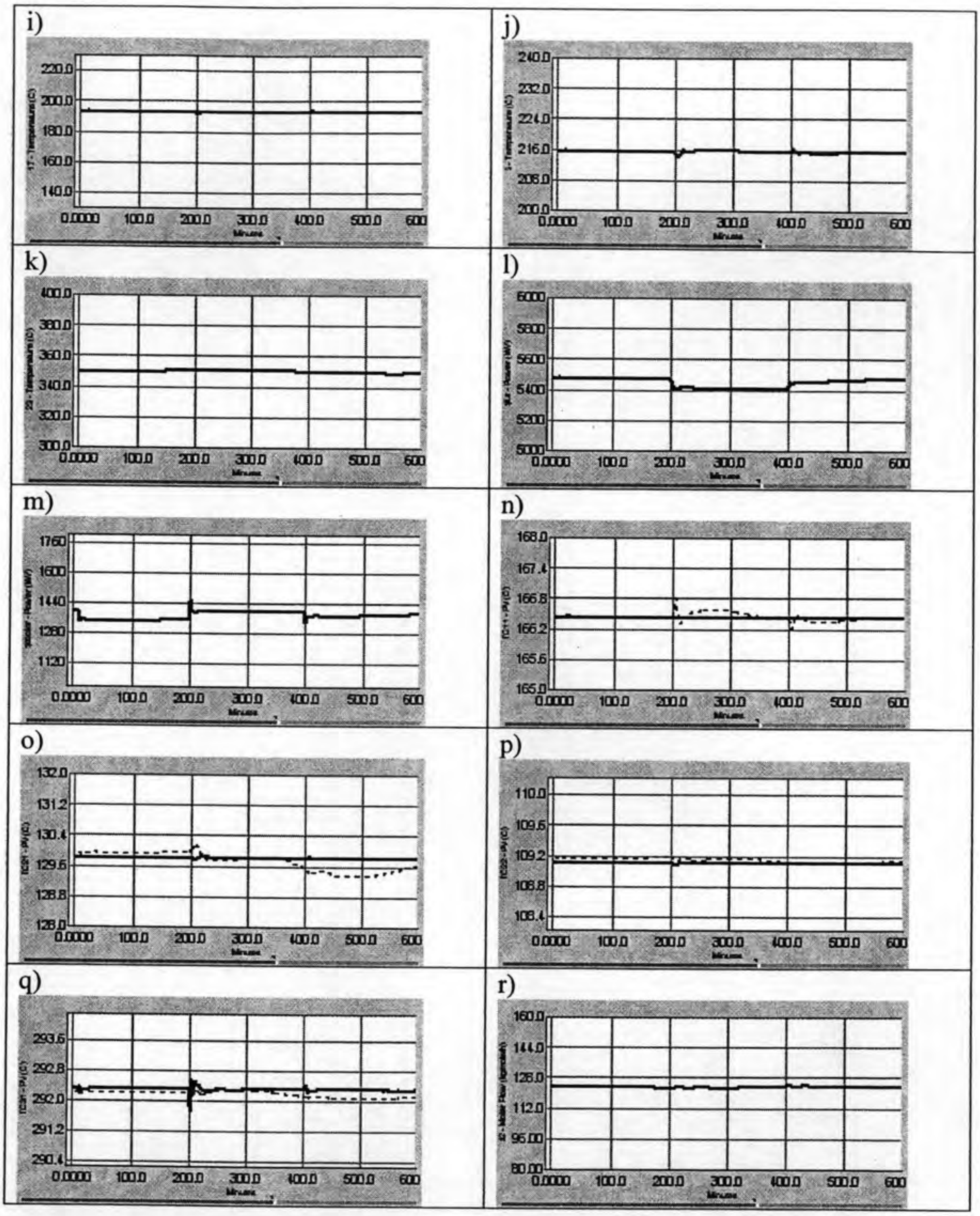

Figure 6.64 (continue)

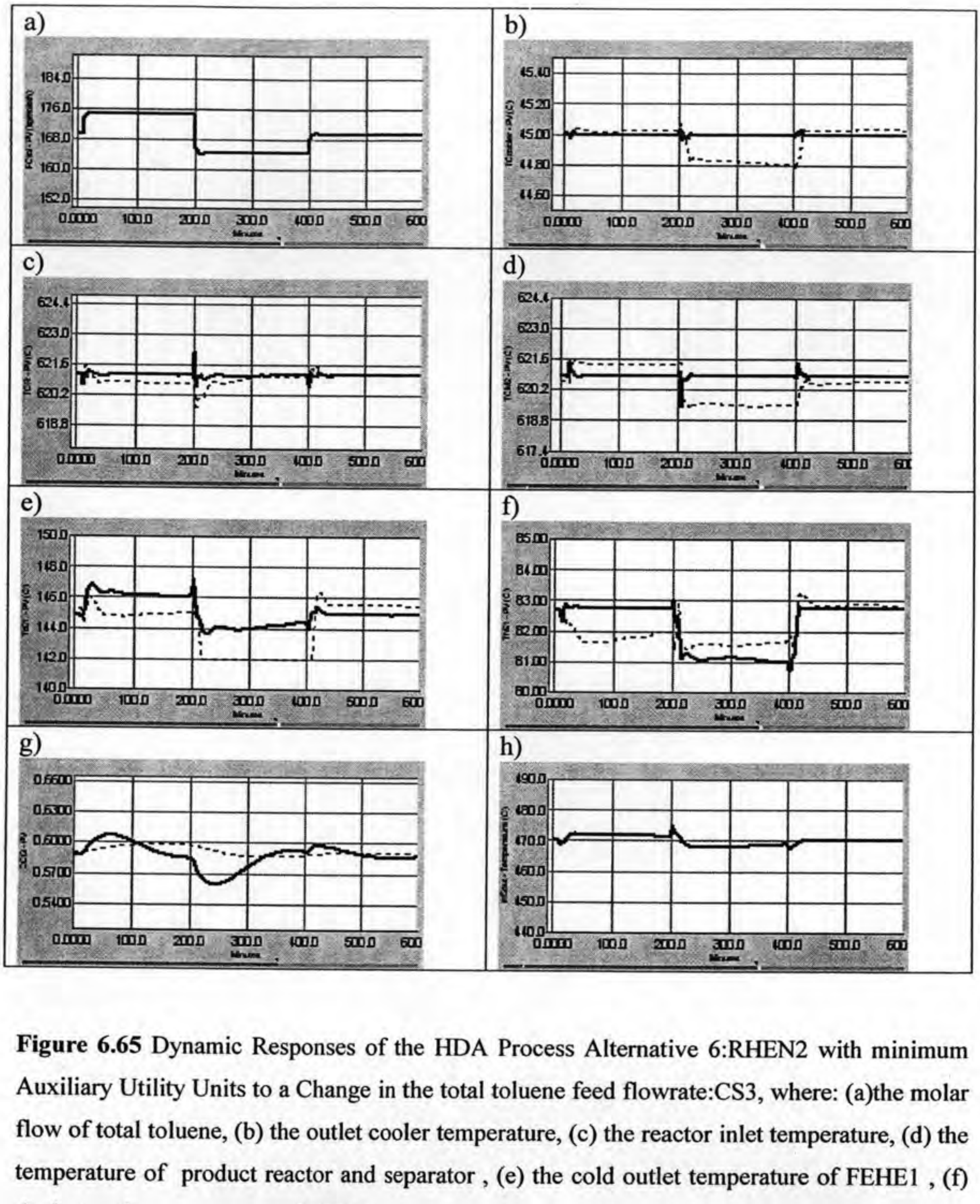

Figure 6.65 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS3, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ▬▬ Process variable (PV) , ‧‧‧‧‧‧ Manipulated variable)

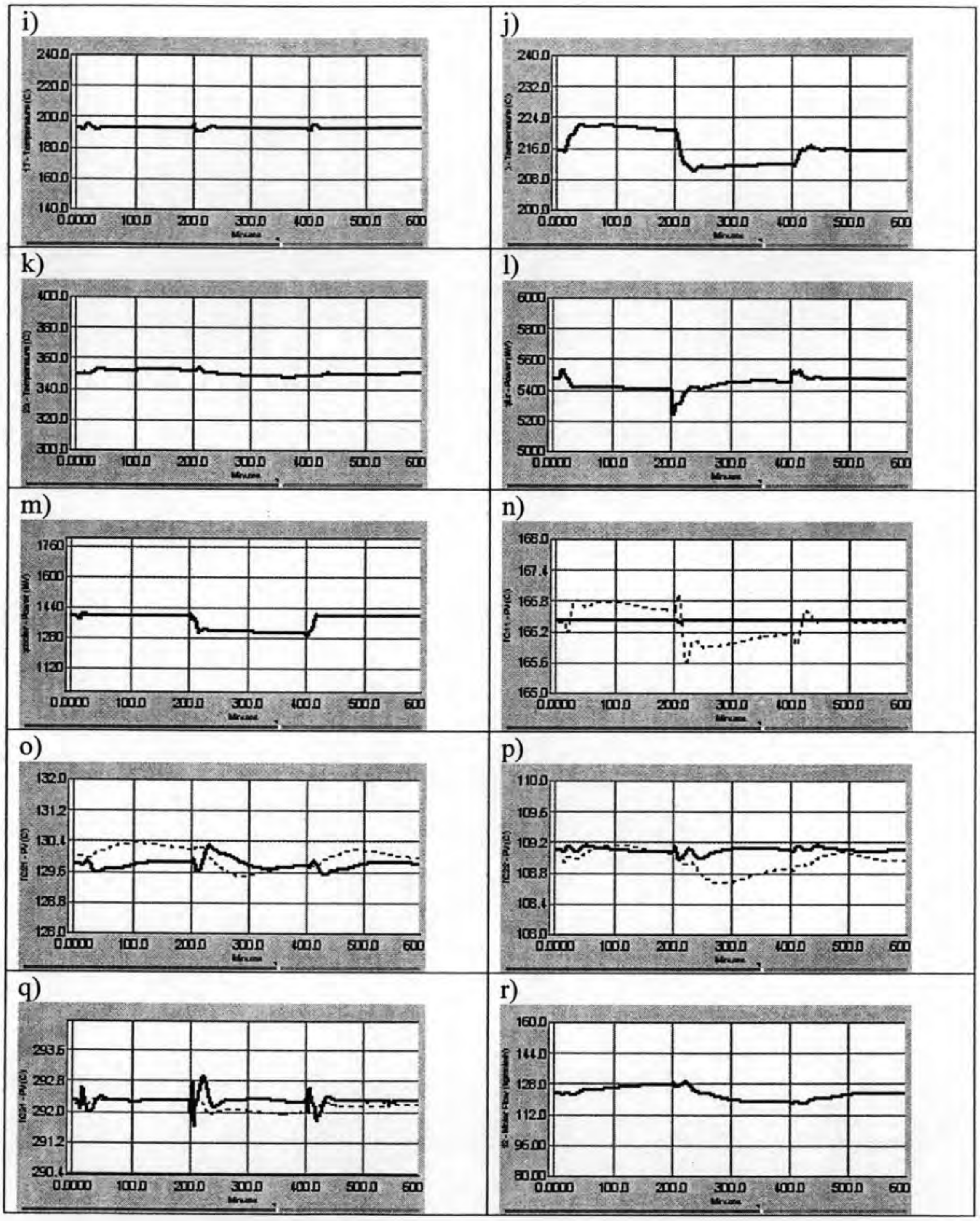

Figure 6.65 (continue)

6.17 Dynamic Simulation Results for HDA Process Alternative6 (RHEN2) with minimum Auxiliary Utility Units: CS4

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.66 to 6.68. Results for individual disturbance load changes are as follows

6.17.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.66 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS4 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.66.c and d), the oscillations occur about 5°C in the tray temperature of the stabilizer and the product column (Figure 6.66.n and o). The tray temperature in the recycle column has a large oscillation and it takes more than 800 minutes to come back to setpoint (Figure6.66.p). The oscillations occur in the molar flow of the benzene (Figure 6.66.q).

6.17.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.67 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.67.d and c). A deviation of 6°C happens in the tray temperature of the recycle column and it takes over 800 minutes to return to its nominal value of 290.3°C (Figure 6.67.p) and the oscillations occur in the molar flow of the benzene (Figure 6.67.q).

6.17.3 Change in the Total Toluene Feed Flow rate

Figure 6.68 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.68.d).A small oscillation of 3°C happens in the product column (Figure6.68.o), Also a slightly worse controlled occurs in the tray temperature of the stabilizer column (Figure6.68.n). The tray temperature of the recycle column has a large deviation about 20°C and it takes over 900 minutes to return to its nominal value (Figure6.68.p). The oscillations occur in the molar flow of the benzene (Figure 6.68.q).

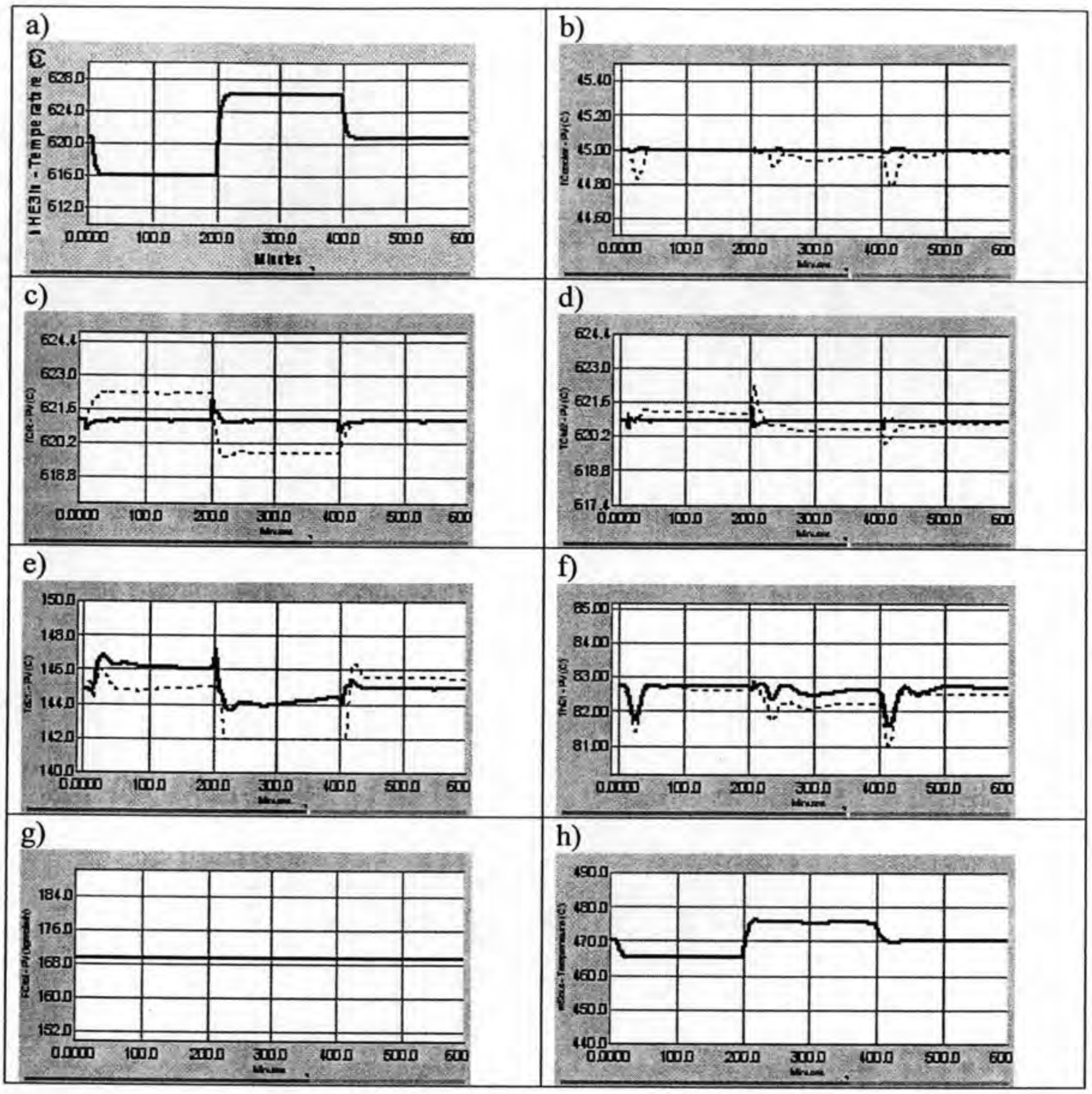

Figure 6.66 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS4, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

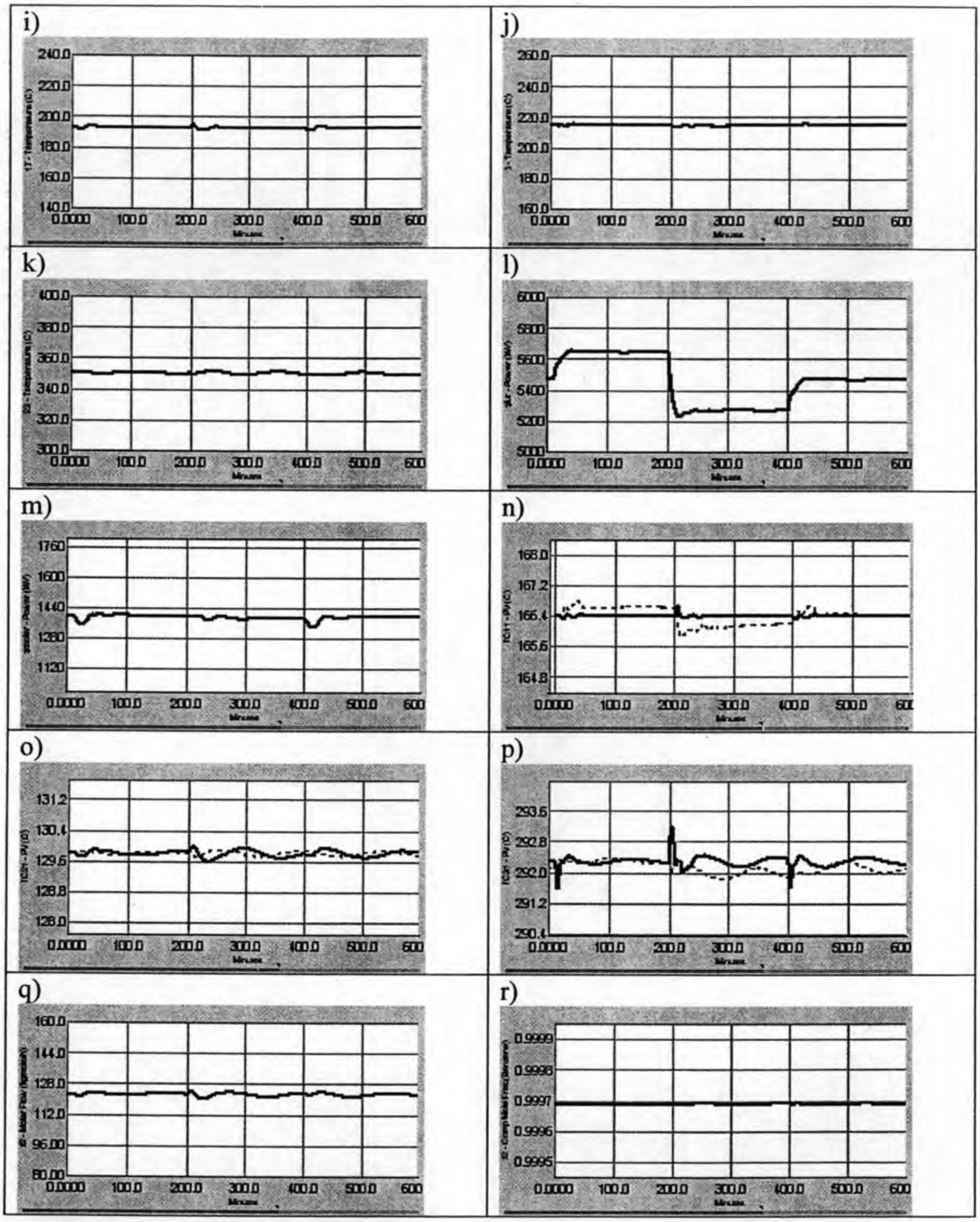

Figure 6.66 (continue)

