Proportional-only control – why won't it work?

foreword by Ron Beaufort: I have previously posted much of the material contained in this paper on the "Live Question and Answer" forum at www.PLCs.net ... this was just one in a series of related threads which discussed the basic characteristics of the three components of PID control ... anyone who is interested in following the full context of the questions and answers of the original threads should be able to find them at the following links:

What Is P in PID? http://www.plctalk.net/qanda/showthread.php?t=13459
What Is I in PID? http://www.plctalk.net/qanda/showthread.php?t=11242
What Is D in PID? http://www.plctalk.net/qanda/showthread.php?t=11969
Proportional-only Control – Why Won't It Work?
http://www.plctalk.net/qanda/showthread.php?t=14497

since my original postings, many readers have requested that I make the text and illustrations easier to access by providing a single continuous PDF file of the material ... this document is the result of those requests ... I've reformatted some parts of the text and added more detail in certain places to make the ideas easier to follow ... most of the forum's original conversational tone has been left in place ...

I hope that this material proves helpful ... corrections, comments, and suggestions from readers are always welcome ...

some time ago I posted another article about the Proportional component of PID control and used a gas-fired oven as a example ... a student replied and said that he fully understood how the oven would not be able to reach the desired setpoint using only Proportional action for its controller ... but then he asked a perfectly valid (and very common) question about why other types of systems (level, flow, pressure, etc.) might not be able to reach the desired setpoint when using Proportional-only control ...

paraphrasing slightly, he asked:

"I understand that the oven system achieves a steady state condition, but what would keep other PVs from just climbing until they reached the setpoint using Proportional only? Can you give me another example?"

personally, I can remember having exactly the same questions when I first started learning about PID control ... I had already accepted the textbook's "rule" which says that Proportional-only control cannot maintain a desired setpoint ... but still, in the back of my mind, was always the nagging question: "but WHY won't it work?" ... it seemed quite simple ... the controller sees a small error ... it makes a small correction ... the process moves closer to the target and gives an even smaller error ... the controller gives a smaller correction ... and so on

... eventually we SHOULD be right on target and the Proportional-only controller SHOULD be able to maintain the setpoint ... but it doesn't work that way ... or does it? ... as most experienced technicians know, there ARE some exceptions to the "rule" ...

the fact is that SOME systems CAN reach the setpoint using only Proportional action ... but only under certain conditions ... my own personal word for this type of situation is a "sealed system" ... the basic idea is that if there is NO LOSS from the system, then Proportional action alone might be enough to reach the setpoint ... let's use an example ...

