CHAPTER 7: MULTIVARIABLE SYSTEMS

7.1 MULTI CONTROL LOOPS

In chapter 6, the concept of single feedback control loop was discussed. Usually all chemical processes particularly the case studies presented in PCLAB have several process outputs. It is common practice that each input-output pair is linked through a single control loop. Therefore, the overall control system of a typical process or plant will contain multi single control loops. This idea is the scope of PCLAB exercise that will be discussed in this section.

Refer again to Fig. 1.16, one can simply choose the multiloop control option, By doing so, the following Simulink window pops up:

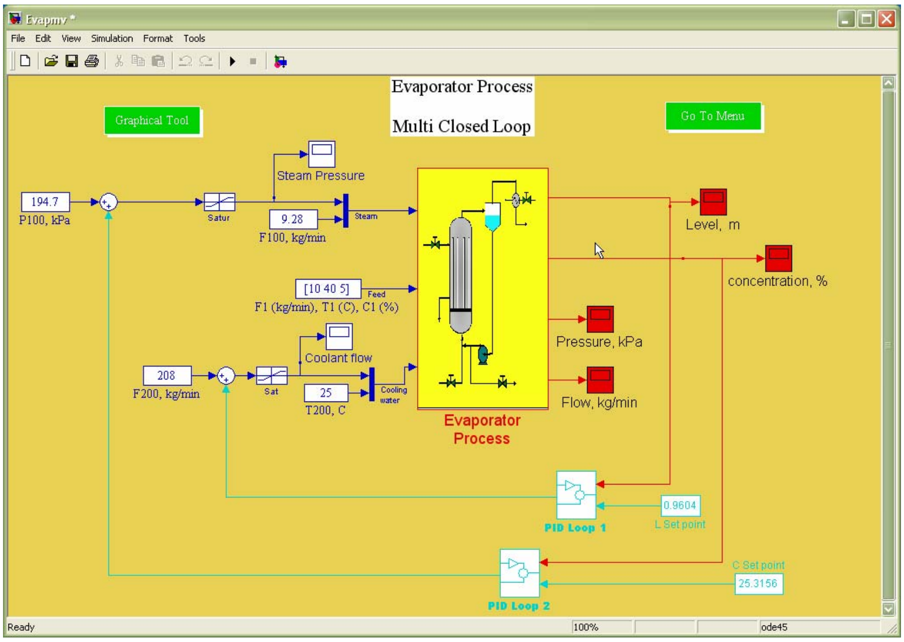

Fig. 7.1 Evaporator Process with two control loops

Fig. 7.1 shows two independent control loops. One loop pair the output concentration with the steam pressure and the other loop pairs the liquid level with the coolant flow rate. These two loops are chosen arbitrary simply for demonstration purposes. This means that the user can create as many control loops as the number of process outputs which is four in this case study. Moreover, the user can change the loop pairing, for example one can choose one of the available inputs (i.e., F100, F1, F200, T200) as the manipulated variable instead of P100 to control the product concentration.

The modifications discussed above can be carried out by simple mouse operations. However, it is suggested that only expert users can do so. The concept of selecting appropriate controlled variables, manipulated variables and pair them together is known as control structure design. This issue will be discussed later in this section.

7.1.1. Tuning of Multi Control Loops

As far as tuning is considered, the user can tune each loop independently using the procedure discussed in chapter 6. Following the Ziegler-Nichols procedure used in chapter 6 for each loop and with the aid of Table 6.2, the calculated PI settings are listed in table 7.1. Note that the ZN method is applied to each loop while the other loop is in open mode.

Table 7.1 Estimated Parameter values for a PID controller

	Loop 1	Loop 2
K_u	800	-350
P_u	50	94
K_c	360	-157.5
τ_I	41.6	78.3
K_I	8.6	-2

Next we examine the performance of the two control loops system. Let us introduce a disturbance in the form of a step change of magnitude 0.2% in the feed concentration, C_1. The process response in open-loop mode, i.e. with both controllers are disabled is shown in Fig. 7.2.