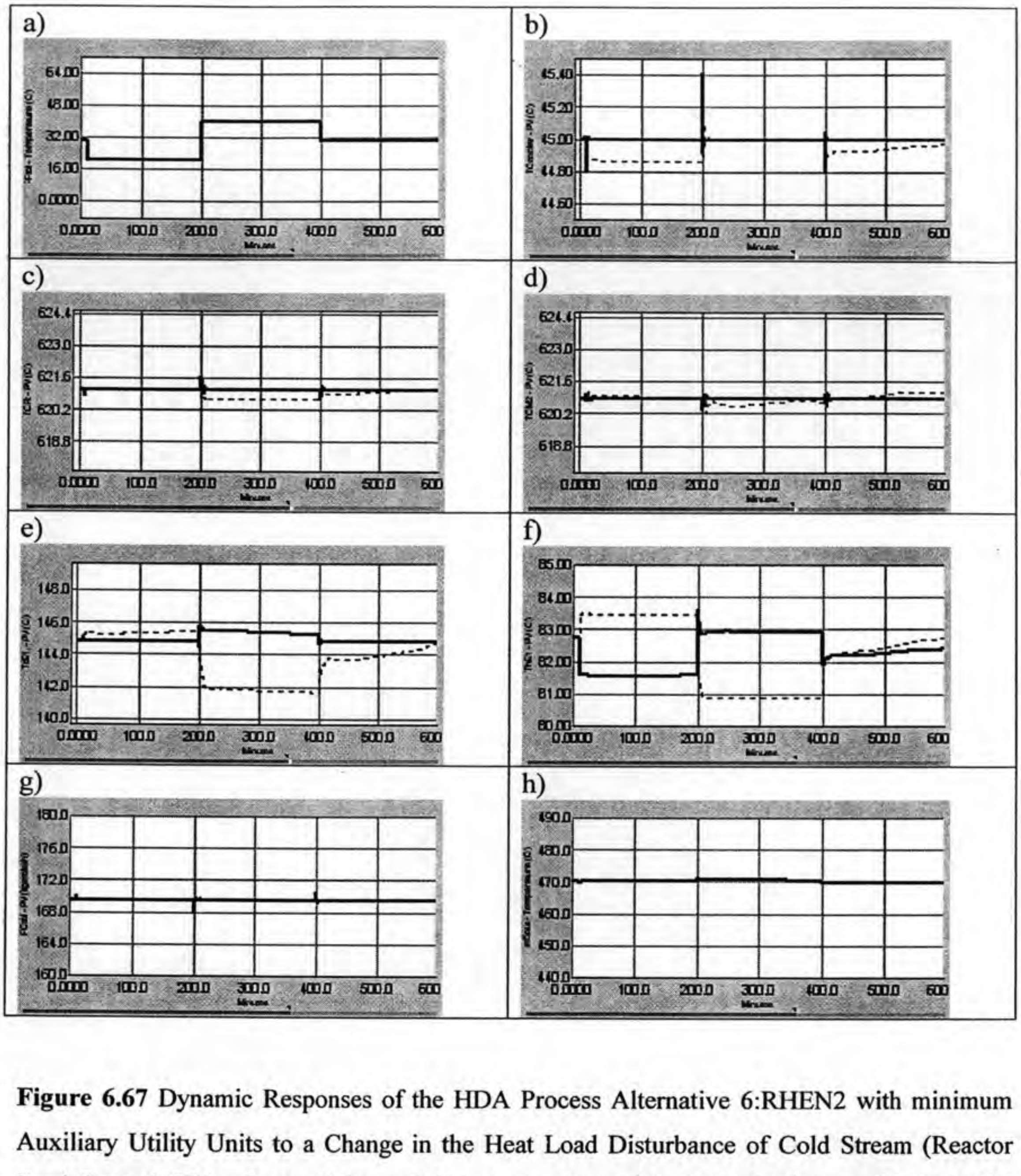

Figure 6.67 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS4, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

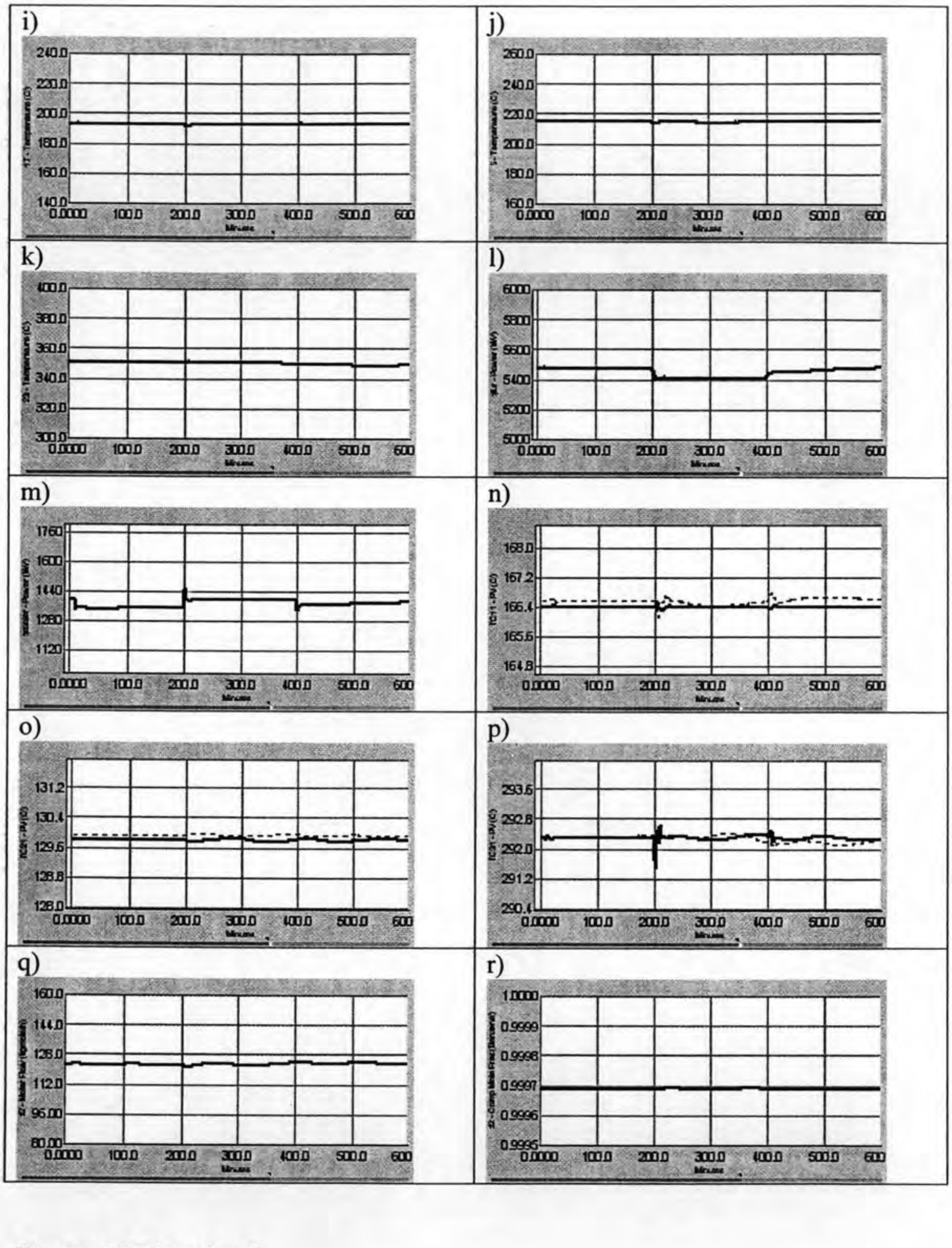

Figure 6.67 (continue)

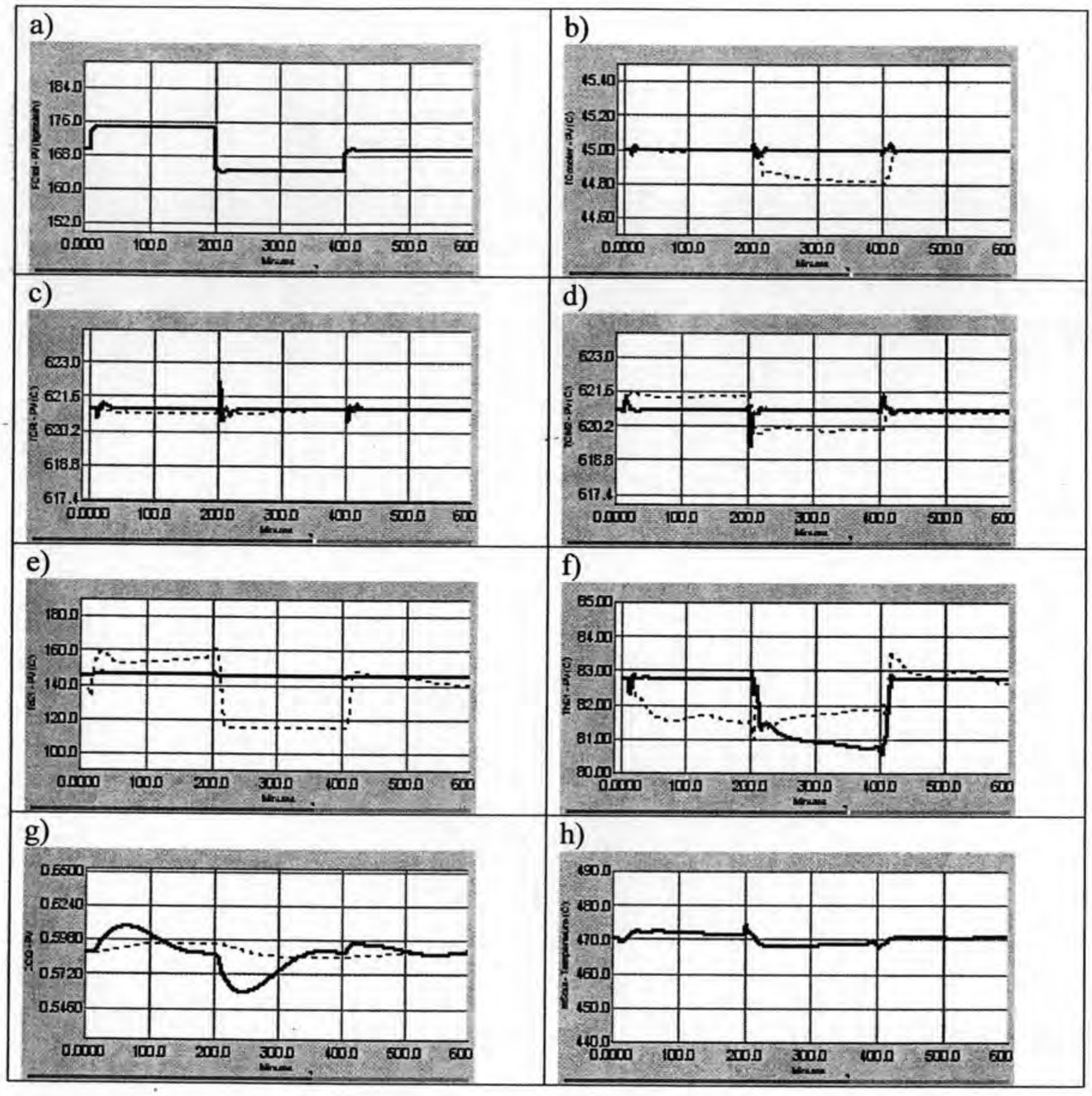

Figure 6.68 Dynamic Responses of the HDA Process Alternative 6:RHEN2 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS4, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

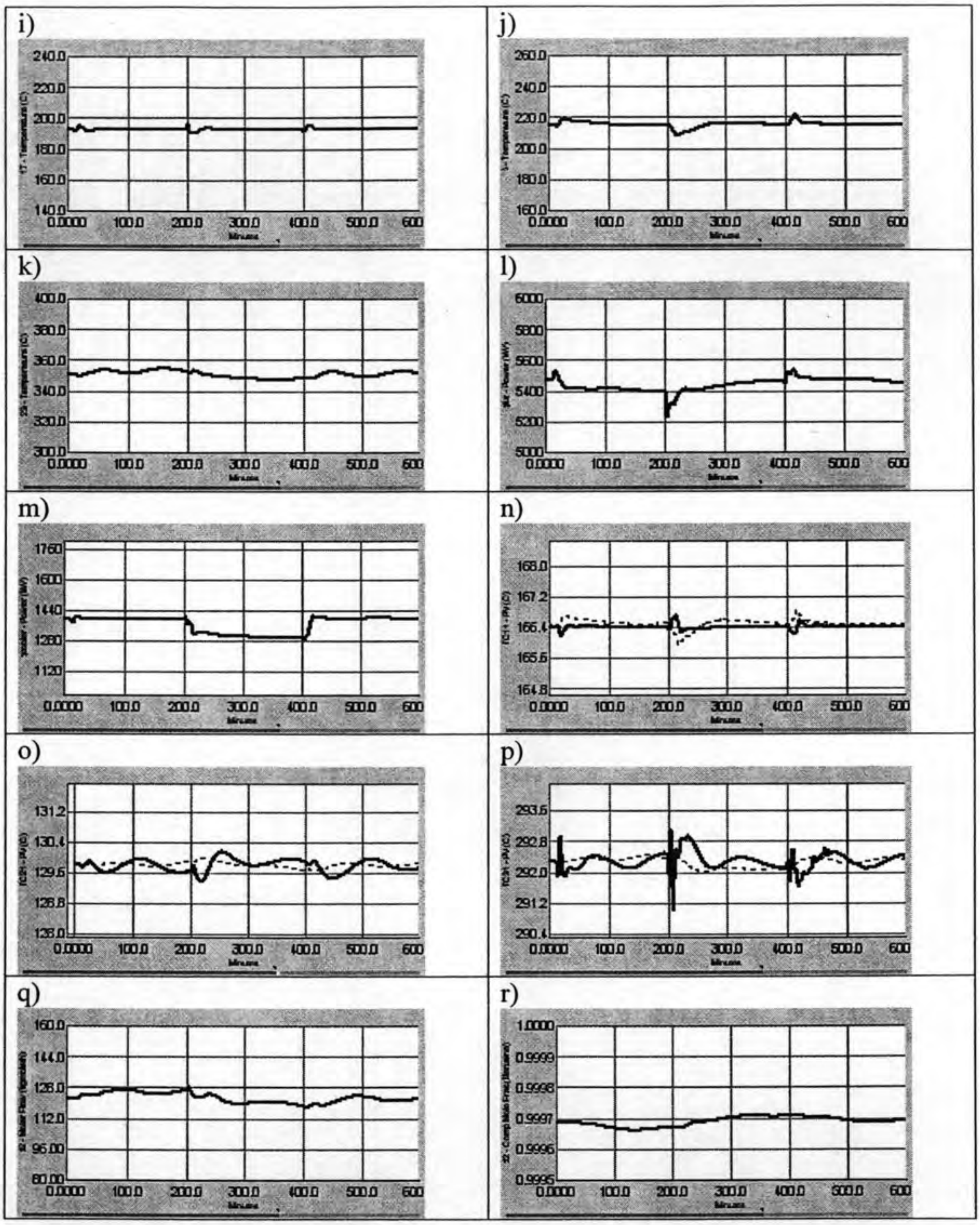

Figure 6.68 (continue)

6.18 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN3) with minimum Auxiliary Utility Units: CS1

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.69 to 6.71. Results for individual disturbance load changes are as follows:

6.18.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.69 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS1 are similar to the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.69.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.69.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.69.p).

6.18.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.70 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN2 with CS1 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.70.n and o).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.70.c,d and p).

6.18.3 Change in the Total Toluene Feed Flow rate

Figure 6.71 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.71.d).A small oscillation of 3°C happens in the product column (Figure6.71.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.71.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.71.p).