FIGURE 1 - MANUAL CONTROL - SEALED SYSTEM

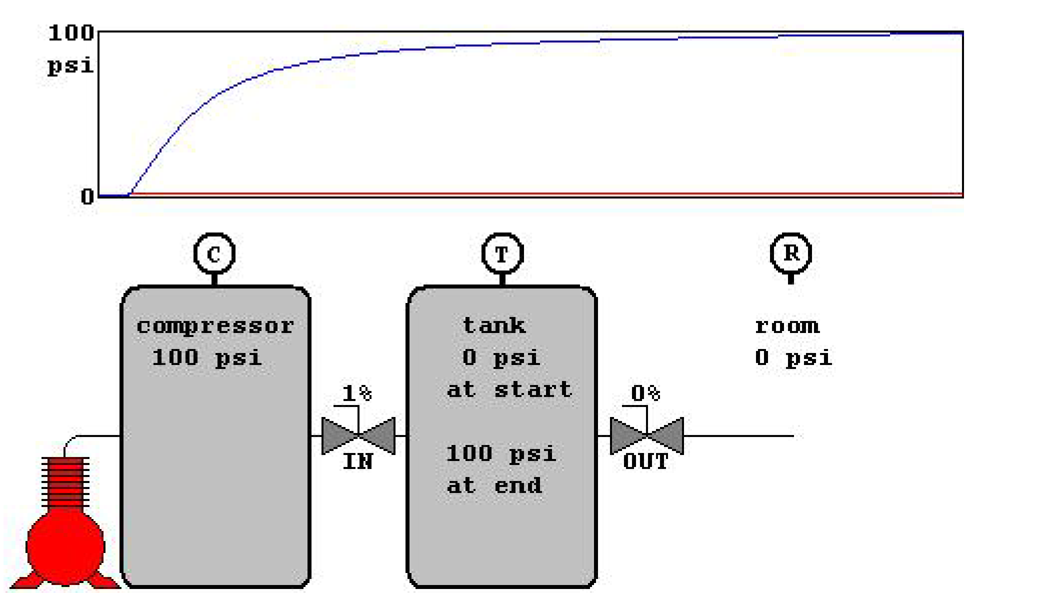


Figure 1 shows manual control (not automatic control) being used to control what I would call a "sealed system" ... a compressor keeps the pressure inside a reservoir (C) at a constant value of 100 psi ... we want to control the pressure in tank (T) ... suppose that we close the outlet valve completely so that there is NO WAY for any air to leave the tank ... then we crack the inlet valve open just a tiny amount ... in our example, we're using a valve setting of 1% ... but ANY amount of opening would give the same final results ... specifically, the pressure in tank (T) will eventually rise to the full supplied pressure of 100 psi ... as I said, if we wait long enough, the final resulting pressure will always be the same ... the only difference would be that smaller valve openings would take longer to reach the full pressure ... and larger valve openings would reach the full pressure quicker ... but the final pressure would ALWAYS eventually be the same ... notice that there is no time scale on the graph ... since we aren't told how large the tank is, or how much air will transfer through our 1% open inlet valve, then there is no way for us to predict just how long it will take tank (T) to reach the full supplied pressure ... maybe minutes ... maybe hours ... maybe years ... but EVENTUALLY the pressure in tank (T) WILL reach the full pressure of the compressor reservoir (C) ...

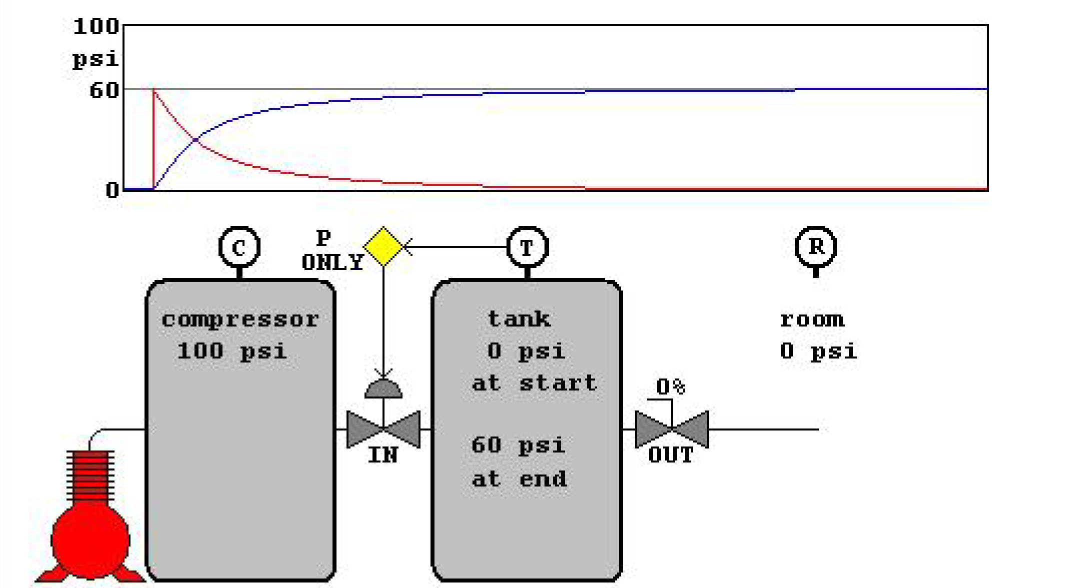
now let's look at the graph in Figure 1 ... notice that when the graph starts, the inlet valve is fully closed ... the pressure in tank (T) is zero psi ... shortly into the graphing period, the inlet valve is cracked open 1% as shown by the red trace ... the pressure in the tank starts to rise rapidly at first ... but then it begins to rise less rapidly as the test continues ... until finally it is rising VERY slowly as the pressure makes its final approach to the full supplied value ...

the basic shape of this curve should be familiar to everyone who has ever studied electronics ... it's basically the same curve followed by a capacitor being charged through a resistor ... the main idea is that as the pressure in tank (T) rises, the higher pressure opposes a further rise in pressure ... said another way, when the pressure in tank (T) is very low (at the beginning), then it's very easy for more air to flow into the tank and quickly raise the pressure ... but ... when the pressure in tank (T) is very high (at the end), then it's much harder for more air to flow into the tank ... and so the pressure rises much more slowly ...

the most important thing to notice is that regardless of how small a setting we use for our inlet valve, if we leave it cracked open long enough (even if just a pinhole), then the pressure in tank (T) will EVENTUALLY rise all the way up to the full supplied pressure ... just as long as there is NO leakage from the tank ...

