Guided Exercise for Control Module#1

Tip: For entering new controller parameter values and the inlet temperature value, you can either use the toggle button (arrow up or down) or click the green dot in the middle (located between the two arrows) and then enter the value from the small window in the upper-right corner. If you use the latter method, ***make sure you type "Enter" afterward and see the new value appear in the diagram.***

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

1. Observe that the process variable (PV) is at 75% while the setpoint (SP) is at 50%. Start the simulation by pressing "Run" button and try to adjust the steam valve position (MV) interactively by using the arrow for MV (in blue) so that PV goes to 50% and remains there. 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. Return the MV position to 75%. 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" to "AUTOMATIC". 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 (compared to you).

Lesson: No free lunch. First, you have to 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. Change the controller setting from "Reverse" (denoting reverse-acting) to "Direct" (denoting direct-acting). Set SP to 75% and run the simulation. What happens when you choose the wrong mode?
4. Change the controller setting back to "Reverse" 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. Go to "P-Control" only by setting $1/\tau_I$ to 0. Change SP to 50%. Then, run the simulation. Does PV go to SP? SP-PV at steady state is called "offset".
6. Increase the gain Kc from 1.0 to 3.0. Run the simulation again. What happens to the offset?

7. Increase the controller gain further from 3.0 to 5.0 and 10.0. 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. Go back to the original controller setting of Kc=1.0 and $1/\tau_I$=1.5. Change the Process Nature from "Normal" to "Hard". Set SP to 75%. Run 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 0.4, set SP back to 50%, run the simulation again and observe the response. What do you gain and what do you lose? Try Kc=0.2 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. Set SP to 75% and 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=0.5. Set SP to 50% and run the simulation. Does the response improve? Try with τ_D=1.0 also.
12. Set τ_D=2.0. Set SP to 75%. 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 0.5. Now run the simulation until the end. Restart the simulation, 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 "No Derivative Kick" button and see it highlighted (by green color). Start the simulation, pause it at time 2.5. Change SP by +10% (to 75%). Resume the simulation. Do you see smoother 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 $1/\tau_I$=1.5 and τ_D=0.0. Run the simulation and examine that this tuning is fairly good. Now restart the simulation and pause it around t=2.0. Change the inlet temperature from 18 to 10 (disturbance). Click on the inlet temperature reading and a control knob (up/down toggle buttons as well as the green activation dot) and this variable will appear. Resume the simulation. Pause it again, around t=5. Change the inlet temperature back to 18 (hence, the disturbance is gone at this point). Resume the simulation and run it until the end. What problem do you with what MV is doing after the disturbance is gone (starting at t=5)?
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 highlighting it. Then repeat the three-step simulation of 15. Watch the valve returning to the normal position almost immediately after the disturbance is gone.
17. You can observe windup phenomenon in another context.
    - Turn off the "Anti-Reset-Windup" option. Choose the "Direct" mode of the controller. Run the simulation to the end. You should see huge error in the PV response due to the wrong choice.
    - Now turn off the button "Reinitialize I-Mode of PID. This means the integral mode of the controller will not be reset and hence the wound-up integral term will continue to take effect in the next simulation. You can think of this as continuing on the simulation from the previous run.
    - Change the controller mode back to "Reverse". Run the simulation. You will see that MV does not respond for quite some time during which the error built up in the integral term dissipates (i.e., cancelled by the error in the opposite direction).
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.