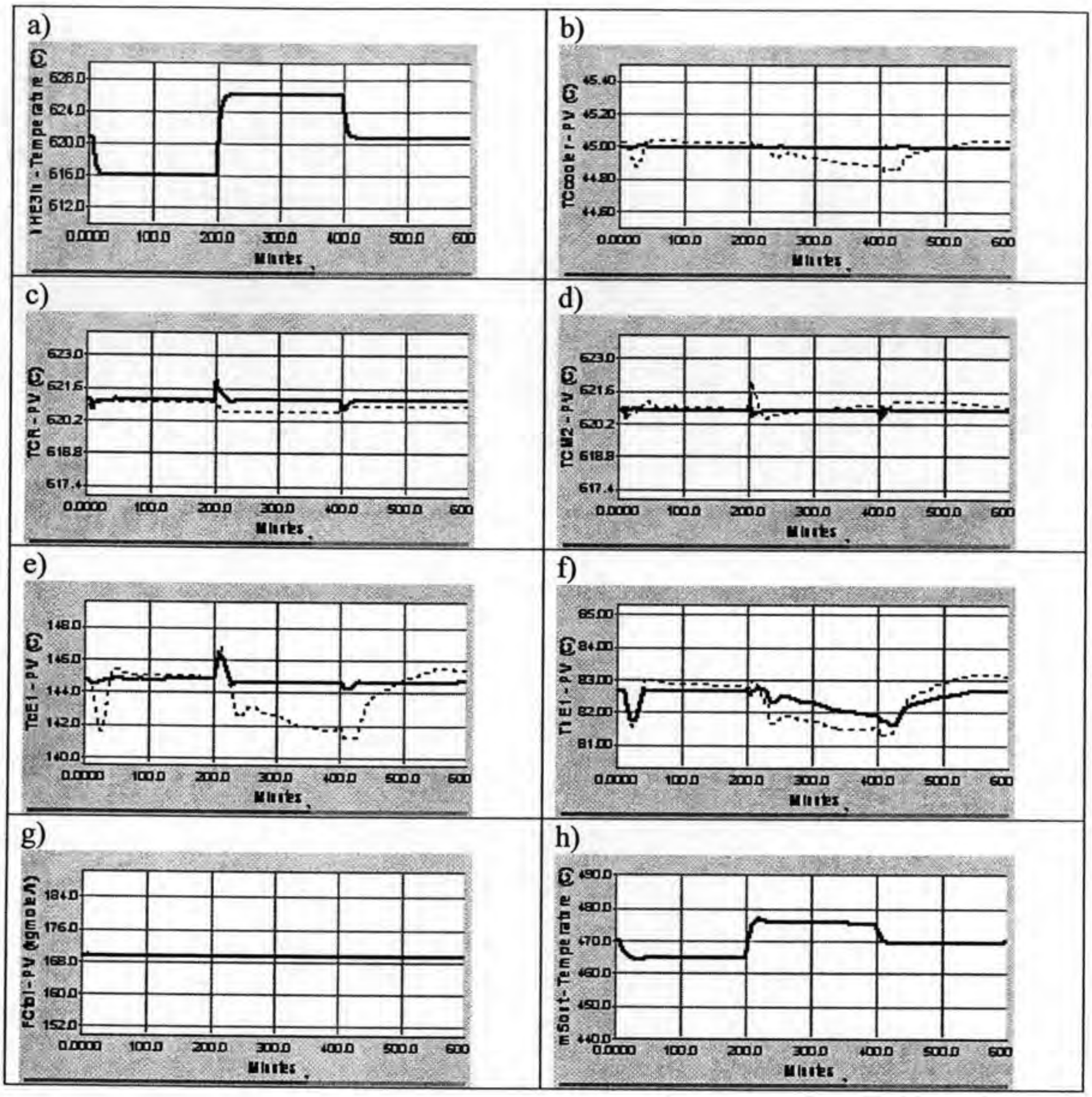

Figure 6.69 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS1, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

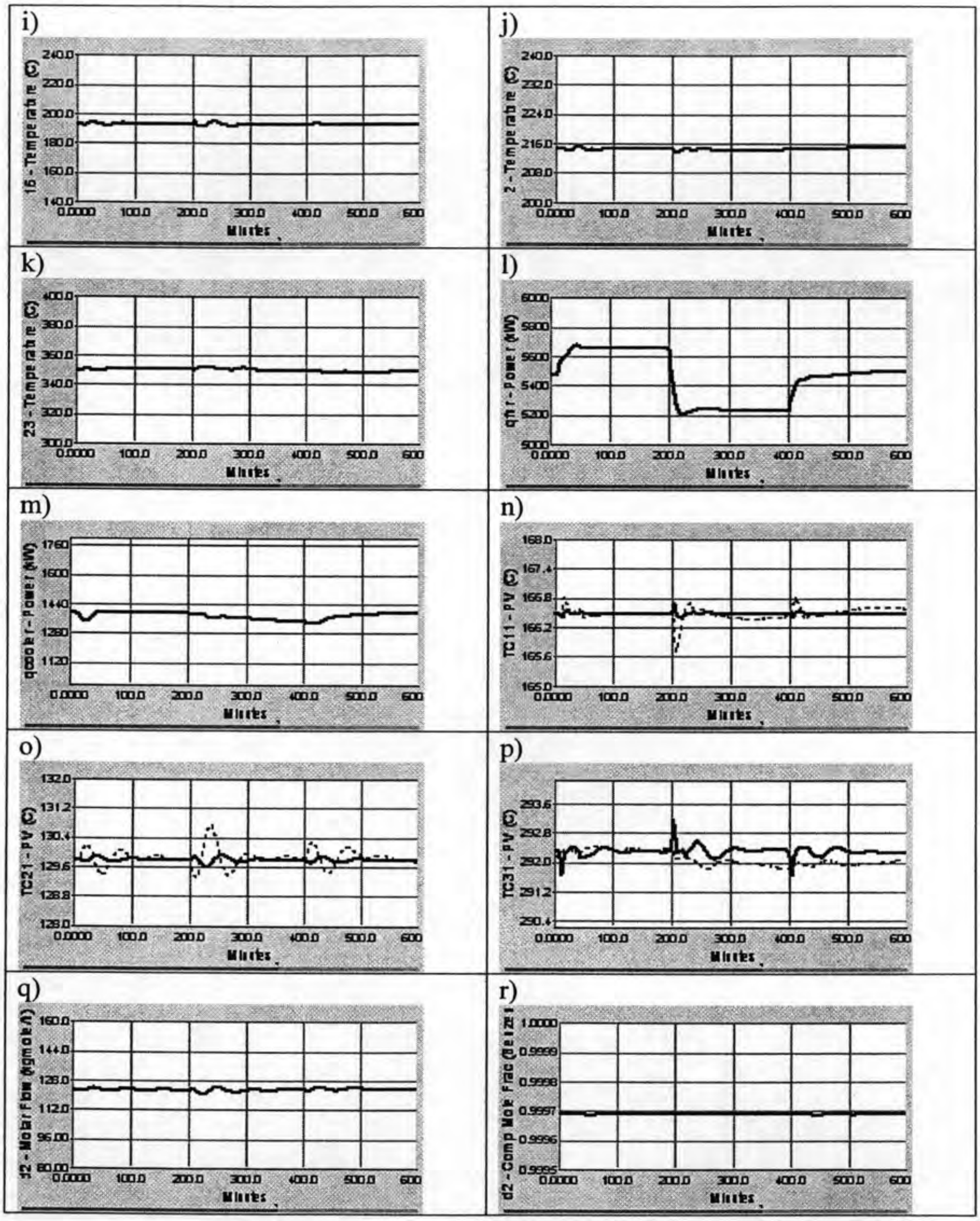

Figure 6.69 (continue)

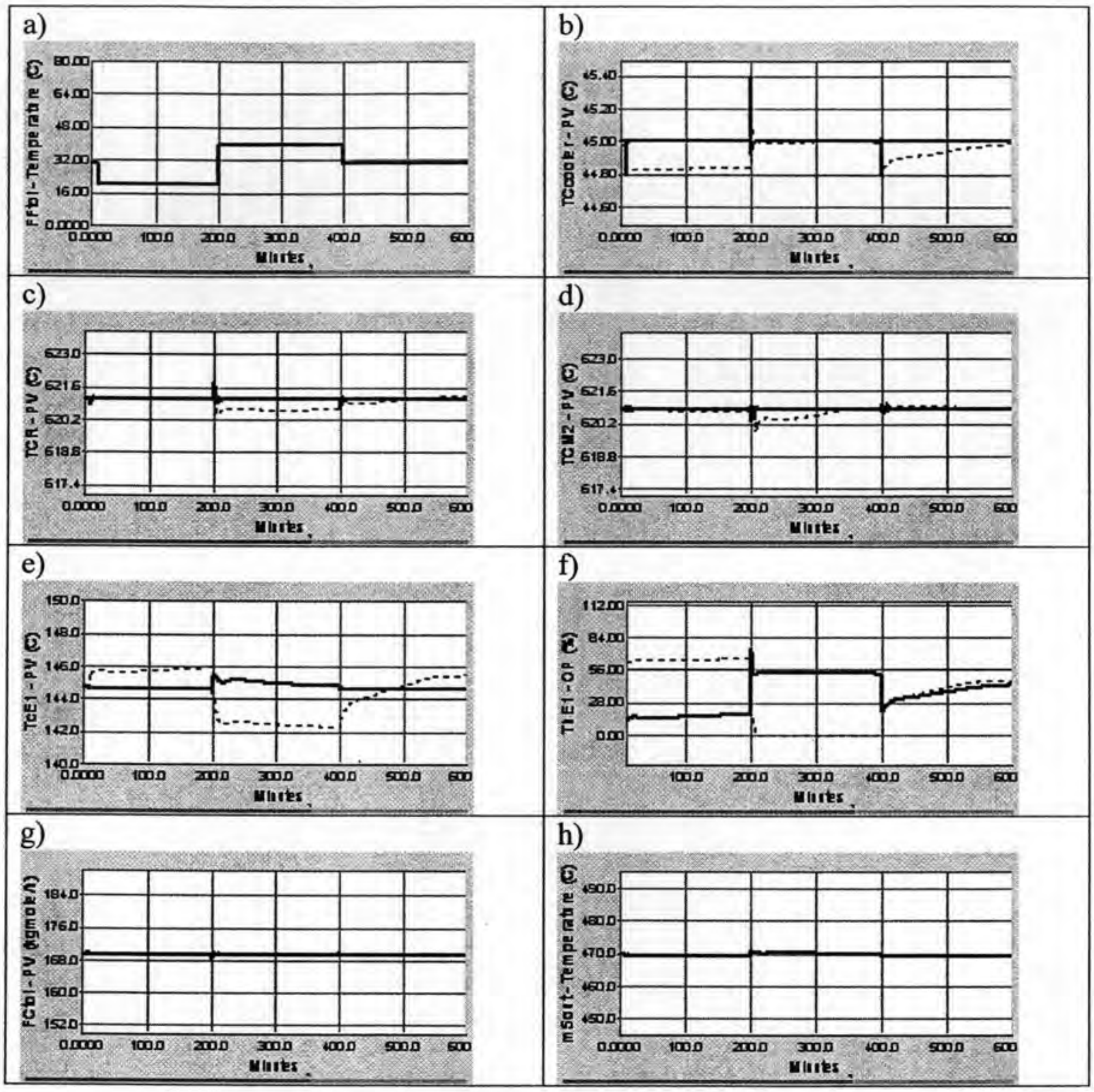

Figure 6.70 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS1, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ⋯⋯ Manipulated variable)

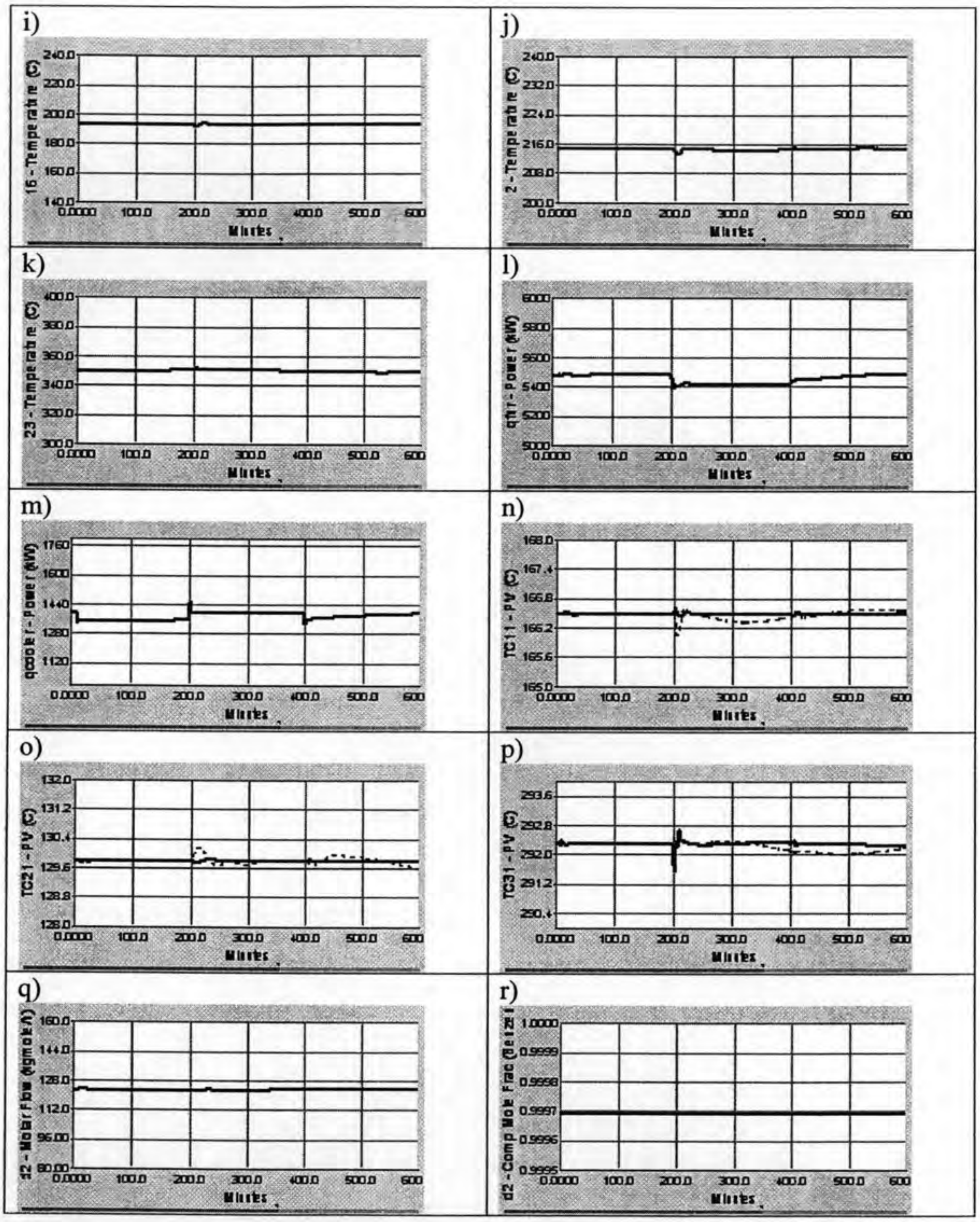

Figure 6.70 (continue)

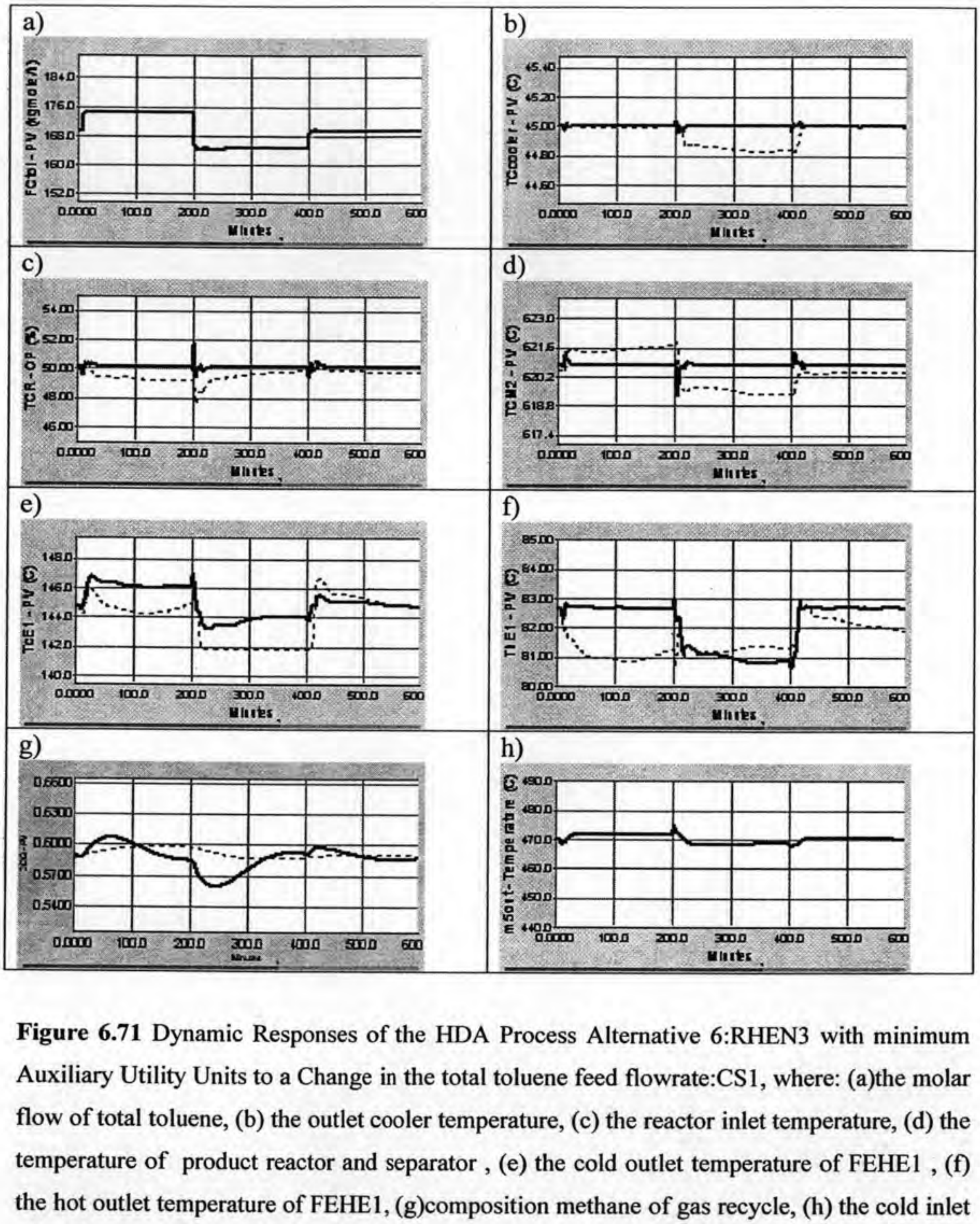

Figure 6.71 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS1, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

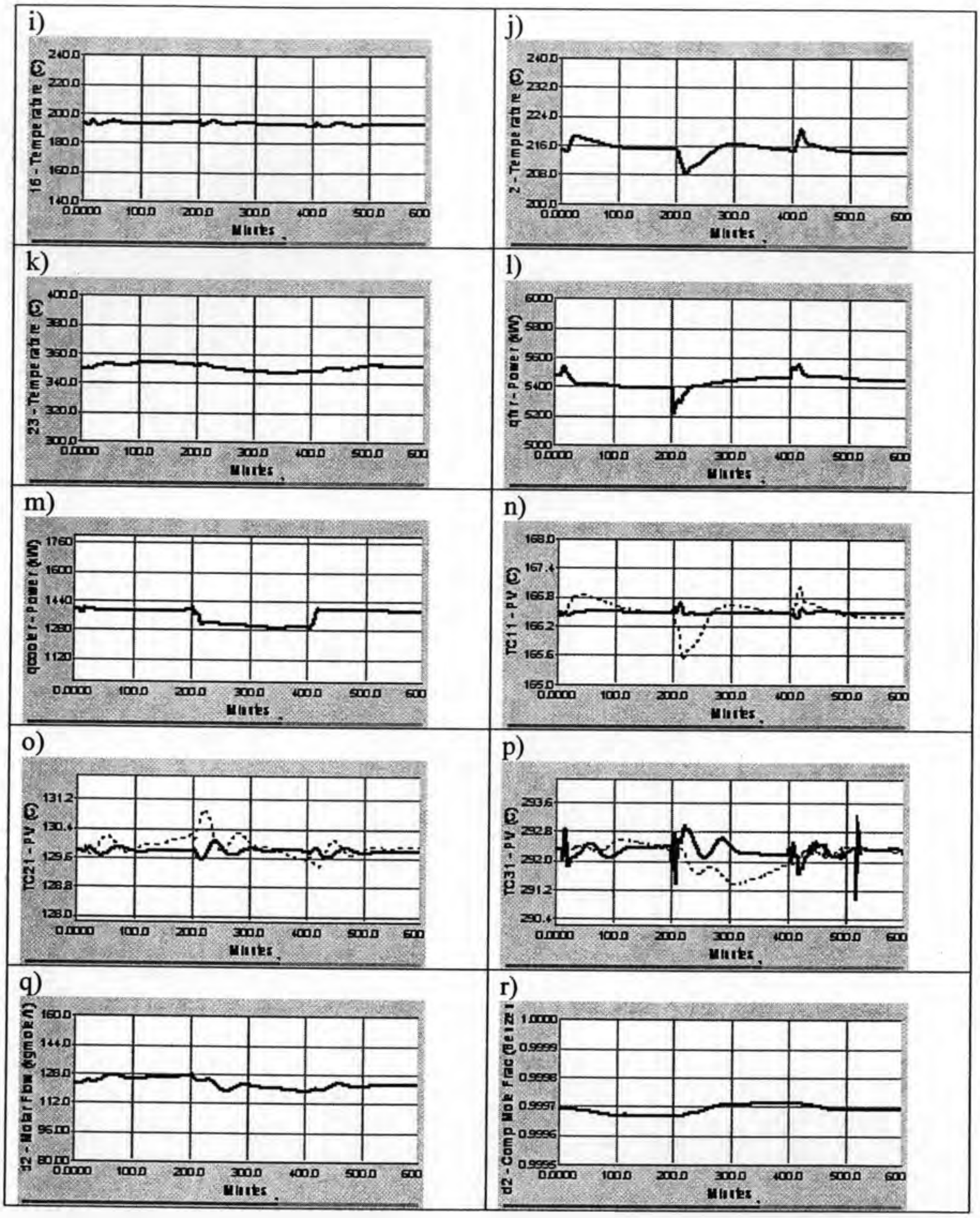

Figure 6.71 (continue)

6.19 Dynamic Simulation Results for HDA Process Alternative6 (RHEN3) with minimum Auxiliary Utility Units: CS2

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.72 to 6.74. Results for individual disturbance load changes are as follows

6.19.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.72 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS2 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.72.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.72.n and o). The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.72.p). The oscillations occur in the molar flow of the benzene (Figure 6.72.q).