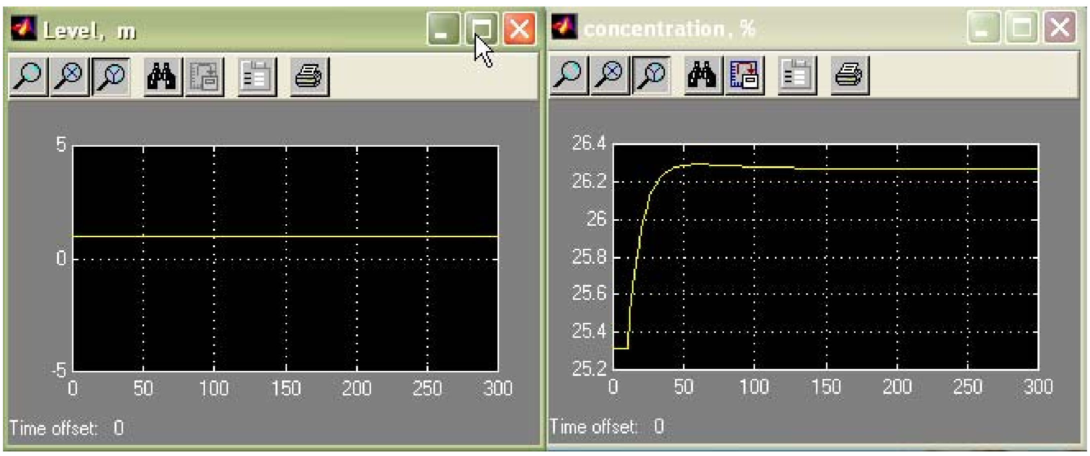

Fig. 7.2 Open-loop response to disturbance in feed concentration

It is obvious from Fig. 7.2 that the variation in the feed concentration affects only the output concentration. Now we repeat the simulation but with both control loops activated using the PI settings listed in table 7.1. The result is shown in Fig. 7.3.

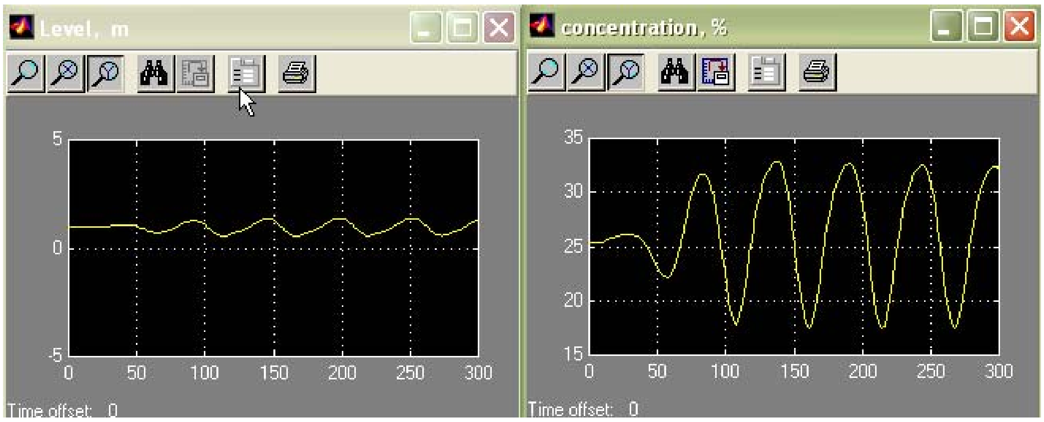

Fig. 7.3 Closed-loop response to disturbance in feed concentration

Fig. 7.3 illustrates that the response of the process is unstable despite the existence of the control system. This finding is not surprising because the loops were tuned independently ignoring their interaction. It is true that each loop will perform excellently when the other loop is open. However when both loops are active, the cross loop interaction is magnified causing poor and even unstable process dynamic behavior. A possible remedy is to fine tune both control loops. For example, if we cut down the PI settings of Table 6.1 by factor of 4 we obtain the results shown in Fig. 7.4.

