CHAPTER 4: STEADY STATE DISTURBANCE SENSETIVITY ANALYSIS

4.1 INTRODUCTION

In this chapter we discuss how steady state disturbance analysis can be implemented on PCLAB. This procedure is very useful to design the appropriate control structure. When controlling a plant or a process with many inputs and outputs, it is usually difficult to optimally pair theses variables into multi single loops structure. SSDA is a tool that can help in this regard, however it can not be implemented on real plant. Instead simulation can be utilized to perform the task.

Referring to the menu of the Evaporator case study in Fig. 1.16, clicking on the "steady state disturbance analysis" button brings up the following window:

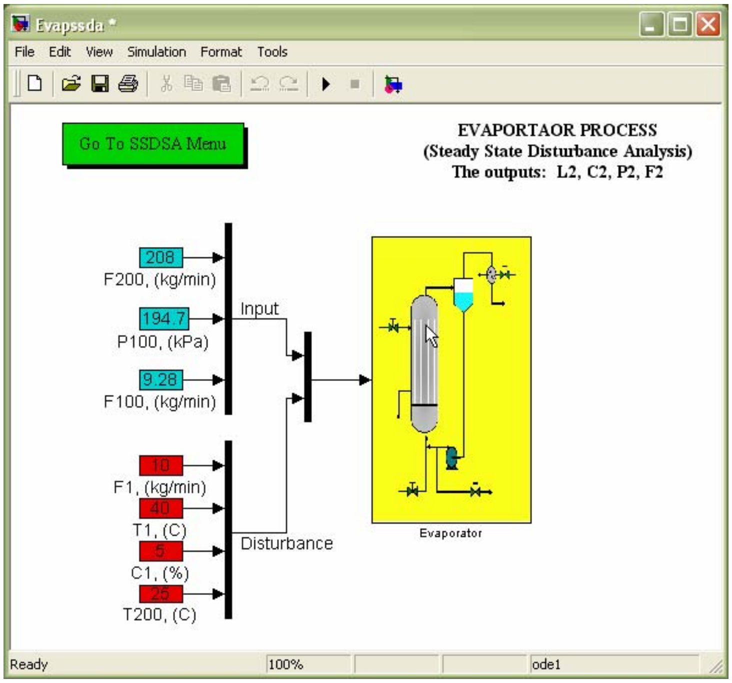


Fig. 4.1 Steady State Disturbance Module for Evaporator Process

Fig. 4.1 shows that the process has three inputs and four possible disturbances. The procedure will focus on investigating the static effect of any disturbance or any combination of disturbances on the process outputs in open-loop mode. This means that the inputs will remain fixed during the test. This is known as the open loop test. It reveals which process output is affected the most and which one is affected in nonlinear fashion. One can also run the test in closed-loop mode. In this case, an output should be selected as the controlled variable and a corresponding input should be selected to be the manipulated variable. The test will then examine the effectiveness of the chosen input to maintain the controlled variable at its nominal value in steady state when the process is under the influence of a range of disturbance values.

To start the procedure, one can simply click on the green button or the start button on Fig. 4.1. By doing so, the following SSAD menu pops up:

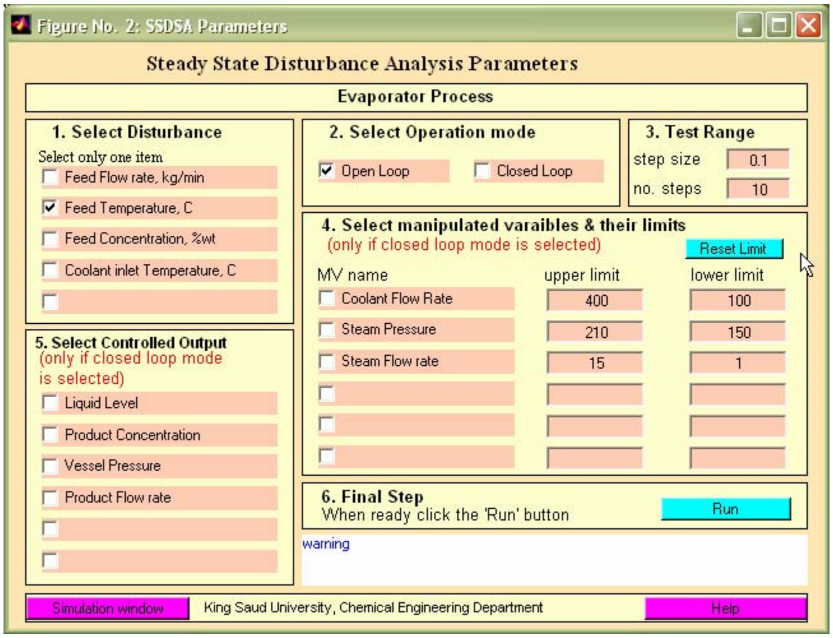


Figure No. 2: SSDSA Parameters

Steady State Disturbance Analysis Parameters

Evaporator Process

1. Select Disturbance
Select only one item
☐ Feed Flow rate, kg/min
☑ Feed Temperature, C
☐ Feed Concentration, %wt
☐ Coolant inlet Temperature, C
☐

2. Select Operation mode
☑ Open Loop
☐ Closed Loop

3. Test Range
step size: 0.1
no. steps: 10

4. Select manipulated varaibles & their limits
(only if closed loop mode is selected)

MV name	upper limit	lower limit
☐ Coolant Flow Rate	400	100
☐ Steam Pressure	210	150
☐ Steam Flow rate	15	1
☐		
☐		
☐		

5. Select Controlled Output
(only if closed loop mode is selected)
☐ Liquid Level
☐ Product Concentration
☐ Vessel Pressure
☐ Product Flow rate
☐
☐

6. Final Step
When ready click the 'Run' button

warning

King Saud University, Chemical Engineering Department

Fig. 4.2 SSDSA menu for the evaporator process.

The menu in Fig. 4.1 has six steps that lead to carry out the SSDA analysis procedure as discussed in the following sections.

4.2 OPEN-LOOP MODE

First the user should select one of the four possible disturbances by marking the appropriate check box. Let us say the feed temperature. Note that the other case studies will have different list of disturbance variables. Next mark the open-loop check box. The third step controls the test range. For example, if the nominal value for the feed temperature is T_0 = 40 ^{o}C and using step size of 0.1 and number of steps of 10 then the disturbance value will have the following range during the test:

$$T \in \left[T_0 + (10/2)*0.1T_0, T_0 - (10/2)*0.1T_0\right]$$

Increasing the number of steps at the same step size will increase the temperature range to be covered. The above values for the step size and number of steps cover a ±50% range which is good enough from practice point of view. Decreasing the step size will help in producing smoother response curves but it will decrease the overall range. Therefore, if one decreases the step size for better resolution, he should also increase the number of steps to maintain the same operating range. It should be noted though that smaller step size requires higher computational load.

In the open-loop mode, steps 4 and 5 must be by passed. If you by mistake marked one of the boxes in step 4 or 5 , you will receive an error message which will be displayed in the warning box. Now press the run button and look at the results shown in Fig. 4.3.

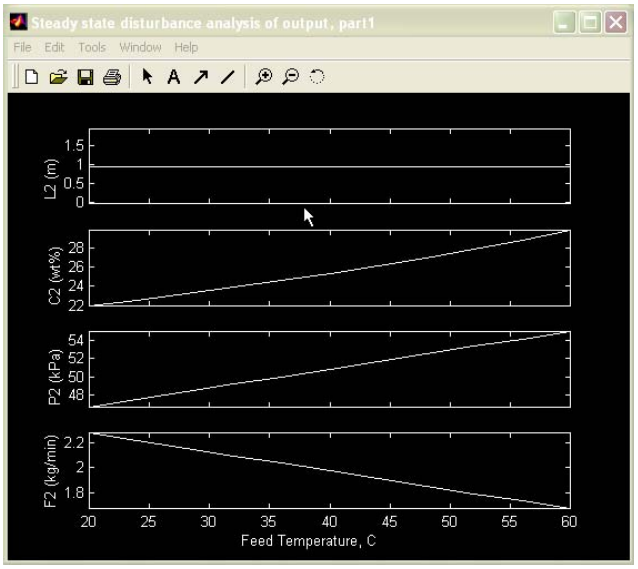


Fig. 4.3 SSDSA results for open loop test.