6.19.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.73 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS2 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.73.d and c). A deviation of 5°C happens in the tray temperature of the recycle column and it takes over 500 minutes to return to its nominal value of 290.3°C (Figure 6.73.p) and the oscillations occur in the molar flow of the benzene (Figure 6.73.q).

6.19.3 Change in the Total Toluene Feed Flow rate

Figure 6.74 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.74.d).A small oscillation of 3°C happens in the product column (Figure6.74.o) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.74.n). The tray temperature of the recycle column has a small deviation about 2°C and it takes over 500 minutes to return to its nominal value (Figure6.74.p). The oscillations occur in the molar flow of the benzene (Figure 6.74.q).

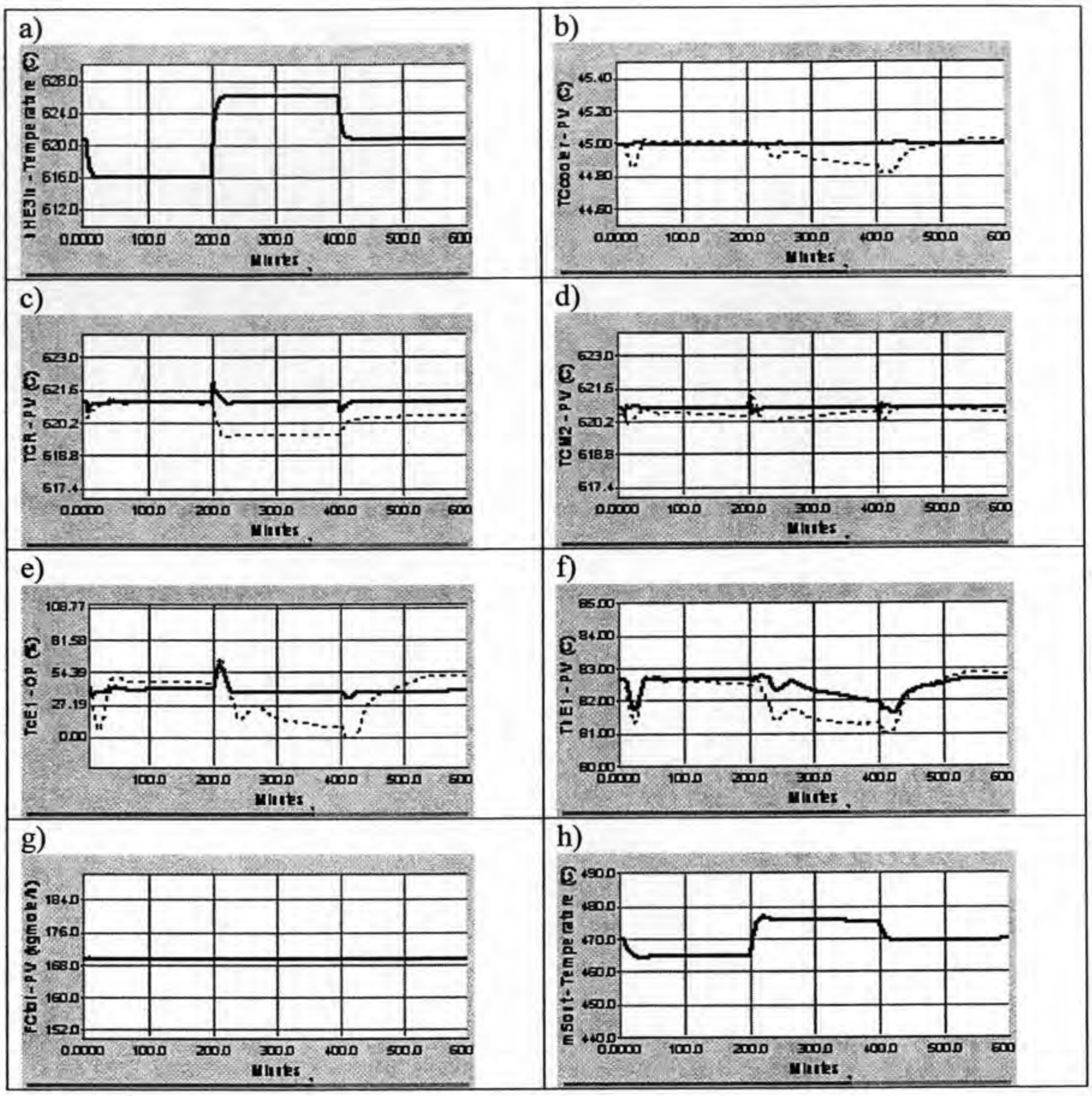

Figure 6.72 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS2, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ━━ Process variable (PV) , ······ Manipulated variable)

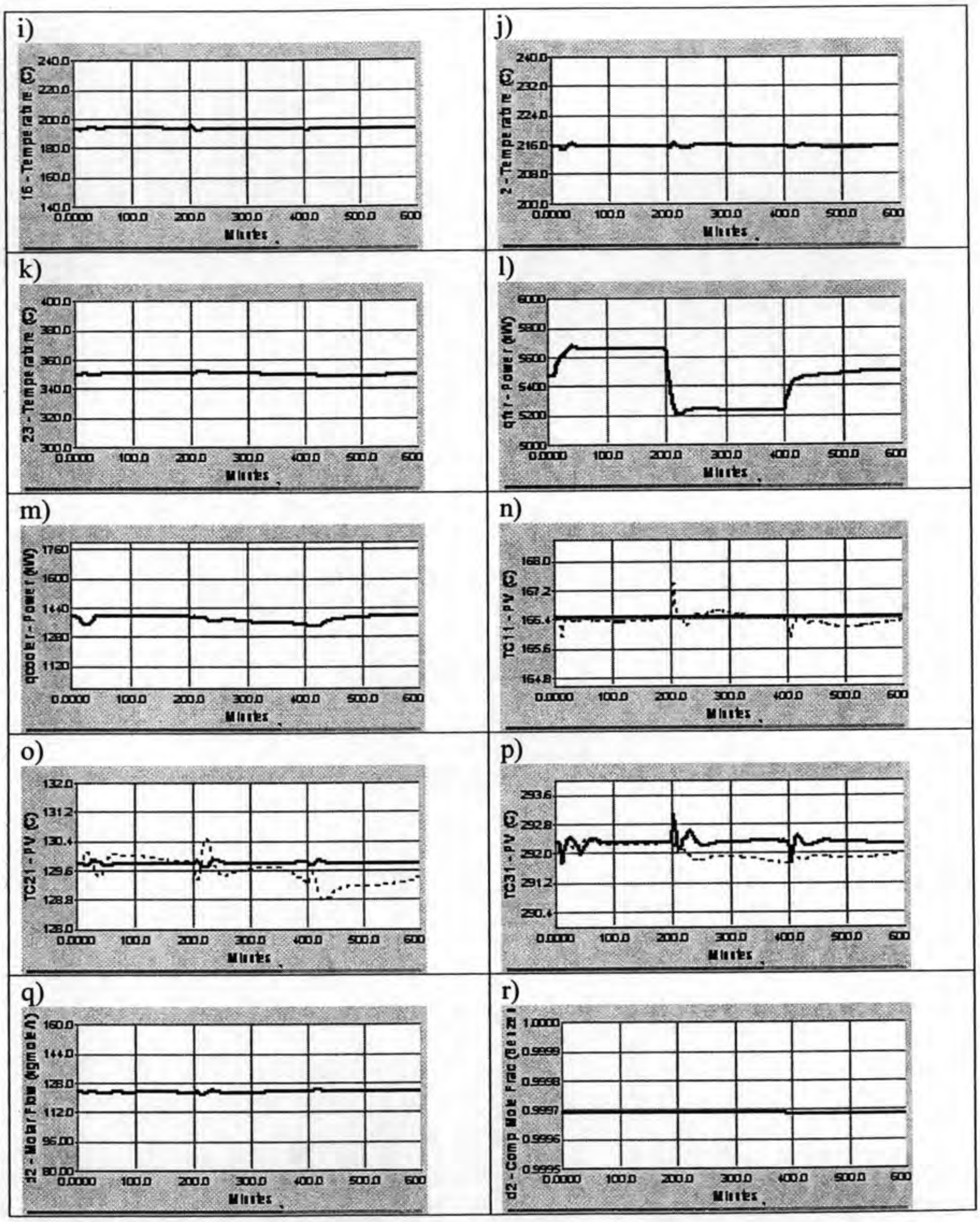

Figure 6.72 (continue)

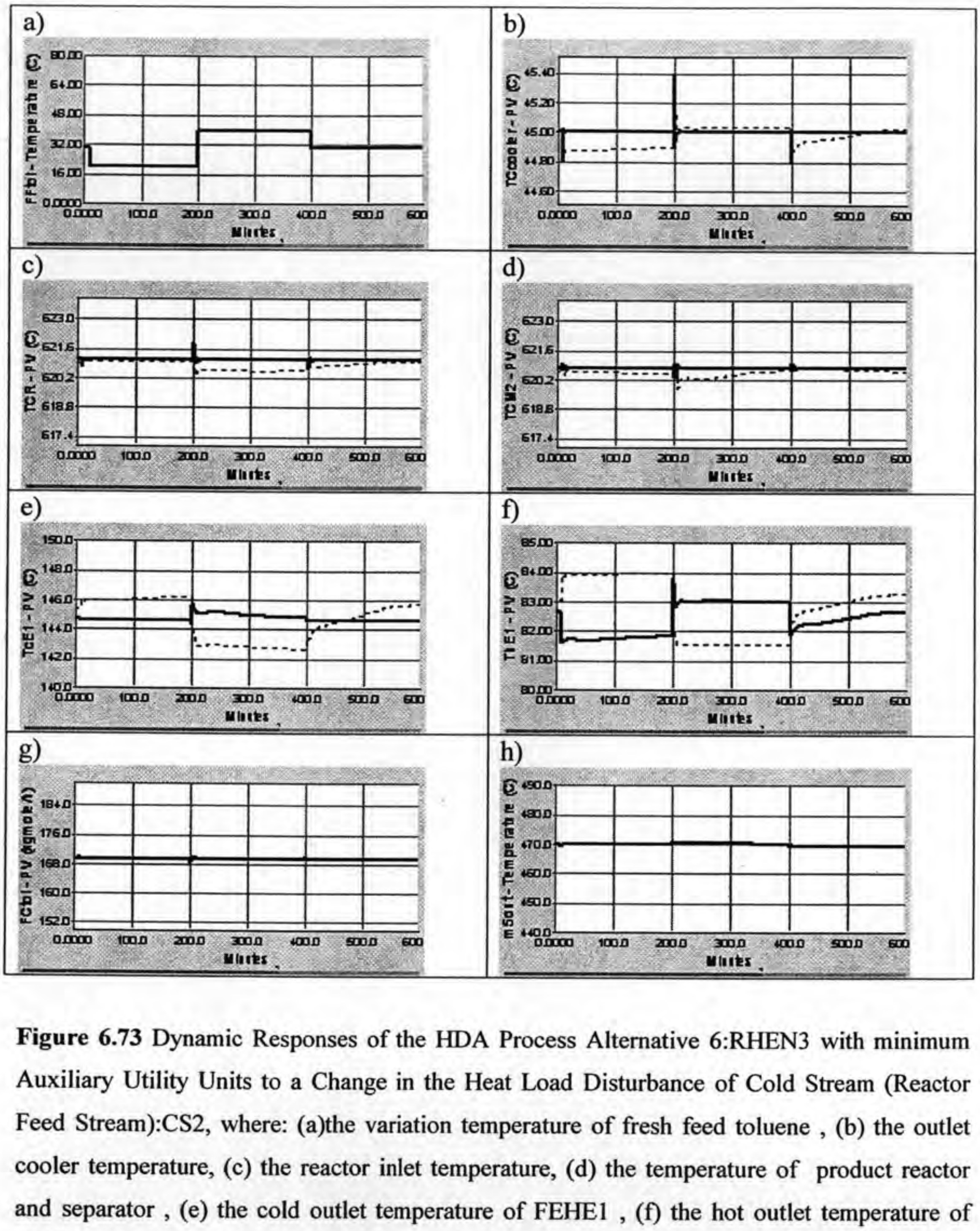

Figure 6.73 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS2, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

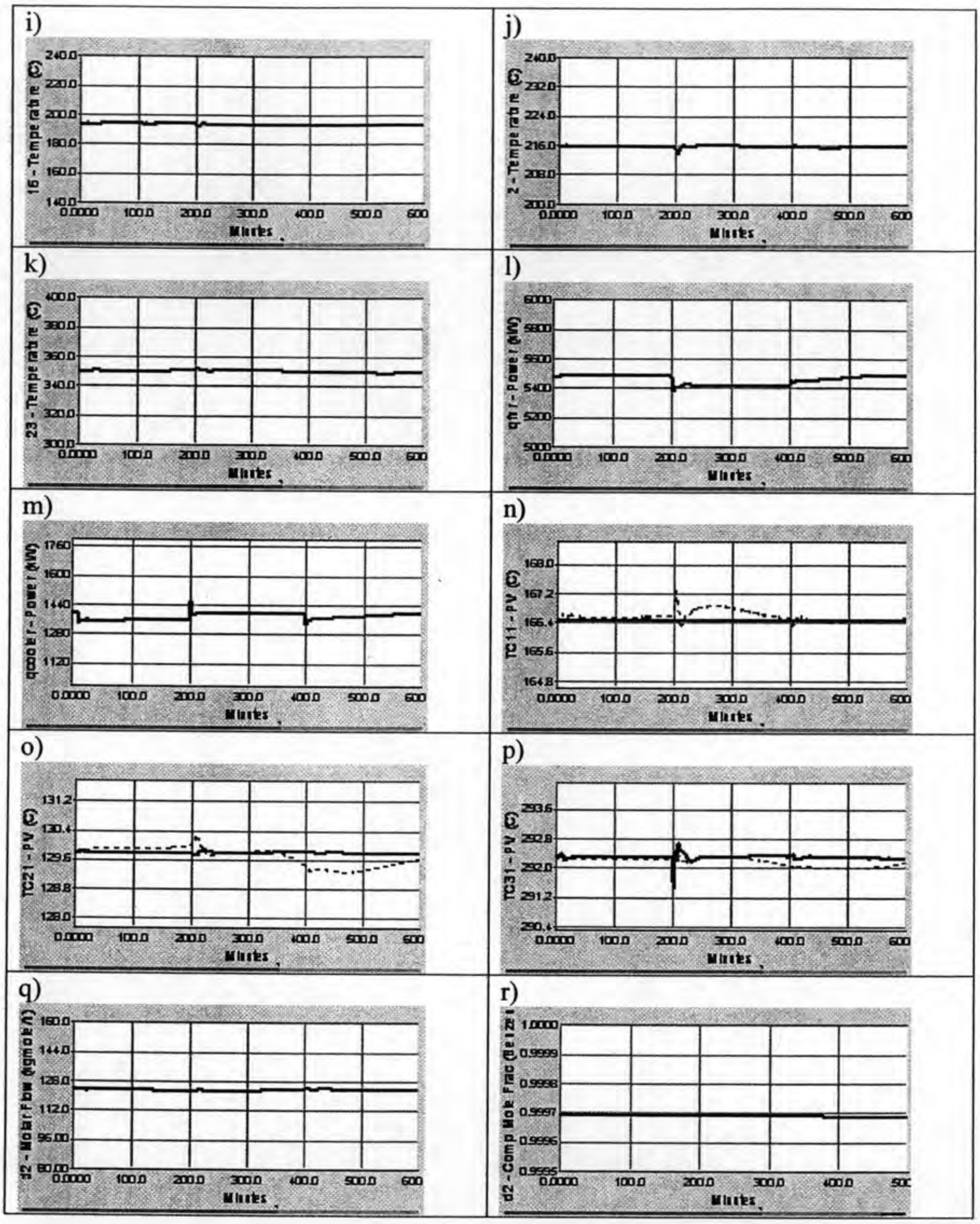

Figure 6.73 (continue)

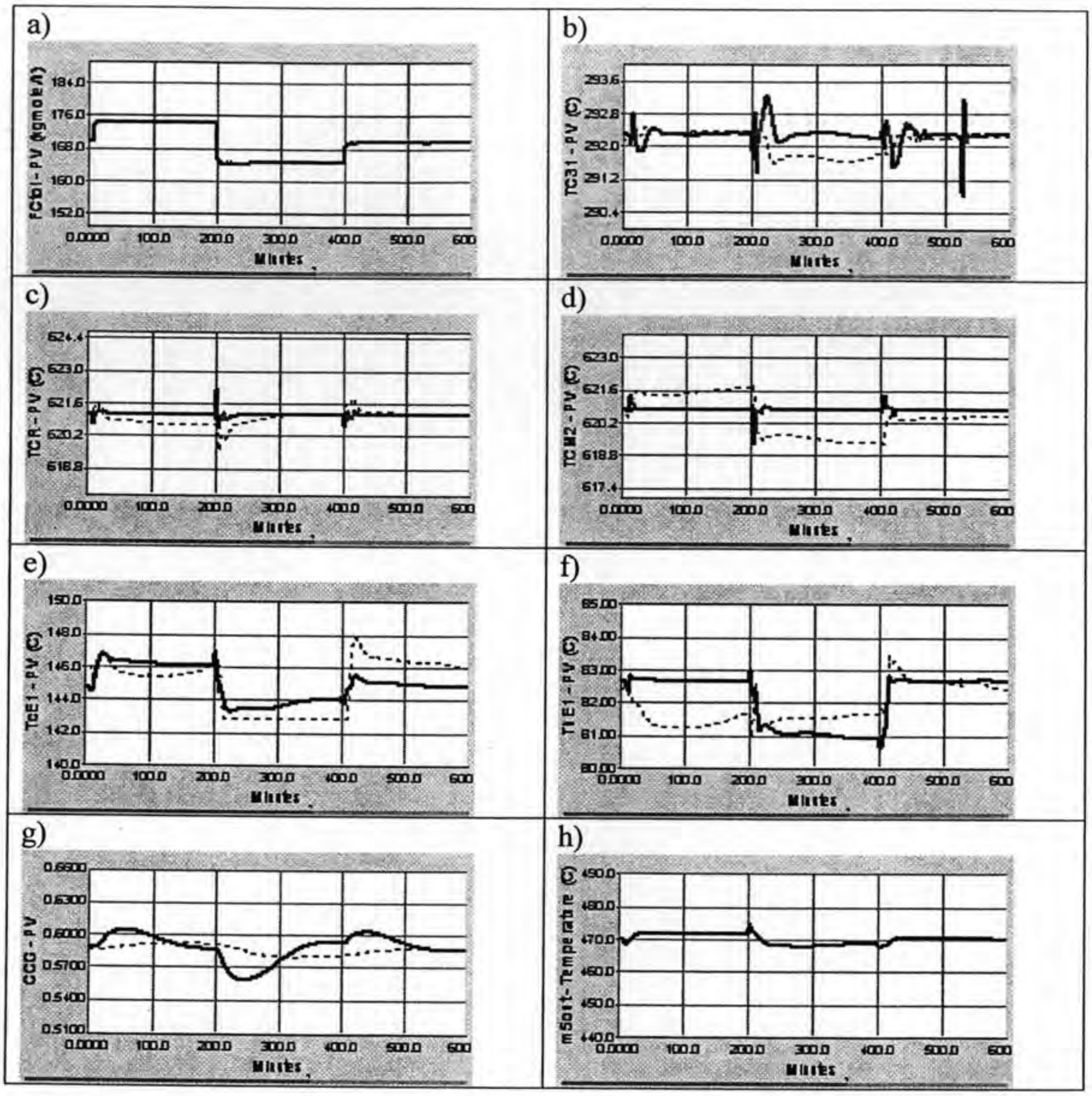

Figure 6.74 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS2, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

