Guided Exercise for Introduction to Process Control

Tip: The values of set point (SP) and manipulated variable (MV) can be changed through the blue and green triangles in the PID panel in the top-right part of process screen. When you move over a triangle, the cursor shape will be changed, and you can double-click. Then the ***sticky mode*** *is activated, and the triangle will move according to the cursor location. At a desired position, single click will disable the sticky mode.*

Lesson: Manual Control is hard (at least not easy in process nature).

1. Try to move the steam valve position (MV) for sticky mode test. Set MV to 80% while the setpoint (SP) is at 50%. With "slow" simulation speed, start the simulation by pressing "Run" button and observe the outlet temperature (PV) changes. Then, try to adjust the MV interactively by using the arrow for MV (in blue) so that PV goes to 50% and remains there. If it reaches end of simulation, you can continue by pressing "Run" button. How successful were you?

Lesson: Automatic control does help you in finding the correct MV value for a desired PV value and current process condition.

2. If you were not successful, then turn on the control instrumentation (two temperature sensors and control valve for the steam flow) by clicking on the three dots shown on the schematic diagram of the process. Then, change the controller mode from "MANUAL (MAN)" to "AUTOMATIC (AUTO)". You should see the controller figure appear in the schematic diagram. Then, press the "Run" button and see how well the controller does in finding the correct value of MV.

   If you were successful, then change MV=80% and run the simulation in "MAN" mode to the end. Then, run the simulation in "AUTO" mode to see how the controller find the correct value of MV compared to what you did in previous question.

Lesson: No free lunch. First, you must make sure you use the right mode (sign of the controller gain) of the controller. Otherwise, the controller will do the opposite of what it is supposed to.

3. Choose "Controller" tab and change the controller setting from default "Reverse-acting" to "Direct-acting" by checking the checkbox. Set SP to 75% and run the simulation. What happens when you choose the wrong mode?
4. Change the controller setting back to "Reverse" by unchecking the checkbox and run the simulation again. Watch PV go to SP of 75%.

Lesson: P-Control leaves an offset. The offset decreases with the increasing controller gain. But one cannot make the controller gain arbitrarily large since too high a gain induces oscillation and/or instability.

5. Set the 'Easy' process nature in "Free Mode" tab. Go to "Controller" tab and choose P-Control only" with K_c=0.1 by setting $1/\tau_I$ to 0. Choose "Closed-loop response (SP)" in "Preset Mode" tab. Then, run the simulation. Does PV go to SP? SP-PV at steady state is called "offset".
6. Increase the gain Kc from 0.0 to 0.5. Run the simulation again. What happens to the offset?
7. Increase the controller gain further from 1.0 to 4.0 and 8.0. Run the simulations and observe what happens. Do you think you can ever remove the offset completely with P-control?

Lesson: Difficulty for controller tuning and the best achievable control performance depend on the process dynamics. Some processes are inherently more difficult to control and the best control performance you can achieve for them is limited (even under best tuning).

8. Set the 'Normal process nature in "Free Mode" tab and go back to the original controller setting of Kc=1.5 and $1/\tau_I$=1.0. Observe the controller performance for "Closed-loop response (SP)" in the "Preset Mode" tab. Change the Process Nature from "Normal" to "Hard". Repeat the simulation and observe the response.
9. If you feel that the response is too oscillatory, you may think about reducing Kc. Reduce Kc to 1.0, run the simulation again and observe the response. What do you gain and what do you lose? Try Kc=0.5 also. Can you make the response settle fast and smoothly?

Lesson: Derivative action can be helpful in reducing oscillation in the response (besides providing anticipatory control action to prevent runaway situations). However, like everything else, too much can be harmful.

10. **Before resuming, change back the Process Nature from "Hard" to "Normal."** Set Kc=1.5 and $1/\tau_I$=2.0. With "Closed-loop response (SP)", run the simulation. What kind of response do you get?
11. One way to reduce oscillation is to add some derivative action. Set τ_D=0.2. Run the simulation. Does the response improve? Try with τ_D=0.5 also.
12. Set τ_D=1.0. Run the simulation. What do you see?

Lesson: Applying derivative control in the face of sharp setpoint changes can make the valve jump – undesirable from the viewpoints of operation and hardware wear-and-tear. You can get rid of this problem by applying the D-action to the feedback signal only (-y instead of e=r-y).

13. Set τ_D back to 0.2. Now run the simulation until the end. Restart the simulation in "Free Mode", pause it at time 2.5. *It helps to change the simulation speed from 'normal' to 'slow'.* Change SP by –10% (to 65%). Resume the simulation. Do you see any problem with the valve action (MV)?

14. The valve action may have been too abrupt. This may be in response to the abrupt change in SP. One way to smoothen the valve response is to remove "derivative kick". Press "D-Kick removal" checkbox and see it is checked. Start the simulation, pause it at time 2.5. Change SP to 75%. Resume the simulation. Do you see different response in the valve position (MV)?

Lesson: Integral mode in PI or PID controller can get wound-up after a period of large, sustained error (due to a very large disturbance, an unrealizable setpoint change, and/or a badly designed controller). The valve becomes inactive until the large accumulated error unwinds to a sufficiently low level. This can have some negative consequences on the control (sustained error in the opposite direction). To prevent reset-windup , one can use a controller equipped with an "anti-reset-windup" scheme, which prevents the integral term from ever becoming too big in these situations.

15. Reset the controller parameter values to Kc=1.0 and $1/\tau_I$=2.0 and τ_D=0.0 with SP=50%. In "Controller" tab, check the "Constrained MV" with Umax=0.7. With feed T=50°C in "Free Mode", run the simulation in "AUTO" mode with "Auto scale on Y" checked and examine that this tuning is somewhat oscillatory but not too bad. Now rerun the simulation and pause it around t=2.0. Change the feed temperature from 50°C to 10°C (disturbance) by adjusting value. Resume the simulation. What problem do you see how MV is doing after the new disturbance is imposed (After the PV goes above SP in about 2min from new disturbance, the error sign is changed.)?
16. The sluggish return of the valve after a period of large error is due to the phenomenon called "Reset-Windup". Choose the option "Anti-Reset-Windup" by clicking on the button and checking it. Then repeat the simulation steps of 15. Watch the MV moving immediately when the error sign is changed.
17. You can observe windup phenomenon in another context. (Reload the page for default setting.)
    - Make sure the "Anti-Reset-Windup" option is unchecked. With SP=60°C, Choose the "Direct" mode of the controller. Run the simulation with "Auto scale on Y" checked to the end. You should see huge error and diverging in the PV response due to the wrong choice of sign of Kc.
    - Now return to Reverse acting model by unchecking the checkbox and run the simulation. Observe unreasonably big MV value is slowly moving toward normal range. Even though you rerun few times, controller is not working properly.
    - Now check the button "Reinitialize I-Mode of PID. This means the integral mode of the controller will be reset and hence the wound-up integral term will be vanished in the next simulation. Run the simulation and observe the MV is moving reasonably.
18. Repeat the same simulation with the "Anti-Reset-Windup" feature on. What is the lesson? Always reset the controller after a period of bad performance or use the controller with an anti-windup feature.