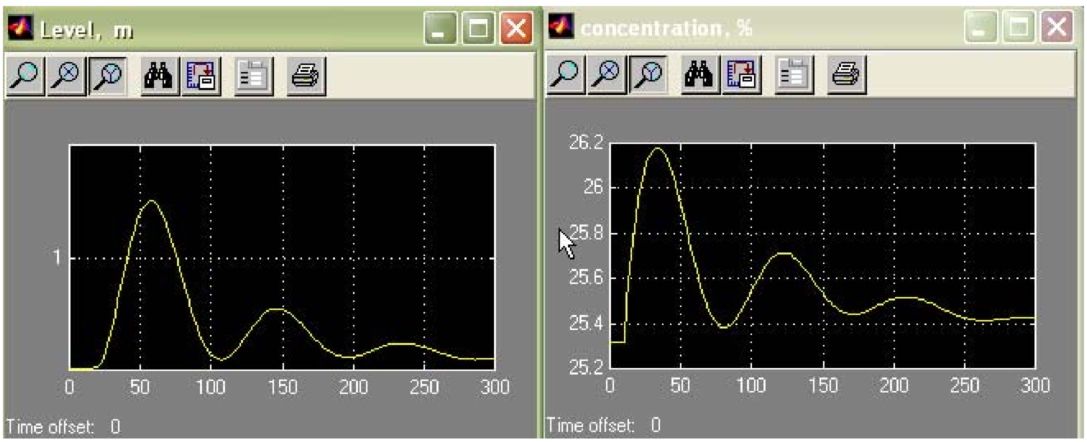

Fig. 7.4 Closed loop response to disturbance using improved PI settings.

There is no doubt that the resulting feedback response is much enhanced however it still suffers from oscillation. One can keep fine tuning the PI setting till desired performance is obtained.

Alternatively, one can use other tuning methods available for multi control loops system. Among these methods is the Biggest Log Modulus (BLT) proposed by Luyben [10]. The attractive feature of this procedure is simplicity since it includes designing only one parameter used as a de-tuning factor for all control loops. However, the resulted controller performance is conservative since the de-tuning factor is determined such that it provides tradeoff between stability and performance. Another design method is the Sequential Loop Closing (SLC) [11]. In this case, the loops are tuned individually but closed one after another so that interaction caused by closing a previous loop is accounted for during tuning the current loop. One drawback of such method is that interaction is taken care of in one direction only. This means that interaction brought by closing a current loop into all previous loops is not accounted for. Discussing these methods is out of scope. Nevertheless, users are encouraged to use the PCLAB platform to test these various procedures reported in literature and compare them.

7.1.2 Control Structure Design

As mentioned earlier control configuration which means selecting the controlled variables and their appropriate manipulated variables in multiloop's framework is an important design step for any successful control system. The control of a process with many variables can also be handled through multivariable control approach which requires advanced control strategies. The latter is out of the scope of the PCLAB.

There are several techniques available for control structure design [5]. The SSDSA method discussed in chapter 4 can also be used for control configuration. The SSDSA can be studied for each loop individually and consequently the appropriate structure can be determined. This approach however ignores the cross loop interaction. Alternatively, one can conduct the SSDSA method over all process variables and determine the best design structure. However, the method is based on steady state behavior only. Moreover, it is designed for a specific disturbance variable and hence may not necessarily work for other disturbances.

Another way to design a multivariable system is to use the concept of loop interaction. A Multivariable process is said to have interaction when process input affect more than one process output. The degree of interaction can be quantified by the so called Relative Gain Array (RGA). Let K be the steady-state gain matrix of the process. Let $\boldsymbol{K}^{+}$ be the transpose of the inverse of the steady state gain matrix:

$$K^{+} = (K^{-1})^{T}$$

The elements of the RGA can be obtained as follows:

$$\lambda_{ij} = k_{ij} k_{ij}^{+}$$

The most important properties of the RGA are as follows:

1. The elements of the RGA across any row, or down any column sum up to 1.
2. λ_{ij} is dimensionless.
3. The value of λ_{ij} is a measure of the steady-state interaction:
    a. $\lambda_{ij} = 1$, implies that u_j affects y_i without interacting with the other control loops. *The system is completely decoupled*.
    b. $\lambda_{ij} = 0$, means that u_j has absolutely no effect on y_i. *Thus, y_i can not be controlled by u_j.*
    c. $0 < \lambda_{ij} < 1$, means an interaction exists, the smaller λ_{ij}, the larger the interaction is.
    d. $\lambda_{ij} < 0$, indicates strong opposite effect compared to its effect when other loops are open. *Such input/output pairing is potentially unstable and should be avoided.*

Based on the above results, RGA pairing rule is: *pair input and output variables that have positive RGA elements and closets to one.*

To compute the RGA, we can do the following steps:

Step 1: step the feed pressure, P100 by amount say 1 kPa with all control loops are disabled and record the reaction curve as shown in Fig. 7.5

Step 2: Using the response in Fig. 7.5 compute the steady state gain for all outputs as explained in chapter 5 and insert in the RGA matrix as the first column.