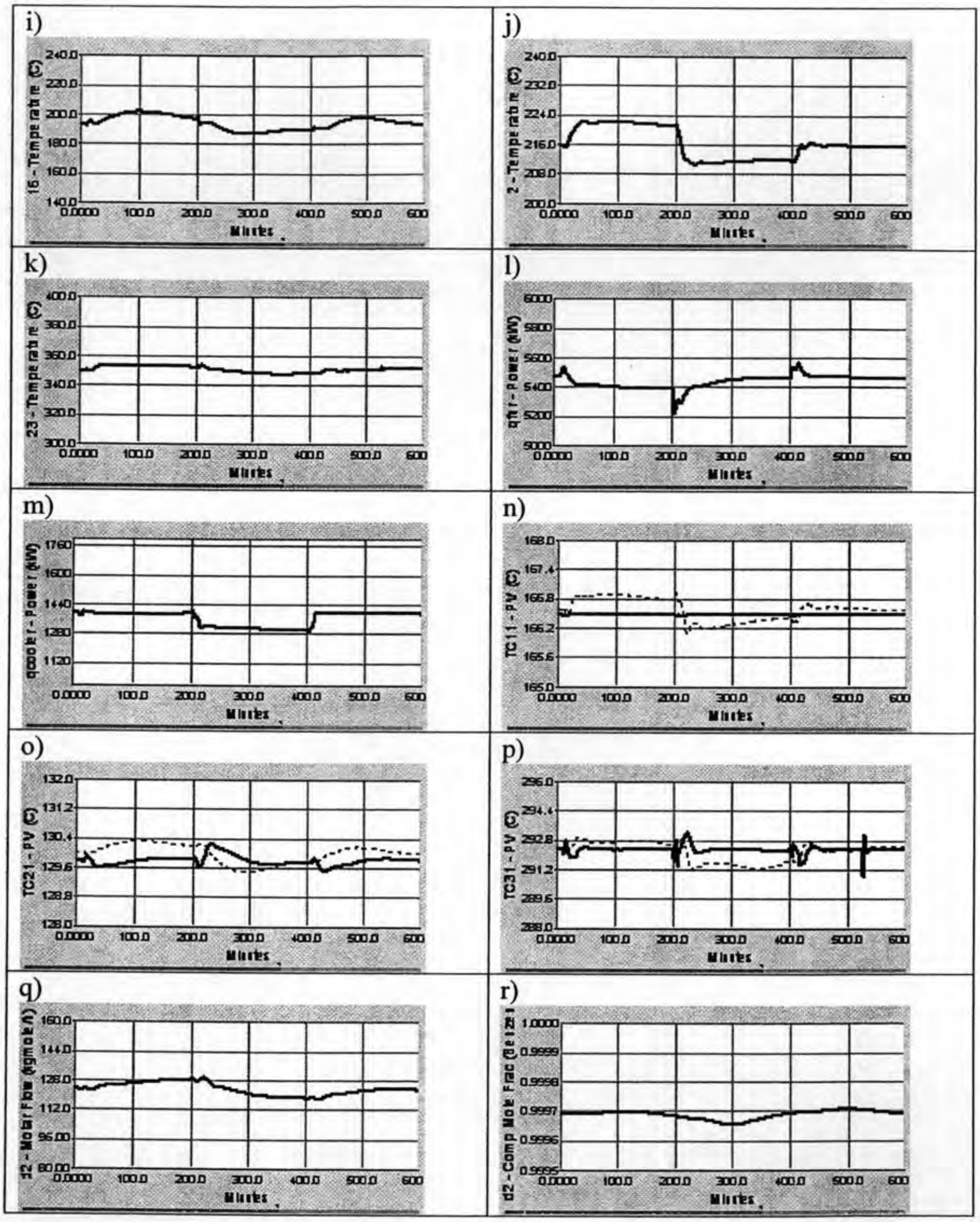

Figure 6.74 (continue)

6.20 Dynamic Simulation Results for HDA Process Alternative 6 (RHEN3) with minimum Auxiliary Utility Units: CS3

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.75 to 6.77. Results for individual disturbance load changes are as follows:

6.20.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.75 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS3 are better than the previous CS1of Basecase i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.75.c and d), the oscillations occur in the tray temperature of the stabilizer and the product column (Figure 6.75n, o and p).Its advantages is that it provides higher performance of the tray temperature control in the product column, since there are two point controls in the product column. The tray temperature in the recycle column has a small oscillation and it takes more than 500 minutes to come back to setpoint (Figure6.75.q).

6.20.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.76 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh

toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes, and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

As can be seen, the dynamic responses of the RHEN1 with CS3 are similar that of the basecase with CS1. Particularly, the tray temperature in the product column and the stabilizer column are well controlled (Figure 6.76.n, o and p), since there are two tray temperature controls in the product column (One is the tray-12 temperature control and the other is tray-18 temperature control).For the other dynamic responses, they are similar to the previous basecase.The small oscillations occur in the reactor inlet temperature, the separator temperature and the tray temperature of recycle column (Figure6.76.c,d and q).

6.20.3 Change in the Total Toluene Feed Flow rate

Figure 6.77 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are better than that of the Basecase. As can be seen, the separator temperature is quite well controlled (Figure 6.77.d).A small oscillation of 3°C happens in the product column (Figure6.77.o and p) but a slightly well controlled occurs in the tray temperature of the stabilizer column (Figure6.77.n). The tray temperature of the recycle column has a small deviation about 4°C and it takes over 550 minutes to return to its nominal value (Figure6.77.q).

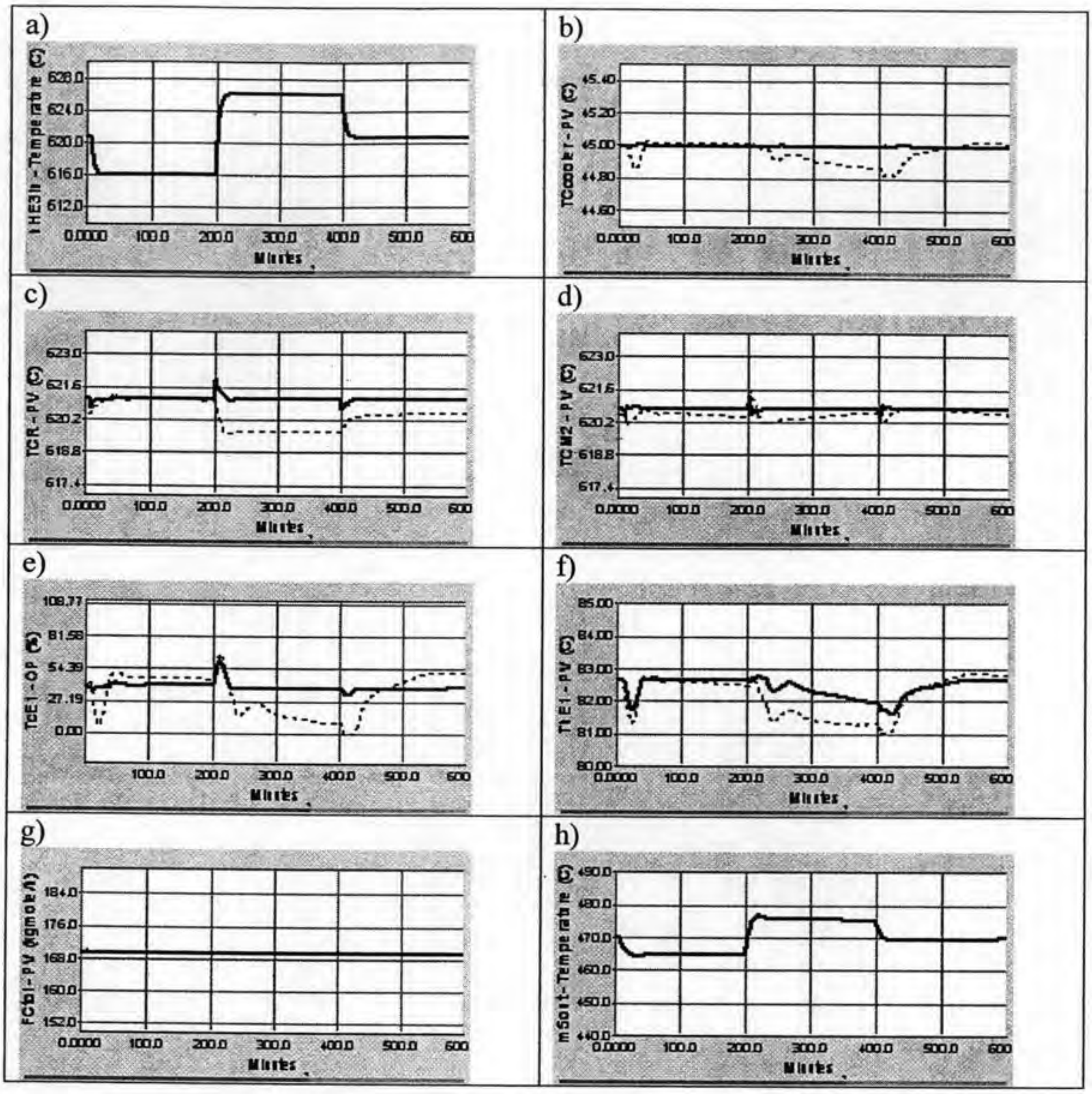

Figure 6.75 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS3, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene of product column

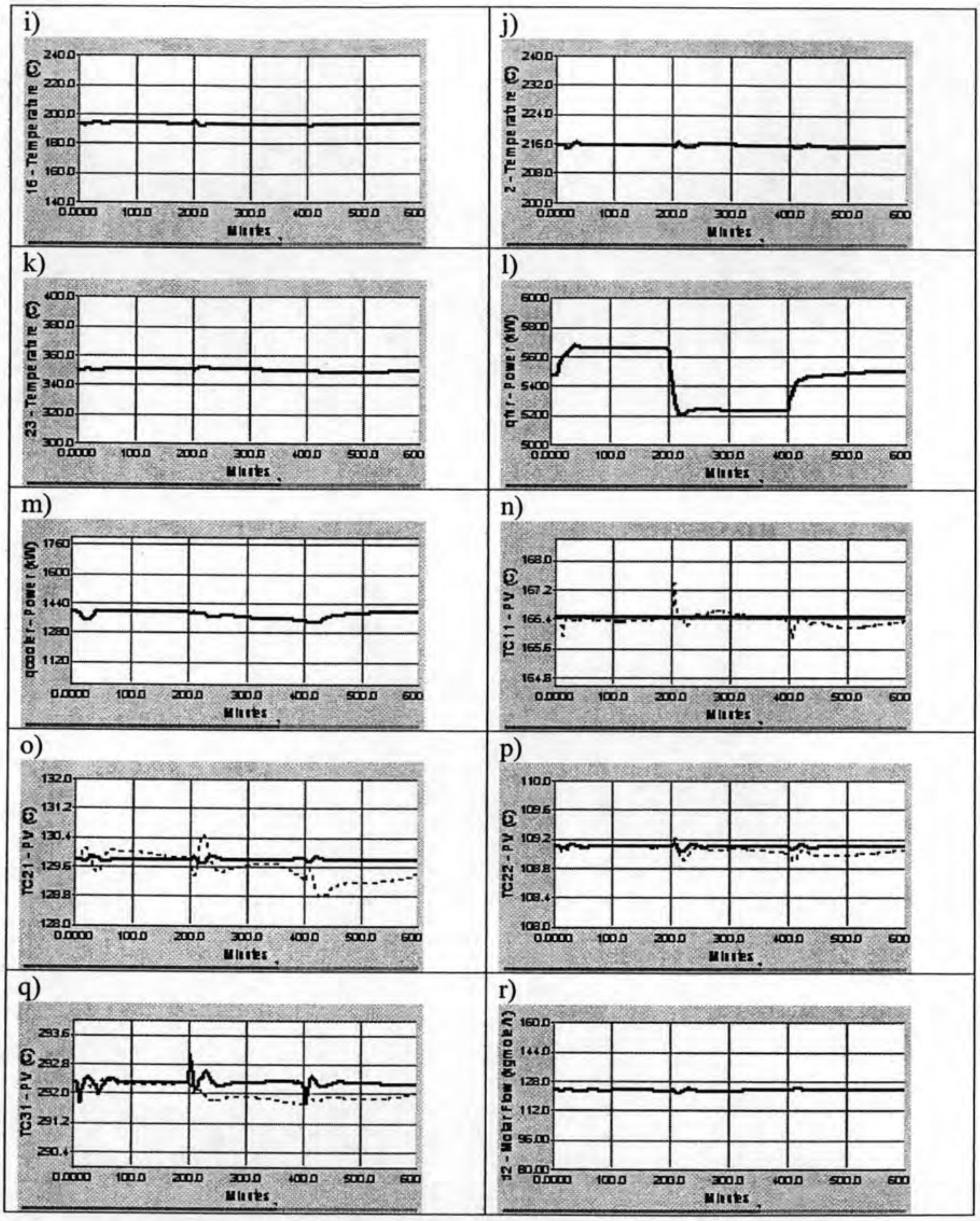

Figure 6.75 (continue)

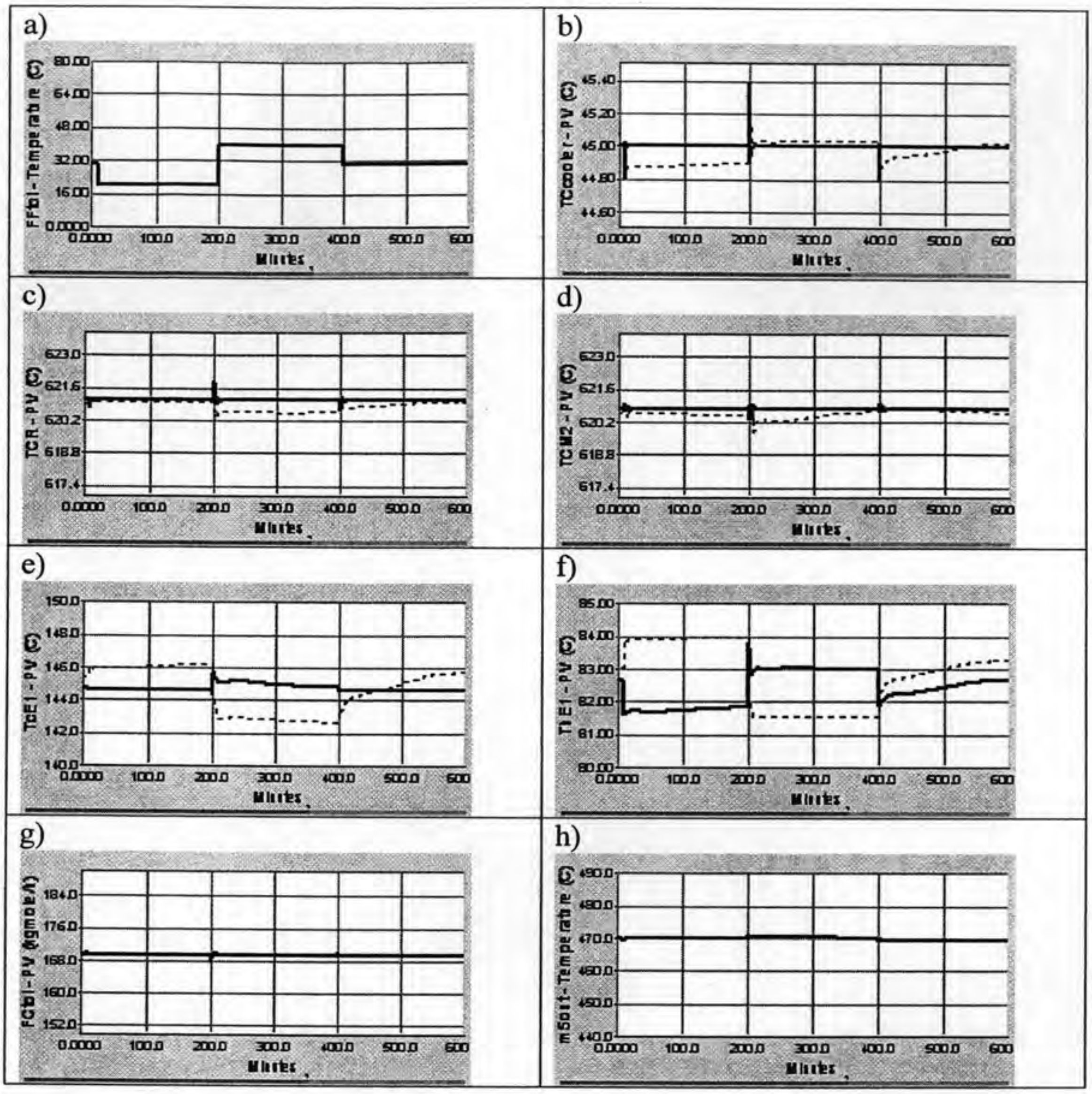

Figure 6.76 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS3, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ——— Process variable (PV) , ······ Manipulated variable)