Figure 2 shows a Proportional-only controller (indicated by the diamond) being used to control a "sealed system" ... here the pressure reading from sensor (T) is being fed back to the controller ... in an Allen-Bradley system, this feedback signal is called the "Process Variable" and is abbreviated "PV" ...

FIGURE 2 - P ONLY CONTROL - SEALED SYSTEM



in this example, the setting of the inlet valve could range anywhere from 0% to 100% of fully open ... we've given the controller a desired target value of 60% of full pressure ... in an Allen-Bradley system, we call the target value the "setpoint" and abbreviate it as "SP" ... as the test begins, we've got our controller turned completely off by setting our Proportional action for a gain of 0.00 ... this means that the inlet valve is now closed completely ... so the pressure in tank (T) is at 0 psi as we start the test ... then shortly into the test, we set our Proportional action for a gain of 1.00 ... the controller sees an error (abbreviated E) of 60% (E = SP – PV) ... it multiplies the error by the Proportional setting (1.00) and calculates an output of 60% ... in an Allen-Bradley system, the controller’s output is called the “Control Variable” and is abbreviated as “CV” ... this causes the red trace to instantly jump from 0 up to 60% ...

and just like in our first example, the curve shows that the pressure in the tank starts to rise rapidly at first ... but then it begins to rise less rapidly as the test continues ... until finally it is rising VERY slowly as the pressure makes its final approach to the setpoint ...

and notice that as the pressure gets closer and closer to the setpoint, the controller keeps steadily decreasing the amount of opening for the inlet valve ... this action was covered in my original “What is P?” article so we won’t go into all of the details again here ... but be sure to notice that just as soon as the pressure reaches the target, then the controller finally closes the inlet valve completely ...

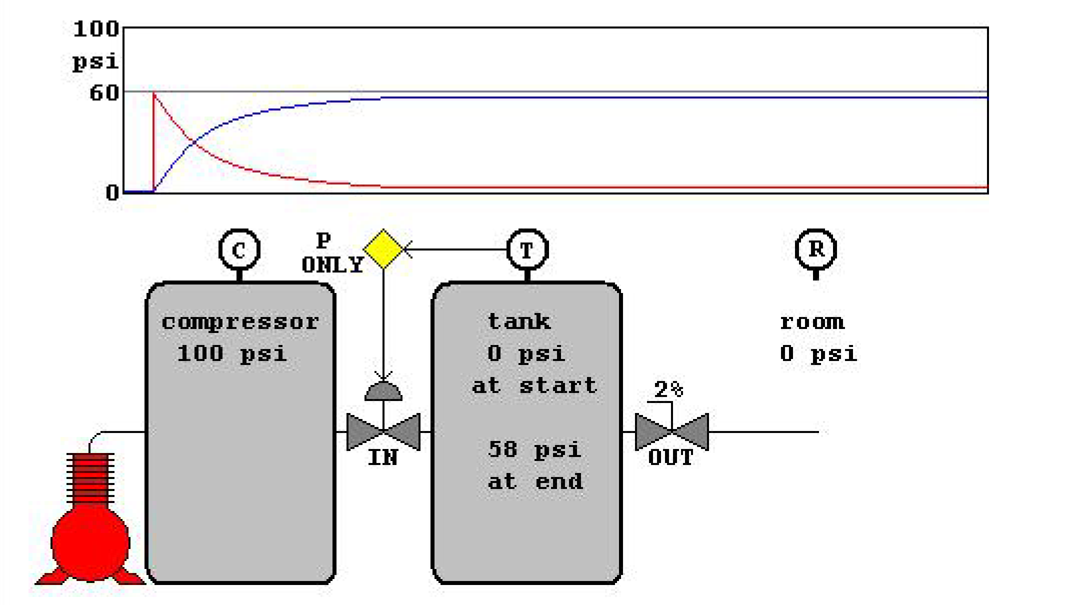
and now we’ve come to a major point of our student’s question ... and the point is that SOME systems WILL be able to reach the setpoint using only Proportional action ... this is one example which seems to defy the textbook’s “rule” that a Proportional-only controller cannot reach or maintain a setpoint ...

just be sure to keep in mind that as long as the inlet valve is opened even a tiny pinhole of a crack, then air will continue to flow from the higher pressure of the reservoir (C) into the lower pressure of tank (T) ... and eventually the pressure WILL reach the setpoint ... AS LONG AS (and here’s the tricky part) as long as THERE IS NO LEAKAGE FROM THE TANK ... and in this example, the outlet valve is being kept completely closed ...

the big question now becomes: “how realistic is this example?” ... and the sad answer is: “it’s not very realistic at all for processes in the real world” ... in other words, pressure controllers aren’t often used on simple “sealed” tanks ... specifically, there’s usually something flowing out of the tank whose pressure we’re trying to control ...