Fig. 4.3 illustrates how the four main process outputs respond at steady state to changes in the feed temperature from 20 to 60 ^{o}C. It is obvious that the liquid level in the separator unit is not affected by this type of disturbance. Thus in the open loop mode, the user can gain information about the *directional*, *magnitude* and *nonlinearity* effect of a disturbance. For example as a directional effect, both C_2 and P_2 will increase when the feed temperature increase while the outlet flow rate F_2 will decrease. One can also observe that the solute concentration (C_2) received the highest (*magnitude*) impact. Moreover, all outputs are altered *linearly* with the temperature variation. Thus, the user can learn how the process operation and product quality may get seriously influenced when the feed temperature is changing freely.

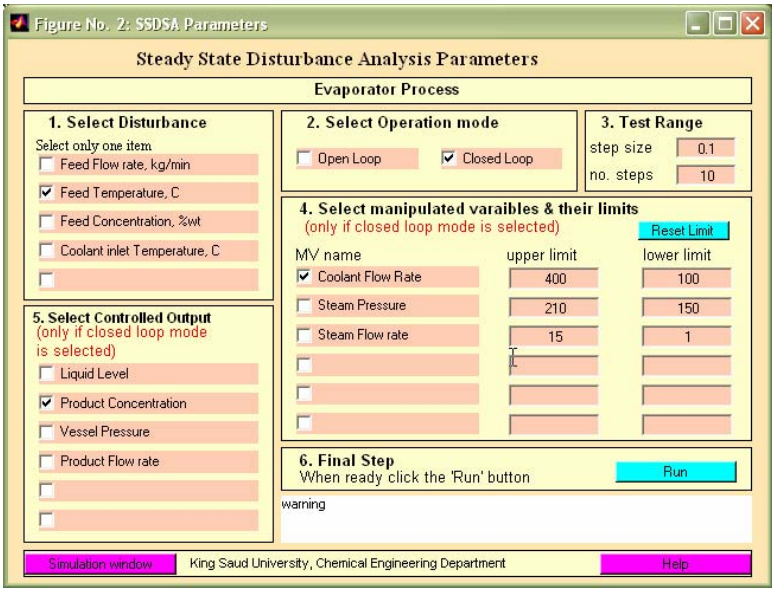


Figure No. 2: SSDSA Parameters

Steady State Disturbance Analysis Parameters

Evaporator Process

1. Select Disturbance
Select only one item
☐ Feed Flow rate, kg/min
☑ Feed Temperature, C
☐ Feed Concentration, %wt
☐ Coolant inlet Temperature, C
☐

2. Select Operation mode
☐ Open Loop ☑ Closed Loop

3. Test Range
step size 0.1
no. steps 10

4. Select manipulated varaibles & their limits
(only if closed loop mode is selected)

MV name	upper limit	lower limit
☑ Coolant Flow Rate	400	100
☐ Steam Pressure	210	150
☐ Steam Flow rate	15	1
☐		
☐		
☐		

5. Select Controlled Output
(only if closed loop mode is selected)
☐ Liquid Level
☑ Product Concentration
☐ Vessel Pressure
☐ Product Flow rate
☐
☐