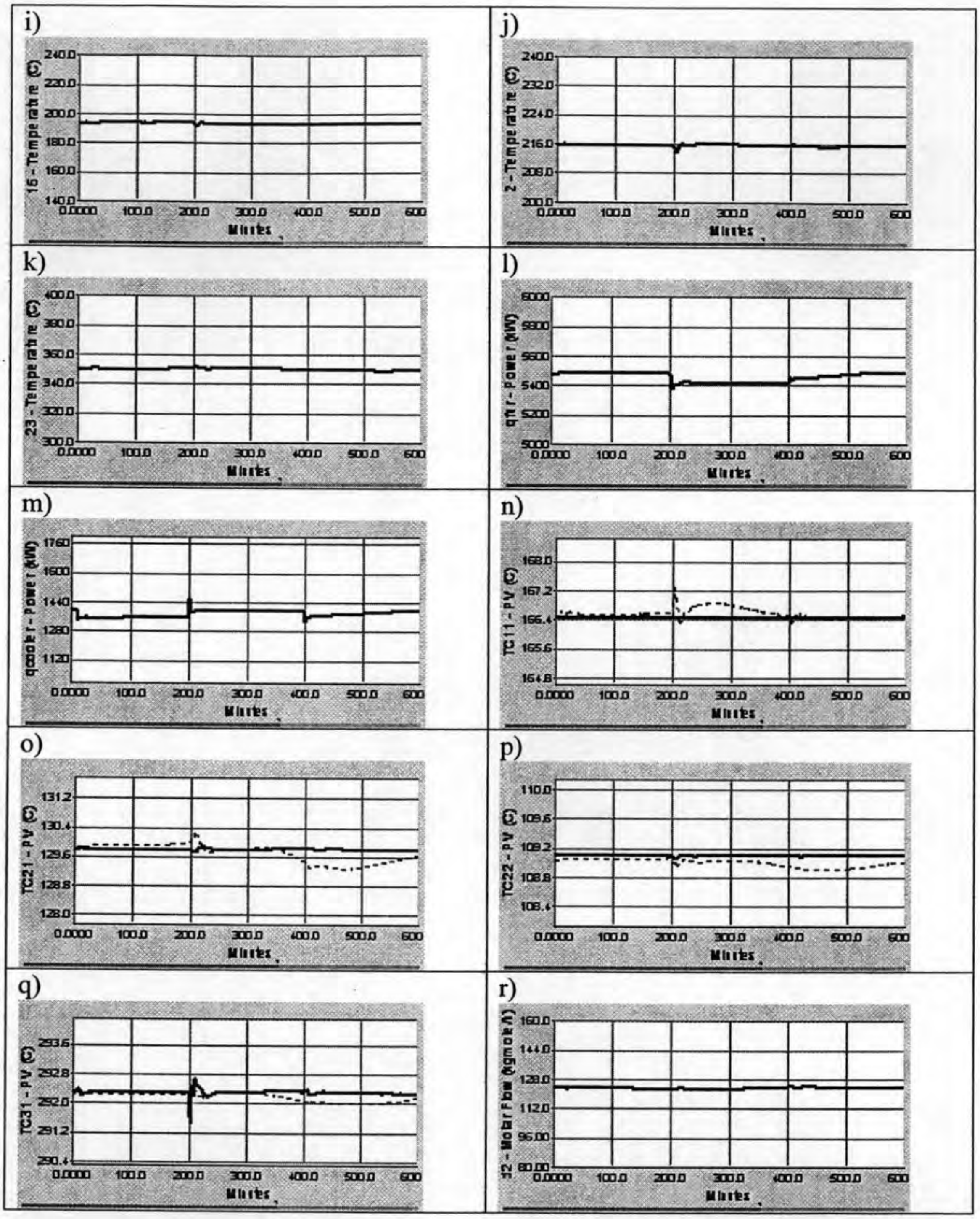

Figure 6.76 (continue)

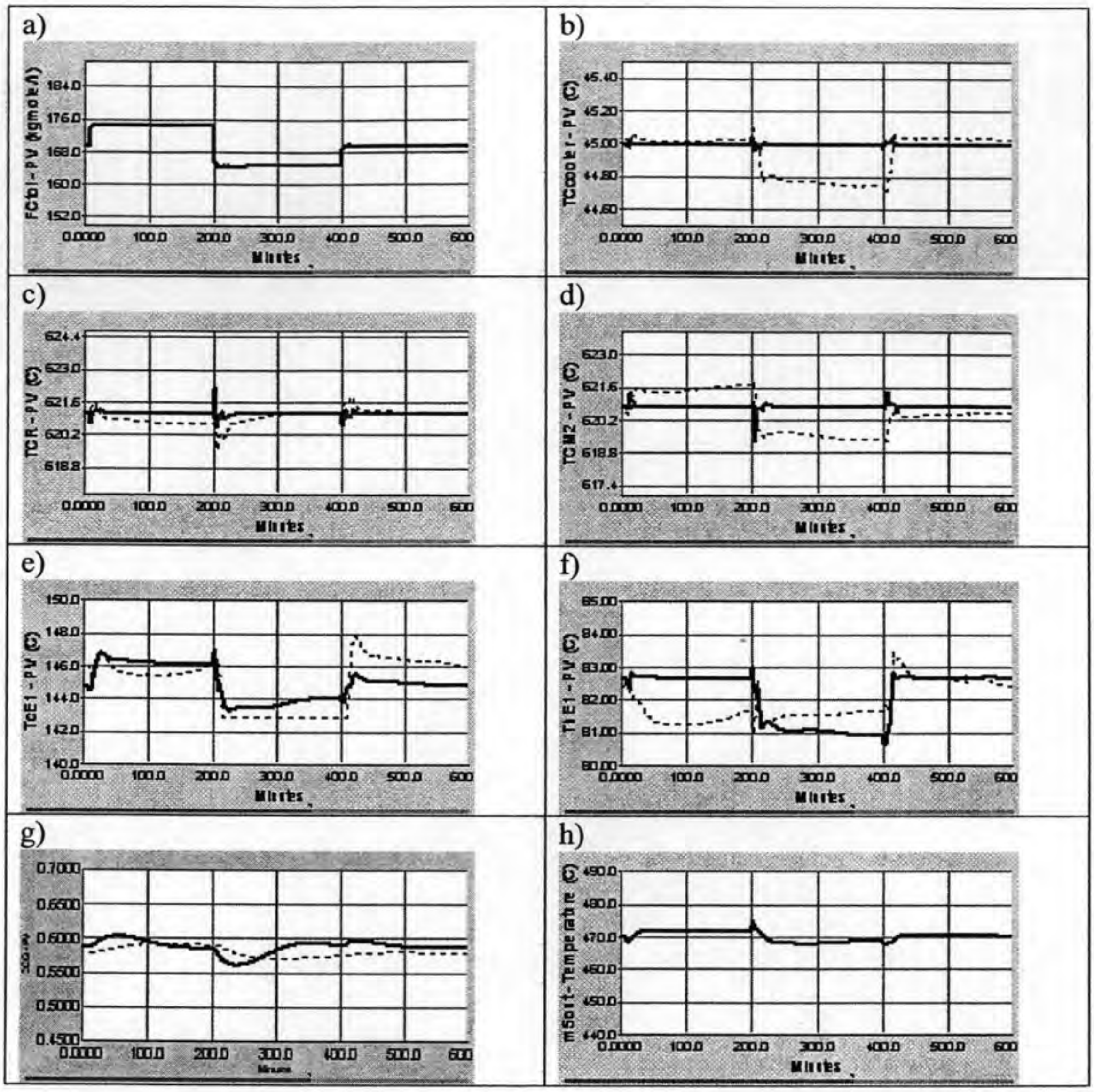

Figure 6.77 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS3, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature1,(p) product column tray temperature2,(q) recycle column tray temperature,(r) molar flow benzene

(Note. ▬▬ Process variable (PV) , ‥‥‥ Manipulated variable)

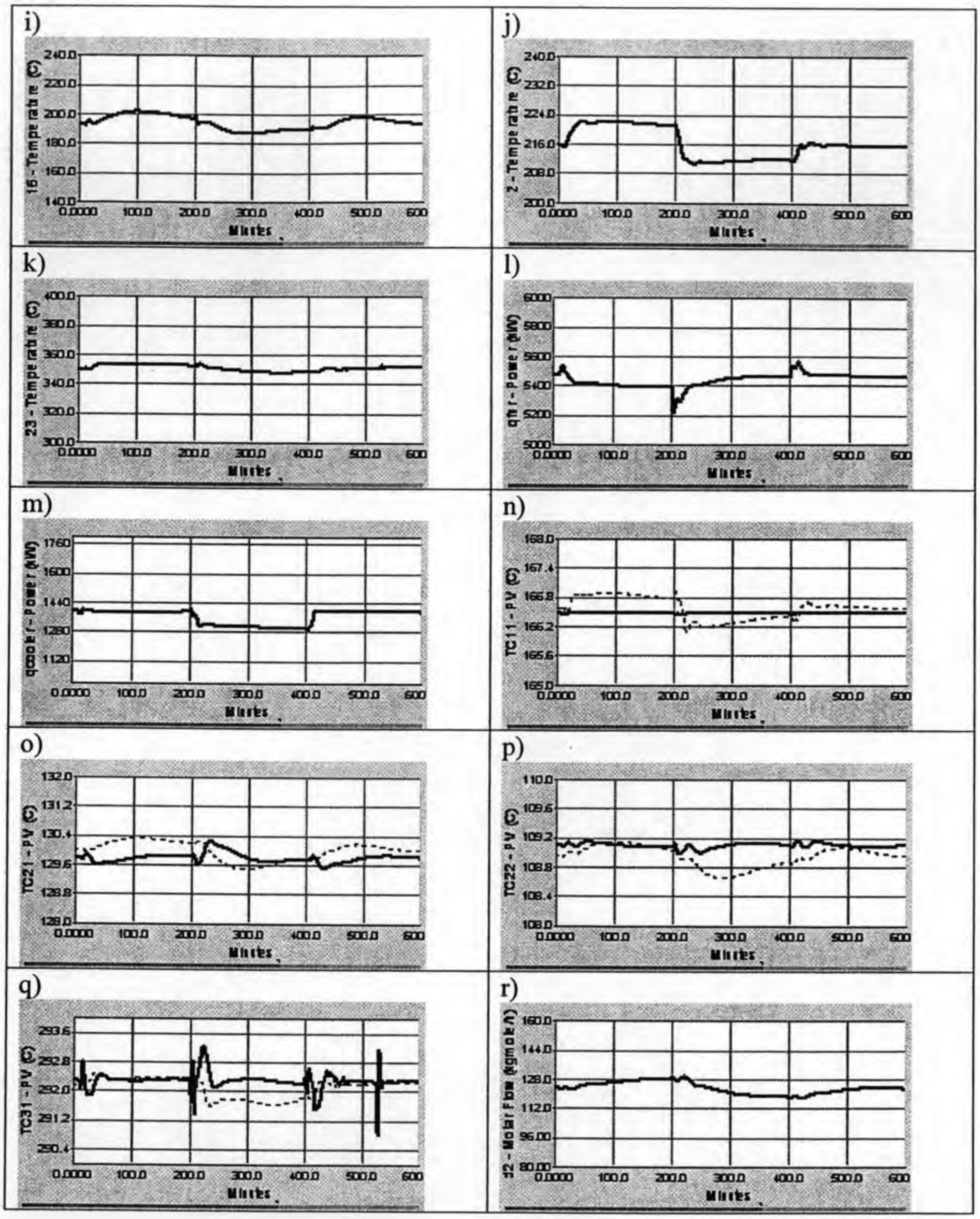

Figure 6.77 (continue)

6.21 Dynamic Simulation Results for HDA Process Alternative6 (RHEN3) with minimum Auxiliary Utility Units: CS4

In order to illustrate the dynamic behavior of the control structure in HDA process, several disturbance loads are made. The dynamic responses of the control system are shown in Figures 6.78 to 6.80. Results for individual disturbance load changes are as follows

6.21.1 Change in the Disturbance Load of Hot Stream (Reactor Product)

Figure 6.78 shows the dynamic responses of HDA process to a change in the disturbance load of hot stream from reactor, by changing its temperature from 620.8°C to 616°C at time equals 10 minutes, and the its temperature is increased from 616°C to 626°C at time equals 200 minutes, then its temperature is returned to its nominal value of 620.8°C at time equals 400 minutes.

As can be seen, the most dynamic responses of the CS4 are worse than the previous CS1 i.e. the separator temperature and the reactor inlet temperature are well controlled (Figure 6.78.c and d), the oscillations occur about 5°C in the tray temperature of the stabilizer and the product column (Figure 6.78.n and o). The tray temperature in the recycle column has a large oscillation and it takes more than 800 minutes to come back to setpoint (Figure6.78.p). The oscillations occur in the molar flow of the benzene (Figure 6.78.q).

6.21.2 Change in the Disturbance Load of Cold Stream (Reactor Feed Stream)

Figure 6.79 shows the dynamic responses to a change in the disturbance load of cold stream (reactor feed stream). This disturbance is made as follows: first the fresh toluene feed temperature is decreased from 30°C to 20°C at time equals 10 minutes,

and the temperature is increased from 20°C to 40°C at time equals 200 minutes, then its temperature is returned to its nominal value of 30°C at time equals 400 minutes.

The dynamic responses of the CS4 are worse than CS1 during the change in the disturbance load of the cold stream occurs. The separator temperature, the reactor inlet temperature are quite well controlled (Figure 6.79.d and c). A deviation of 6°C happens in the tray temperature of the recycle column and it takes over 800 minutes to return to its nominal value of 290.3°C (Figure 6.79.p) and the oscillations occur in the molar flow of the benzene (Figure 6.79.q).

6.21.3 Change in the Total Toluene Feed Flow rate

Figure 6.80 shows the dynamic responses of HDA process to a change in the total toluene feed flowrates from 169.3 kgmole/hr to 174.3 kgmole/hr at time equals 10 minutes, and the its feed flowrate is decreased from 174.3 kgmole/hr to 164.3 kgmole/hr at time equals 200 minutes, then its flowrates is returned to its nominal value of 169.3 kgmole/hr at time equals 400 minutes.

The dynamic responses of this control structure are worse than that of the CS1. As can be seen, the separator temperature is quite well controlled (Figure 6.80.d).A small oscillation of 3°C happens in the product column (Figure6.80.o), Also a slightly worse controlled occurs in the tray temperature of the stabilizer column (Figure6.80.n). The tray temperature of the recycle column has a large deviation about 20°C and it takes over 900 minutes to return to its nominal value (Figure6.80.p). The oscillations occur in the molar flow of the benzene (Figure 6.80.q).

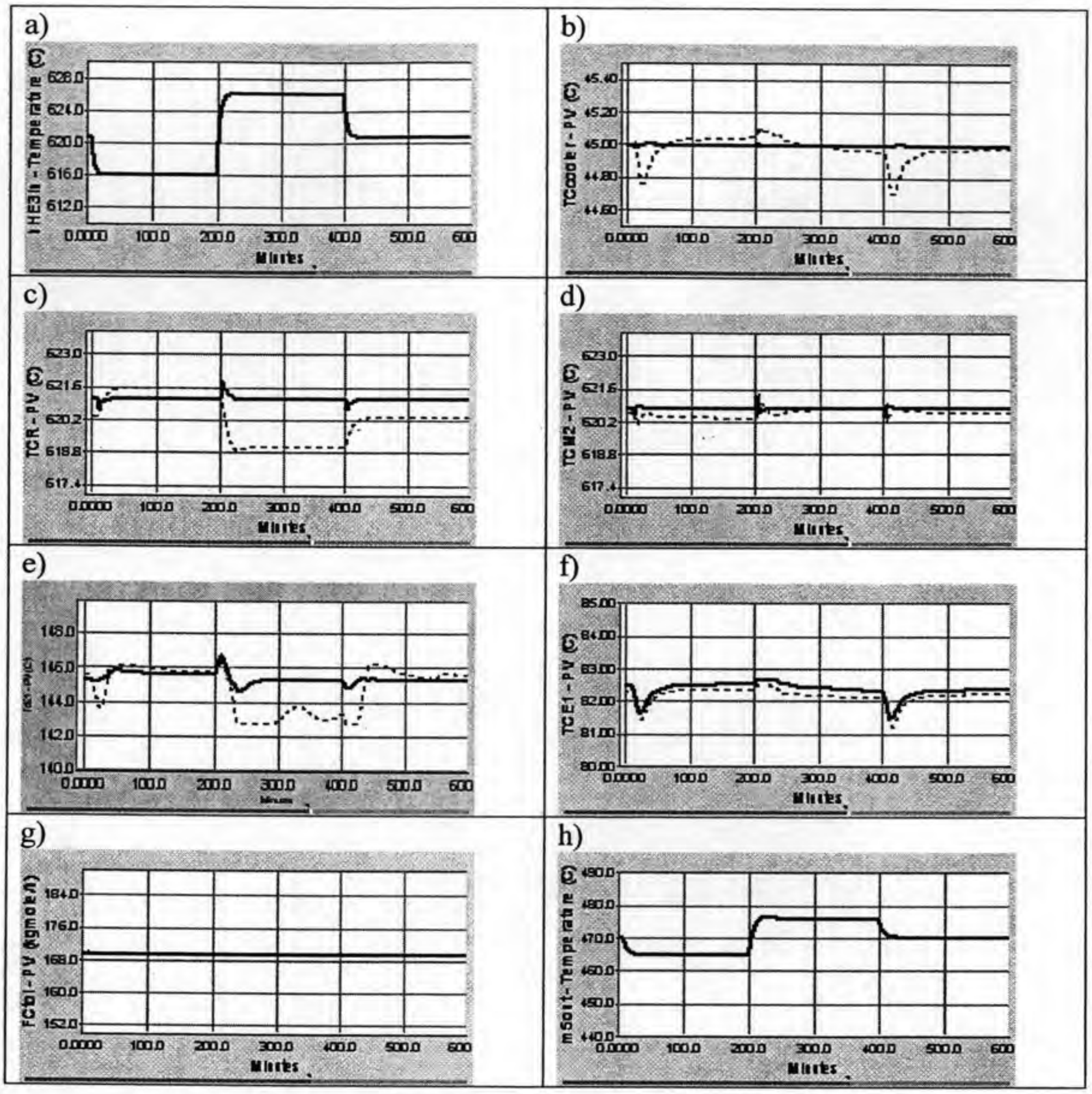

Figure 6.78 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Hot Stream (Reactor Product Stream):CS4, where: (a)the variation hot outlet temperature of reactor , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ······ Manipulated variable)