Figure 3 shows a more realistic application for a pressure controller ... here the outlet valve has been opened for a setting of 2% ... and now we see one of the major drawbacks to a controller which uses only Proportional action ...

FIGURE 3 – P ONLY CONTROL – WITH LOAD



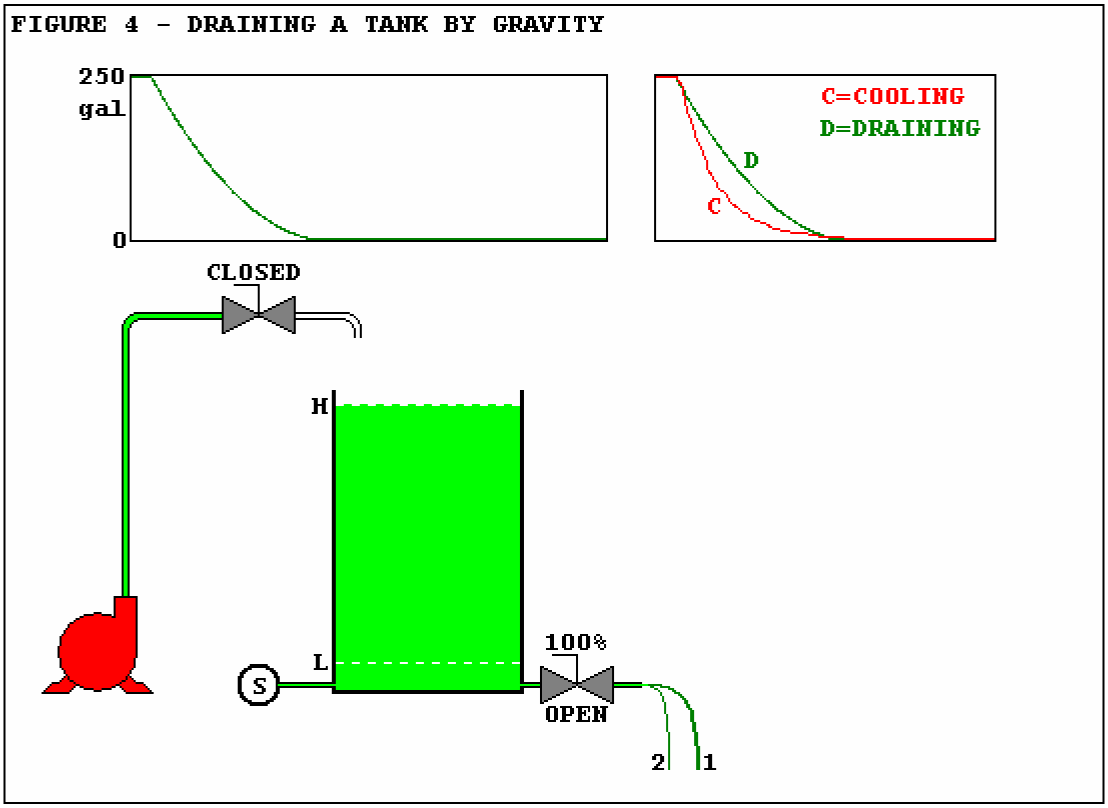
notice that in this example, the pressure never gets quite all the way up to the setpoint ... instead it settles out at some slightly lower pressure and then continues along that path ... this is the same type of “steady state” situation that we had with the oven example in my earlier article ...

we could go through the math involved here if we wanted to ... but some simple common sense should be enough to convince us of what’s going on at the end of this “steady state” test ... suppose that we could somehow (magically?) just nudge the pressure up a little bit more and have it reach the target value of 60 psi ... in that case, the error (the deviation from the target) would become zero ... and in that case, the controller’s output would also be zero ... and now ... what do you suppose would eventually happen to the pressure in tank (T) if the controller gave us a zero signal and closed the inlet valve completely? ... simple answer: “the pressure would eventually drop back BELOW the setpoint” ... the pressure would have to drop BECAUSE OF THE LOAD (the leakage) through the open outlet valve ...

and so to our student, I would say this: the difference between the oven example in my earlier article – and the pressure tank example in Figure 2 - is that the oven can NEVER become a “sealed system” ... specifically, there will always be SOME amount of heat leakage from the oven system ... heat will ALWAYS be able to leave the oven either through conduction, or through convection, or through radiation ... BUT! ... IF (big IF) we COULD somehow design a PERFECTLY insulated and “sealed” oven system, then (and only then) would a controller using Proportional-only action be able to achieve the desired setpoint ...