Step 3: Repeat step 1 and 2 for the other inputs, say F100, T200, F200. The final RGA matrix is:

$$K = \begin{bmatrix} -0.018 & -2.0 & 0.017 & -0.35 \\ -0.02 & 10.4 & 0.01 & -0.2 \\ 0.0037 & 10.7 & -0.08 & 1.4 \\ 0.0015 & -0.8 & 0.0067 & -0.12 \end{bmatrix}$$

The resulted RGA matrix is thus:

$$K = \begin{bmatrix} 0.3161 & 0.1164 & -4.19 & 4.76 \\ 0.0505 & 0.8704 & 0.332 & -0.253 \\ 0.096 & 0.2933 & 17.99 & -17.38 \\ 0.5374 & 0.28 & -13.133 & 13.87 \end{bmatrix}$$

The RGA matrix shows that the system is highly interacting. It is obvious that the third and fourth manipulated variables, i.e. F200 and T200, are collinear. We can see that they have the same effect on all output but at the opposite direction. This is expected because the coolant temperature and its flow has the same thermal effect but at the reverse directions. The first MV can be used to control either the liquid level (first output) or the output flow rate (fourth output). The second MV can be used to control product concentration (second output). Nevertheless, the control structure is not well defined. Another input, other than the coolant temperature, shall be examined.

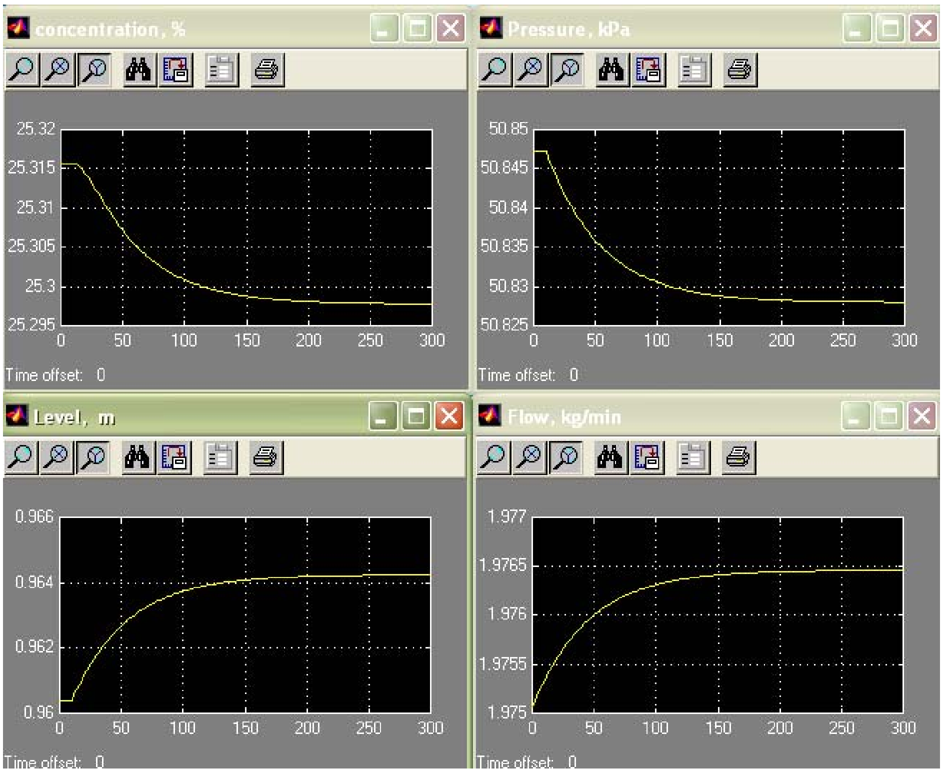

Fig. 7.5 Open loop response for a step change in the steam pressure