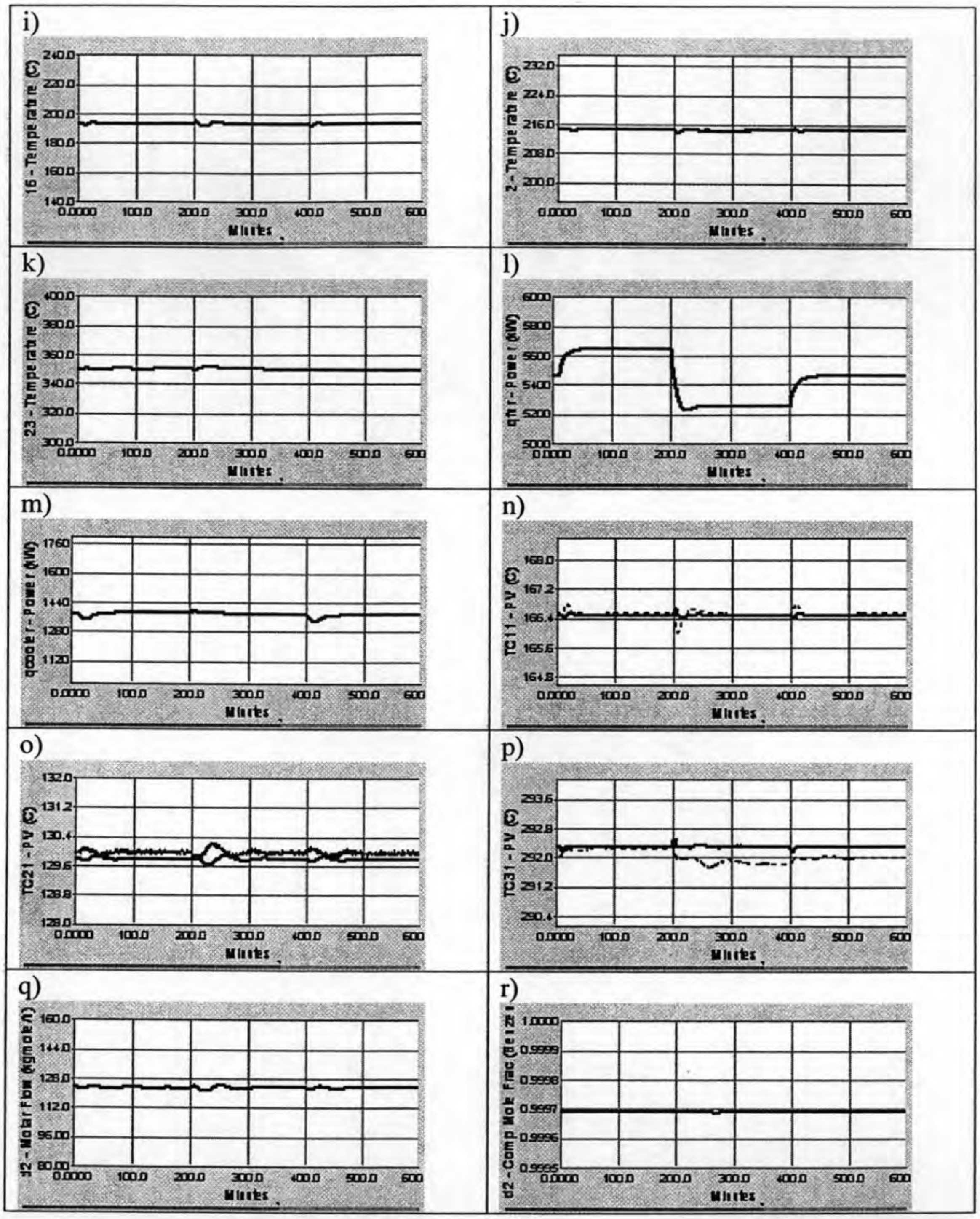

Figure 6.78 (continue)

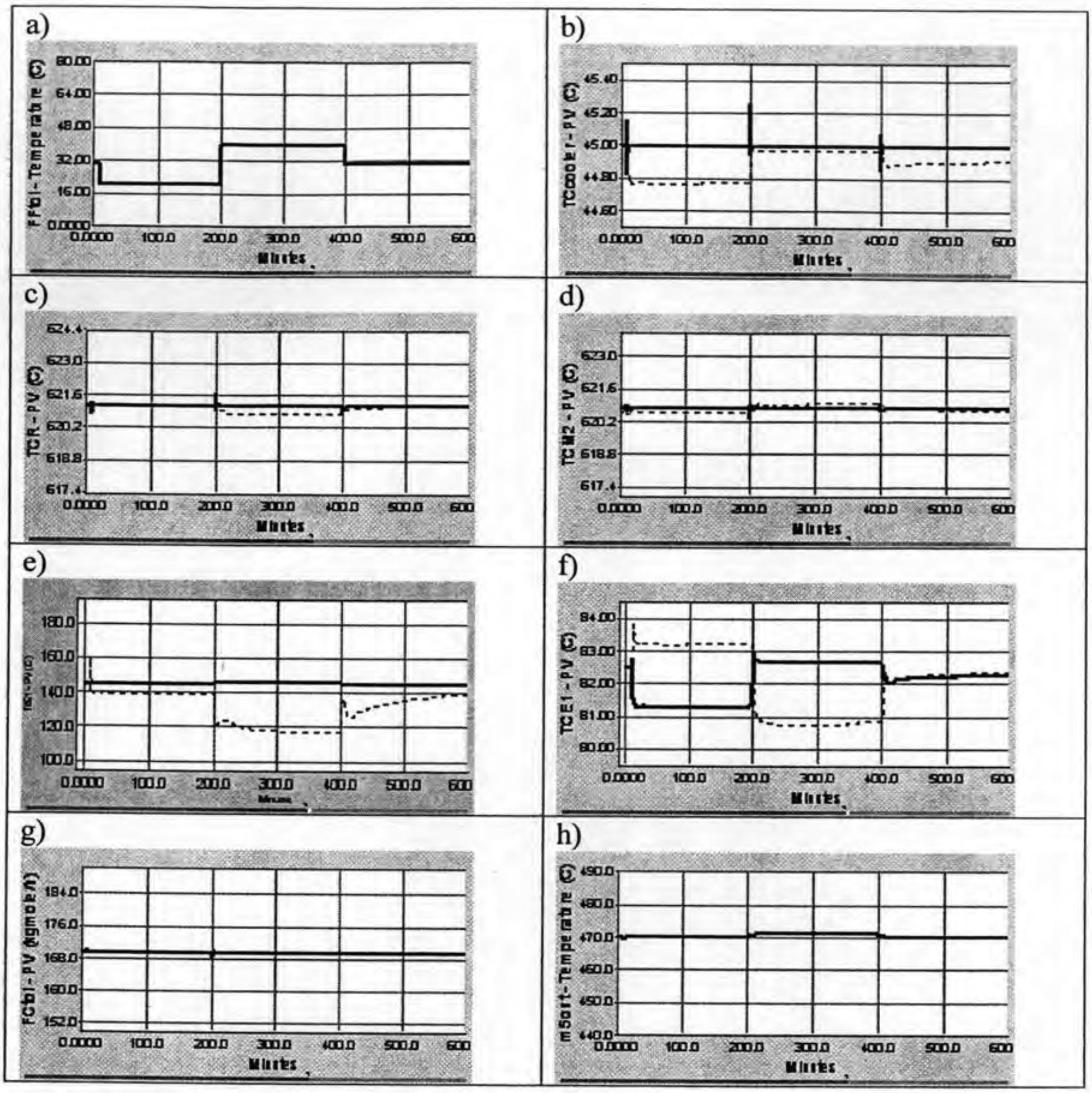

Figure 6.79 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the Heat Load Disturbance of Cold Stream (Reactor Feed Stream):CS4, where: (a)the variation temperature of fresh feed toluene , (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g) molar flow of total toluene, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. ——— Process variable (PV) , ▪▪▪▪▪▪ Manipulated variable)

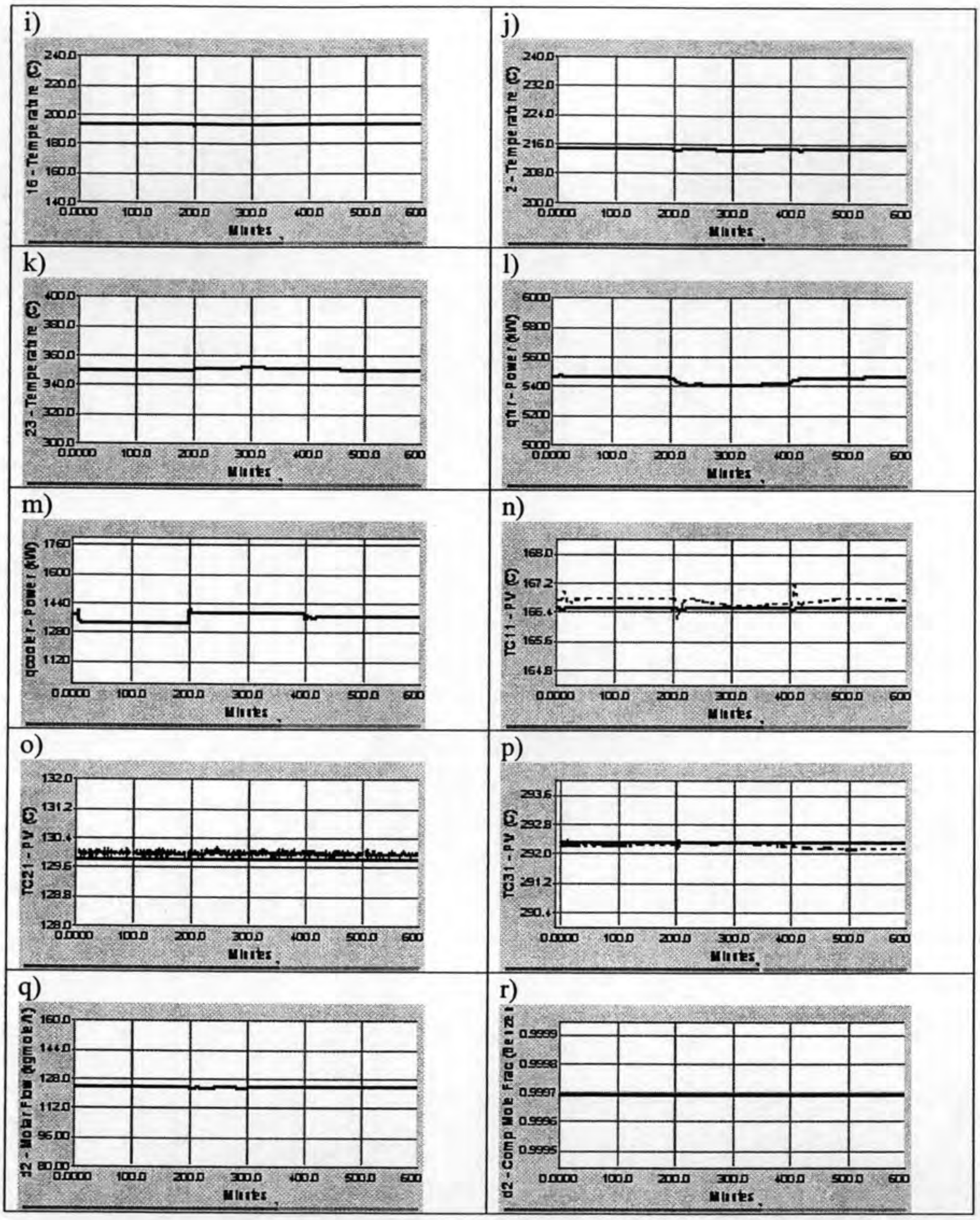

Figure 6.79 (continue)

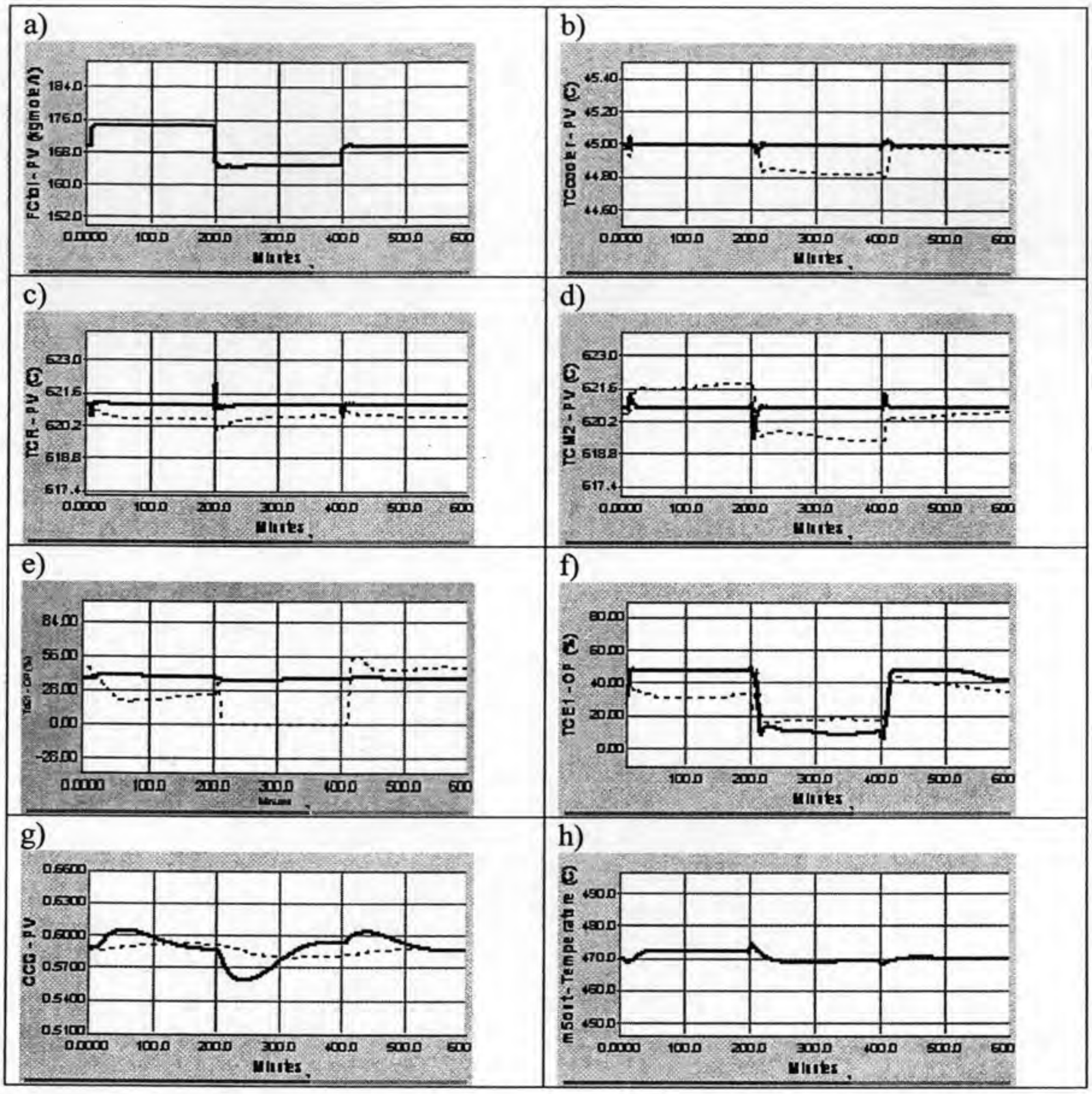

Figure 6.80 Dynamic Responses of the HDA Process Alternative 6:RHEN3 with minimum Auxiliary Utility Units to a Change in the total toluene feed flowrate:CS4, where: (a)the molar flow of total toluene, (b) the outlet cooler temperature, (c) the reactor inlet temperature, (d) the temperature of product reactor and separator , (e) the cold outlet temperature of FEHE1 , (f) the hot outlet temperature of FEHE1, (g)composition methane of gas recycle, (h) the cold inlet temperature of Furnace, (i) the bottom temperature of product column, (j) the bottom temperature of stabilizer column, (k) the bottom temperature of recycle column, (l) furnace duty, (m)cooler duty, (n) stabilizer column tray temperature, (o) product column tray temperature,(p) recycle column tray temperature,(q) molar flow benzene,(r) composition benzene of product column

(Note. —— Process variable (PV) , ······ Manipulated variable)

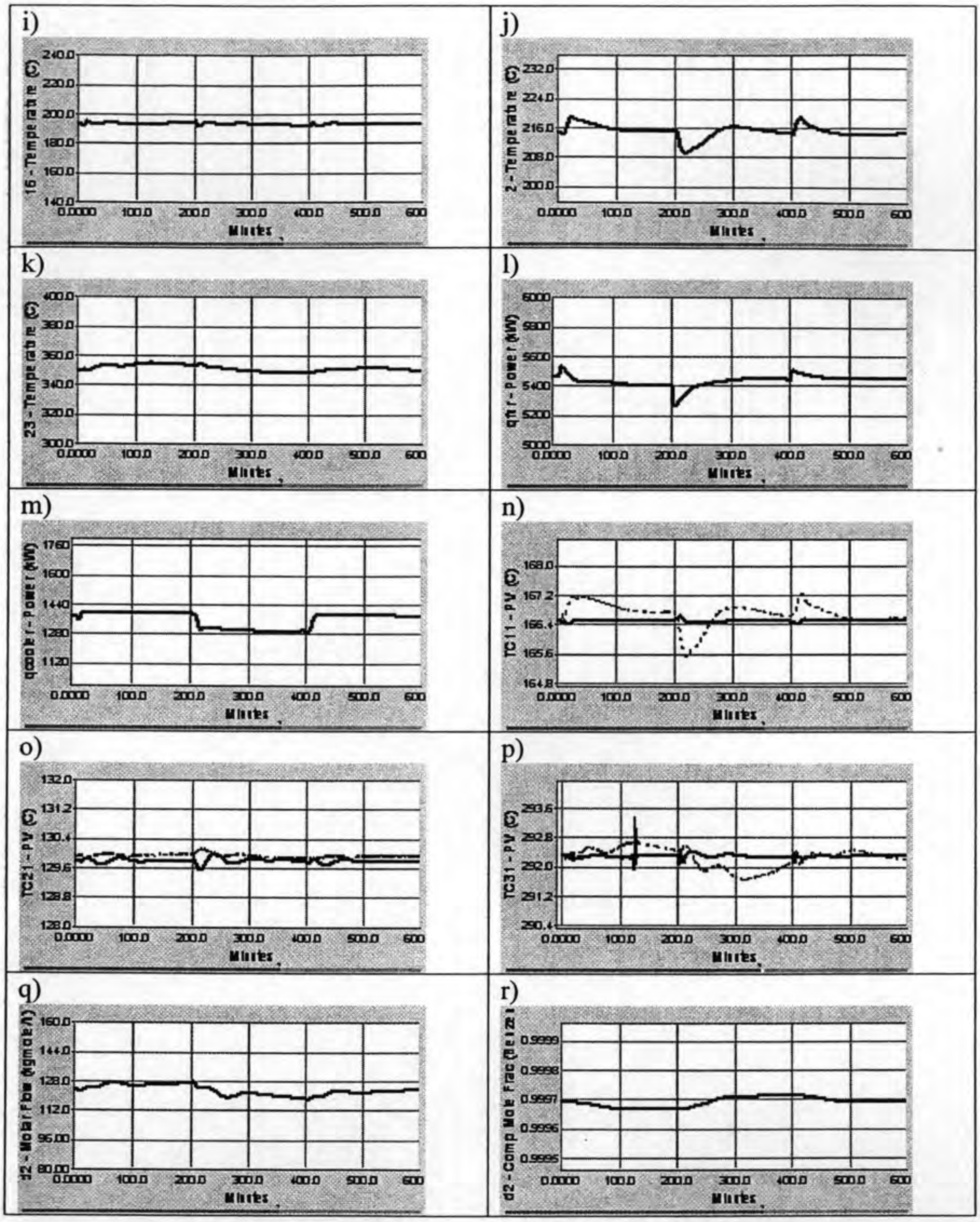

Figure 6.80 (continue)

6.22 Evaluation of the Dynamic Performance

The estimation of the achievable variance of SISO controller variable from 'normal' closed-loop data compared that minimum variance control has been widely used as a benchmark for assessing control loop performance. However, minimum variance control based performance assessment methods cannot adequately evaluate the performance for controller with constraints explicitly incorporated or for controllers where transient response and deterministic disturbance regulation are concerned. For assessing constraints control loop performance the proposed dynamic performance index is focused on time related characteristics of the controller's response to set-point changes or deterministic disturbances. There exist several candidate performance measures such as settling time and integral absolute error (IAE). Integral absolute error is well known and widely used. For the formulation of a dynamic performance as written below:

$$IAE = \int |\varepsilon(t)|\, dt \qquad (6.1)$$

Note that $\varepsilon(t) = y_{sp}(t) - y(t)$ is the deviation (error) of the response from the desired setpoint.