6. Final Step
When ready click the 'Run' button

warning

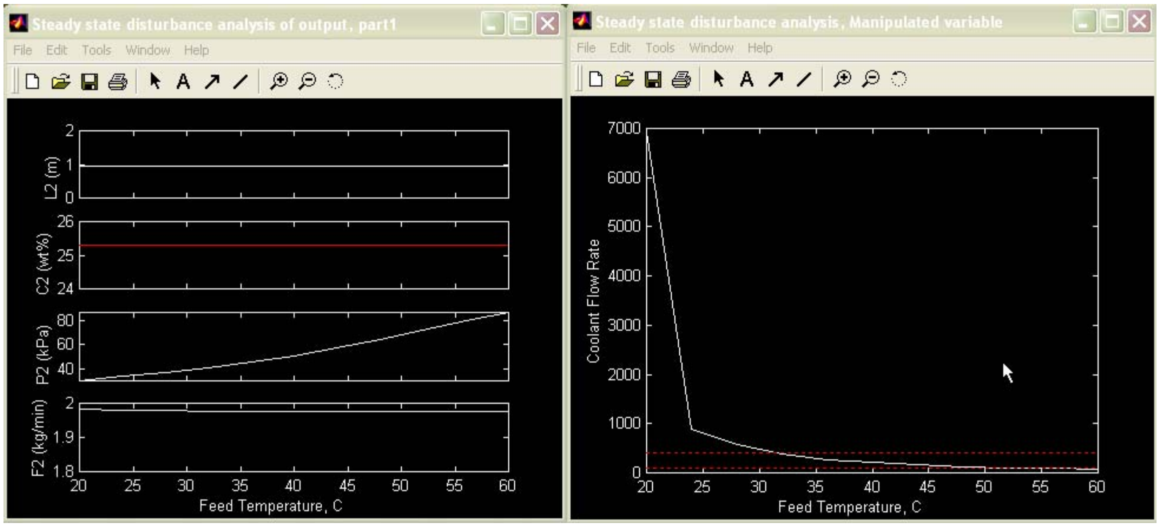
King Saud University, Chemical Engineering Department

Fig. 4.4 SSDSA menu for the closed-loop test case

4.3 CLOSED LOOP MODE

In this test mode, the user should unmark the open-loop checkbox and mark the close-loop checkbox instead. Furthermore the user needs to specify a controlled variable. Let us choose for example the output concentration C_2. In addition, the user should select one of the manipulated variables listed in Step-Box 4 as the candidate one. Let the candidate manipulated variable be the coolant flow rate. The user has the choice to either change the upper and lower permissible values for the candidate manipulated variable or leave them at their default values. See for example Fig. 4.4. Note that the user can restore the default values for the upper and lower limit any time by simply clicking the “reset limit” button.

After the user finishes marking the required checkboxes in the SSDSA menu, he can simply click the run button in Step-Box 6. The result for the above specification is shown in Fig. 4.5.



(a) (b)

Fig. 4.5 Output responses to disturbance in feed temperature when the coolant flow rate is used as manipulated variable

By inspecting the output response in Fig. 4.5a, we can observe that the controlled variable C_2 is well maintained at the nominal value. Note that a red color is used for the controlled variable to distinguish it from the other uncontrolled outputs. Because the evaporator pressure is not controlled, it increases as expected with disturbance but this time with a larger magnitude. On the other hand, the feedback control helped in making the output flow rate changes slightly with disturbance.

More important is the response of the manipulated variable. The red lines in the right plot of Fig.4.5b shows the upper and lower limits for the coolant flow rate which is set at 400 and 100 respectively. The white line represents the response of the coolant flow rate to disturbances in order to maintain C_2 at nominal value. For large disturbances, i.e. when the feed temperature exceeds 55 ^{o}C, the coolant flow should be reduced slightly below the lower limit in order to reject the effect of the disturbance. However, at feed temperature below 30 ^{o}C, the coolant flow rate must be increased by many folds, especially below 25 ^{o}C, to maintain the required operation. Low feed temperature requires higher steam pressure to provide enough heat of evaporization which in turn increases the process temperature. As a result large amount of coolant flow is needed to absorb the extra heat and to cool down the vapor.

One can conclude that the coolant flow rate is a good manipulated variable for controlling the product concentration at moderate to high disturbances in the feed temperature. However, the coolant flow is recommended at low feed temperature. The user can test other candidate manipulated variable and can also repeat the procedure for the other controlled variables. At the end, the user can build up a satisfactory control structure for the process, i.e. can select the appropriate input-output pairing 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