In this work, IAE method is used to evaluate the dynamic performance of the designed control system. Table 6.21a to 6.24a shows the IAE results for the change in the disturbance loads of hot steam in HDA process alternative 6 with different resilient heat exchanger networks (BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3) for CS1 control structure to CS4 control structure respectively, table 6.21b to 6.24b shows the IAE results for the change in the disturbance loads of cold steam in HDA process alternative 6 with different resilient heat exchanger networks (BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3) for CS1 control structure to CS4 control structure respectively, table 6.21c to 6.24c shows the IAE results for the change in the total toluene feed flowrates in HDA process alternative 6 with different resilient heat exchanger networks (BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3) for CS1 control structure to CS4 control structure respectively.

6.22.1 Evaluation of the Dynamic Performance for CS1 Control Structure Case

Table 6.21a to 6.21c show the IAE results for the change in the disturbance loads of hot steam in HDA process, the IAE results for the change in the disturbance loads of cold steam in HDA process and the IAE results for the change in the total toluene feed flowrates in HDA process respectively.

For the change in the disturbance loads of the hot steam on HDA process case the control system (CS1) compared with those in HDA process BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3, i.e. the value of IAE in HDA process RHEN3 is smaller than those in RHEN1, BC 3 aux, BC min aux and RHEN 2 respectively.

As can be seen the similarity result the change in the disturbance loads of the cold steam and the change in the disturbance loads of the total toluene feed flowrates, the value of IAE in HDA process RHEN3 is smaller than another alternatives.

6.22.2 Evaluation of the Dynamic Performance for CS2 Control Structure Case

Table 6.22a to 6.22c show the IAE results for the change in the disturbance loads of hot steam in HDA process, the IAE results for the change in the disturbance loads of cold steam in HDA process and the IAE results for the change in the total toluene feed flowrates in HDA process respectively.

For the change in the disturbance loads of the hot steam on HDA process case the control system (CS2) compared with those in HDA process BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3, i.e. the value of IAE in HDA process RHEN3 is smaller than those in RHEN2, BC 3 aux, RHEN1 and BC min aux respectively. As can be seen the similarity result the change in the disturbance loads of the cold steam and the change in the disturbance loads of the total toluene feed flowrates, the value of IAE in HDA process RHEN3 is smaller than another alternatives.

As can be seen that the IAE results for CS2 control structure is smaller than CS1 control structure results, but the IAE value of the disturbance loads of the total toluene feed flowrates is larger than CS1.

6.22.3 Evaluation of the Dynamic Performance for CS3 Control Structure Case

Table 6.23a to 6.23c show the IAE results for the change in the disturbance loads of hot steam in HDA process, the IAE results for the change in the disturbance loads of cold steam in HDA process and the IAE results for the change in the total toluene feed flowrates in HDA process respectively.

For the change in the disturbance loads of the hot steam on HDA process case the control system (CS3) compared with those in HDA process BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3, i.e. the value of IAE in HDA process RHEN3 is smaller than those in BC 3 aux, BC min aux, RHEN1 and RHEN2 respectively. As can be seen the similarity result the change in the disturbance loads of the cold steam and the change in the disturbance loads of the total toluene feed flowrates, the value of IAE in HDA process RHEN3 is smaller than another alternatives.

As can be seen that the IAE results for CS3 control structure is smaller than CS1 and CS2 control structure results, but the IAE value of BC 3 aux and BC min aux to change in the disturbance loads of cold steam is larger than CS1 and CS2.

6.22.4 Evaluation of the Dynamic Performance for CS4 Control Structure Case

Table 6.24a to 6.24c show the IAE results for the change in the disturbance loads of hot steam in HDA process, the IAE results for the change in the disturbance loads of cold steam in HDA process and the IAE results for the change in the total toluene feed flowrates in HDA process respectively.

For the change in the disturbance loads of the hot steam on HDA process case the control system (CS4) compared with those in HDA process BC 3 aux, BC min aux, RHEN1, RHEN2 and RHEN3, i.e. the value of IAE in HDA process RHEN3 is smaller than those in RHEN1, BC 3 aux, BC min aux and RHEN2 respectively. As can be seen the similarity result the change in the disturbance loads of the cold steam and the change in the disturbance loads of the total toluene feed flowrates, the value of IAE in HDA process RHEN3 is smaller than another alternatives.

As can be seen that the IAE results for CS4 look just the same as CS1 control structure results, but IAE results for CS1 control structure are larger than CS2 and CS3 control structure. The performance of these control structures can be arranged from the best to lowest performance (error of controllability point of view) as the following sequences: CS3, CS2, CS1 and CS4.

Table 6.21a The IAE results of the CS1 control structure to the change in the disturbance load of hot steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	1.134316761	1.143456902	0.863232615	0.977166684	0.956546
TC2	0.705089248	0.73624989	0.964797168	1.04196287	0.809433757
TC3	1.259710779	1.304215127	0.888956309	1.514981798	0.8156156
TCR	1.528503799	1.539687395	1.38112727	1.676626876	1.487778024
TCS	0.7156595	0.78126562	0.584579758	0.717475771	0.62005146
TCQ	0.817936484	0.819831039	0.858433194	0.915734291	0.881723438
ThE2	1.382017754	1.394764497	1.498899552	1.091626567	1.025969835
sum	7.543234325	7.719470472	7.040025866	7.935574857	6.597118115

Table 6.21b The IAE results of the CS1 control structure to the change in the disturbance load of cold steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.449525675	0.44970548	0.448628229	0.543070458	0.322831623
TC2	0.178382797	0.179517736	0.178764141	0.178212454	0.108788201
TC3	0.226308596	0.226798327	0.241260396	0.454546349	0.243497773
TCR	0.438554922	0.439878936	0.442441576	0.442625745	0.370473245
TCS	0.769357869	0.799618878	0.770073204	0.802434989	0.801494387
TCQ	0.399493726	0.399185242	0.384120932	0.489786173	0.419308438
ThE2	0.228992024	0.230560476	0.261221901	0.198634834	0.116840554
sum	2.690615609	2.725265077	2.726510379	3.109311003	2.383234221

Table 6.21c The IAE results of the CS1 control structure to the change in the disturbance load of total toluene feed flowrates

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	1.808886965	1.867362206	2.56142362	2.469950975	1.439631908
TC2	2.436756635	2.497768263	1.510648619	1.545240751	1.564933021
TC3	2.155645	2.21689756	1.808072339	1.561390719	1.455585673
TCR	1.038120362	1.132093171	1.400523644	1.446632934	1.548160434
TCS	1.383904829	1.51245011	1.080209095	0.956752995	0.956312353
TCQ	1.019298367	1.243689334	1.952813182	1.891319093	2.027539938
ThE2	1.5789516	1.579235565	1.492268649	1.514445859	1.349063737
sum	11.42156376	12.04949621	11.80595915	11.38573333	10.34122706

Table 6.22a The IAE results of the CS2 control structure to the change in the disturbance load of hot steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.808797978	0.828233668	0.869937934	0.68209618	0.655544882
TC2	0.690177199	0.690417662	0.669149804	0.672275145	0.649228207
TC3	0.730326757	0.738406108	0.742102229	0.707500149	0.701117114
TCR	1.566974799	1.573135763	1.577012058	1.661790748	1.531814908
TCS	0.948084477	0.992994296	0.9123568	0.8821266	0.769252918
TCQ	0.772468063	0.774640342	0.782789163	0.802345729	0.76566253
ThE2	1.2671596	1.27982321	1.282096535	1.292348172	1.175267526
sum	6.783988872	6.87765105	6.835444523	6.700482724	6.247888084

Table 6.22b The IAE results of the CS2 control structure to the change in the disturbance load of cold steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.428352097	0.430246063	0.296621574	0.314236448	0.3075216
TC2	0.220264566	0.220248983	0.225807762	0.239471477	0.213208703
TC3	0.180568005	0.180655993	0.191921791	0.174097835	0.17801478
TCR	0.428538235	0.434662473	0.421480912	0.487372584	0.405108638
TCS	0.869610835	0.874450104	0.871406113	0.839567811	0.737735316
TCQ	0.671860955	0.675237723	0.623389729	0.607028536	0.574428668
ThE2	0.230644315	0.230518692	0.247008242	0.208868248	0.2158766
sum	3.029839008	3.046020031	2.877636124	2.87064294	2.631894305

Table 6.22c The IAE results of the CS2 control structure to the change in the disturbance load of total toluene feed flowrates

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	2.487371221	2.515215861	2.404540923	2.461512304	2.38777818
TC2	1.822983934	1.847502731	1.906325922	1.822989621	1.712226587
TC3	1.569876309	1.628805856	1.597244432	1.689993342	1.561498877
TCR	1.51975771	1.530641713	1.429071877	1.472093834	1.432147518
TCS	1.002612331	1.002760613	1.013324005	1.015700423	1.015050137
TCQ	2.035970663	2.071751409	2.034894575	1.981538438	1.90393105
ThE2	2.082264427	2.090186993	1.504853611	1.486582428	1.425688562
sum	12.5208366	12.68686518	11.89025535	11.93041039	11.43832091

Table 6.23a The IAE results of the CS3 control structure to the change in the disturbance load of hot steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.565861671	0.581825392	0.59364815	0.527116845	0.518065934
TC2	0.532764821	0.538173684	0.493183711	0.496155711	0.499955974
TC3	1.271172471	1.280079128	1.230522378	1.124607345	0.85156165
TCR	0.93119188	1.027029306	1.2564954	1.692850515	0.891226
TCS	0.795552123	0.811694842	0.89456516	0.700553413	0.71855723
TCQ	0.770473756	0.775644329	0.663230319	0.887457283	0.895226923
ThE2	1.121882473	1.135271035	1.318932	1.098946915	1.011649602
sum	5.988899196	6.149717717	6.450577118	6.527688028	5.386243313

Table 6.23b The IAE results of the CS3 control structure to the change in the disturbance load of cold steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.38229765	0.385912491	0.230632377	0.248386695	0.101329135
TC2	0.195905249	0.197120689	0.162156165	0.244370721	0.207279722
TC3	0.437586509	0.451011339	0.425263634	0.513797754	0.297909729
TCR	0.438978021	0.447885311	0.488107185	0.424526928	0.374064546
TCS	0.8315655	0.866697512	0.832008864	0.800358886	0.781256465
TCQ	0.57156156	0.581235757	0.551971311	0.466664022	0.442029033
ThE2	0.248445734	0.25034149	0.285661802	0.194625878	0.124109286
sum	3.106340224	3.180204589	2.975801339	2.892730884	2.327977915

Table 6.23c The IAE results of the CS3 control structure to the change in the disturbance load of total toluene feed flowrates

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	1.167545234	1.224451448	1.872385503	1.154125421	1.114731054
TC2	2.444087844	2.504821922	3.028108442	3.053076822	2.012083949
TC3	1.926398033	1.986669047	2.329647364	2.038142958	1.253671845
TCR	1.275665847	1.293824972	1.433358012	1.367632685	1.126584
TCS	1.015460036	1.022859063	1.226100123	0.962506766	0.946745331
TCQ	1.933799226	1.972228665	1.99362247	1.876648294	1.971120023
ThE2	1.912264126	1.940521164	1.482924722	1.484408697	1.340485597
sum	11.67522035	11.94537628	13.36614664	11.93654164	9.765421799

Table 6.24a The IAE results of the CS4 control structure to the change in the disturbance load of hot steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	1.142676142	1.144676902	0.864576262	0.977343484	0.95365786
TC2	0.704669248	0.725674989	0.965536168	1.053248701	0.808465735
TC3	1.258677793	1.315621513	0.872646275	1.514981798	0.817875156
TCR	1.536837987	1.53587774	1.384562727	1.674567606	1.486436525
TCS	0.71356595	0.78578562	0.585547976	0.715230608	0.654655056
TCQ	0.817078984	0.831039459	0.857243755	0.915733391	0.883456771
ThE2	1.383561775	1.395465497	1.498534552	1.091246672	1.046456456
sum	7.557067879	7.73414172	7.028647715	7.942352259	6.65100356

Table 6.24b The IAE results of the CS4 control structure to the change in the disturbance load of cold steam

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	0.451522375	0.44596348	0.452357657	0.536547705	0.3354567
TC2	0.169862797	0.178457674	0.176546875	0.185578526	0.115578201
TC3	0.23124086	0.246747681	0.254357613	0.447584918	0.236747698
TCR	0.443214922	0.445659365	0.437645766	0.457968745	0.365378963
TCS	0.76734669	0.789756879	0.78454672	0.818679166	0.816474387
TCQ	0.397209373	0.398366524	0.395769321	0.482658657	0.41778988
ThE2	0.227458992	0.243450476	0.256471901	0.196457645	0.135675841
sum	2.687856008	2.748402079	2.757695853	3.125475361	2.42310167

Table 6.24c The IAE results of the CS4 control structure to the change in the disturbance load of total toluene feed flowrates

	BC 3 Aux	BC min Aux	RHEN1	RHEN2	RHEN3
TC1	1.812938523	1.824875231	2.459305948	2.432649435	1.798246453
TC2	2.447553567	2.49897895	1.53656788	1.564587986	1.575687479
TC3	2.254247645	2.313567798	1.879467875	1.643678954	1.447654737
TCR	1.026745678	1.095876537	1.413152364	1.445375769	1.539676547
TCS	1.385747856	1.513764769	1.081210953	0.955534995	0.956235353
TCQ	1.019234837	1.243334705	1.952434357	1.875676293	2.025325671
ThE2	1.568324566	1.568334657	1.49455104	1.521545673	1.35185466
sum	11.51479267	12.05873265	11.81669042	11.43904911	10.6946809

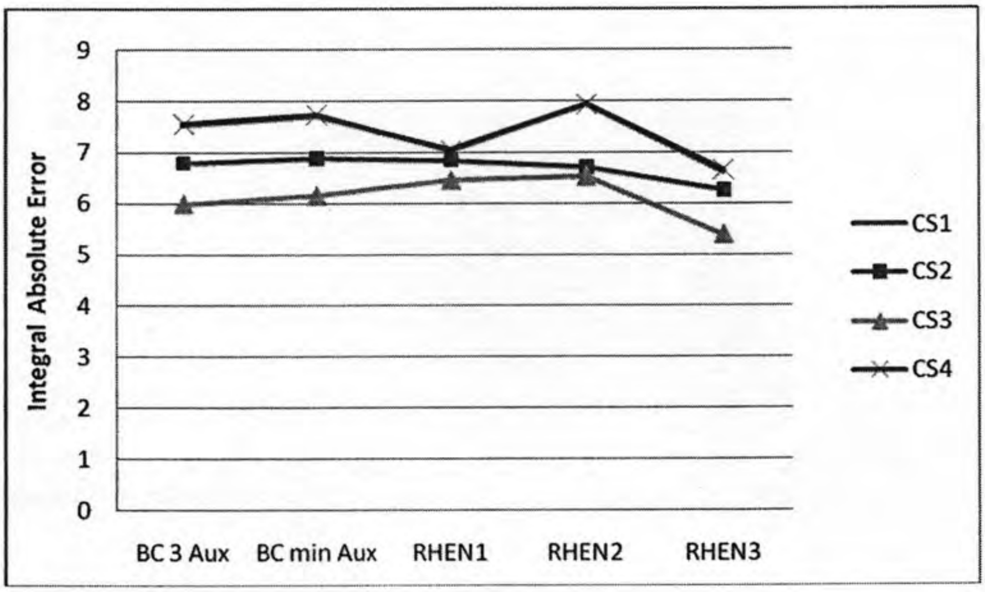

Figure 6.81: The IAE results of a change in the disturbance load of hot stream

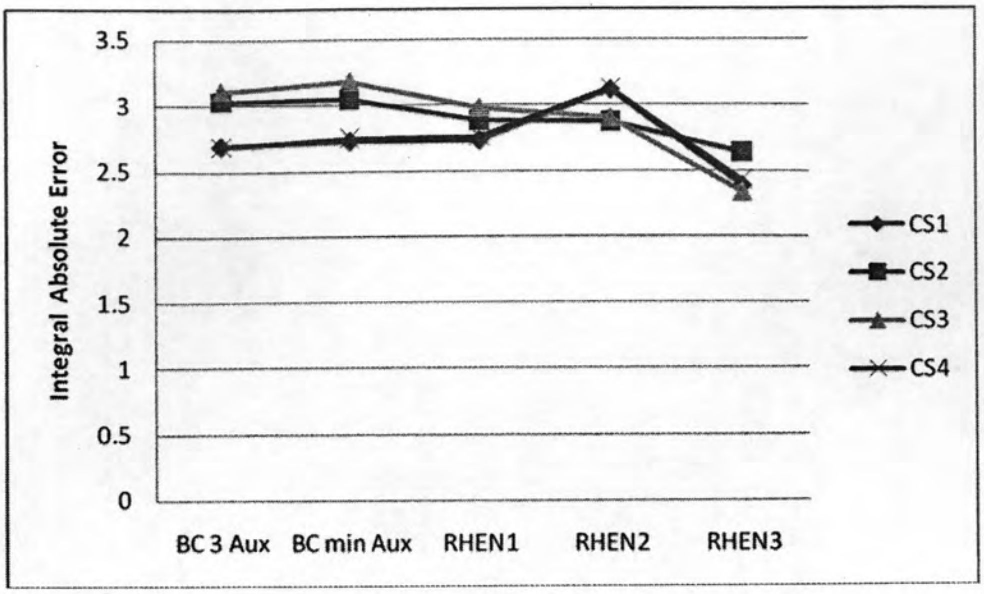

Figure 6.82: The IAE results of a change in the disturbance load of cold stream

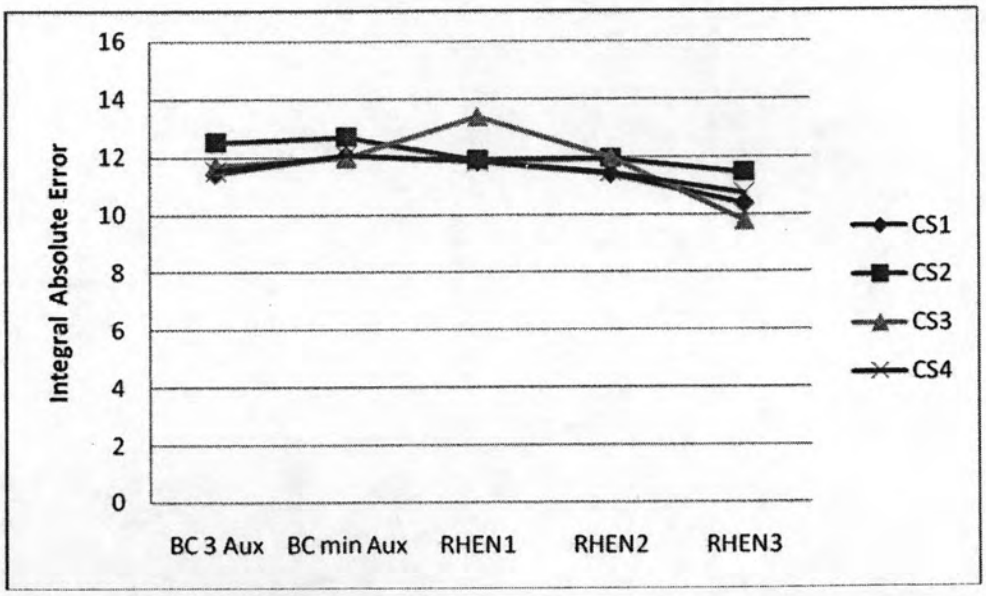

Figure 6.83: The IAE results of a change in the disturbance load of total toluene feed flowrates