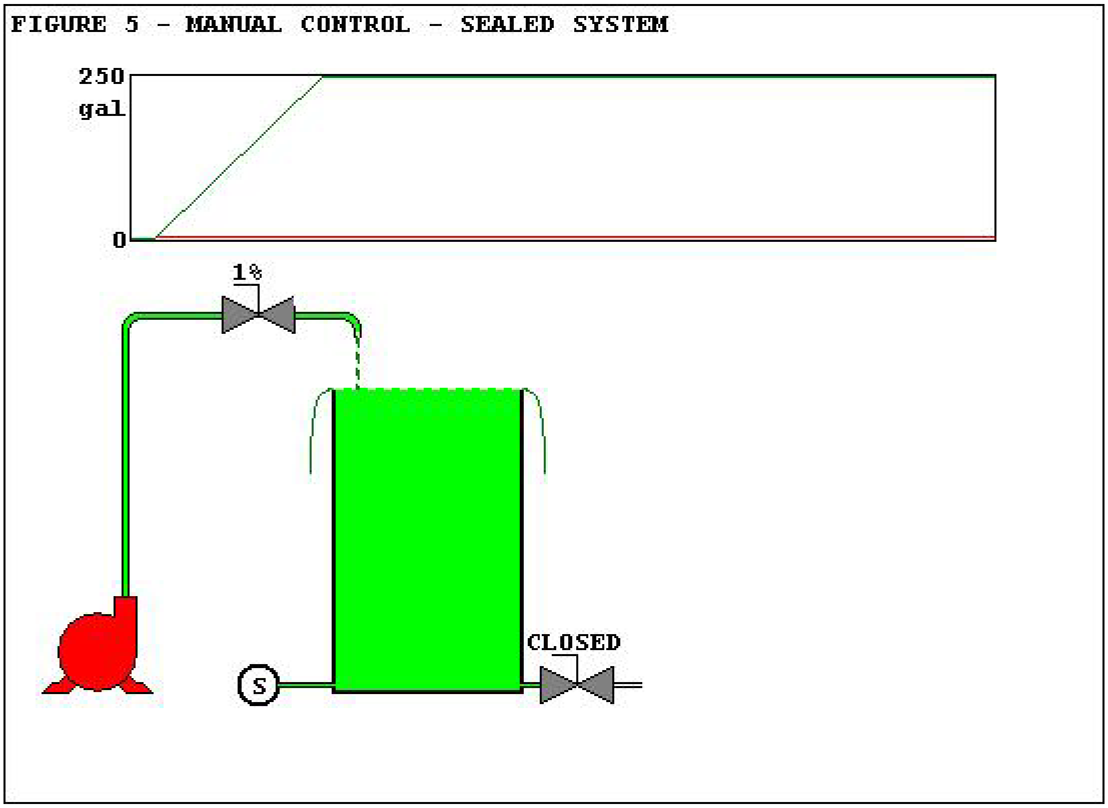
hopefully the examples of Figure 2 and Figure 3 will help answer most of your questions with regard to “pressure” as a Process Variable ...

now in Figure 4 we’ll begin looking at a “level” control application ... in this first example, we’ll simply take a full tank of water and allow it to drain by opening a valve at the bottom ...



as shown in the graph on the left, the tank begins draining rather rapidly at first ... but then the rate of the draining becomes slower as the test proceeds ... so instead of getting a straight line (a constant rate) for our draining process, we get a curve with a characteristic shape ... now at first glance, a beginner might think that the shape of this “gravity draining” curve is exactly like the shape of a capacitor discharge curve ... or like a curve produced by a cooling application ... but the draining curve is not exactly the same shape ... notice the difference as shown in the detailed graph on the right ... the draining curve is not as “rounded” in appearance as the cooling curve ... the reason is that the effect of gravity plays a part in the shape of this curve ... specifically, the amount of water draining when the tank is full is much greater than the amount draining when the tank is nearly empty ... notice the stream of water (1) which results when the level is higher at point (H) ... this stream is much larger than the stream of water (2) when the tank level is lower at point (L) ... anyone who wants to do some research on this effect should start by looking up Torricelli’s Theorem in any decent physics textbook ... for our purposes today, we can simply agree on what basic common sense and life’s experiences tell us is true ... specifically, a tank which is nearly full will drain much faster than a tank which is almost empty ...

in Figure 5 we’ve closed the drain valve completely ... and we’ve manually opened the fill valve just 1% ... since we have SOME water coming in but NO water going out, naturally the level in the tank begins to rise ... and the resulting shape of the trace is different from anything that I’ve shown before ... this one is a straight line ...

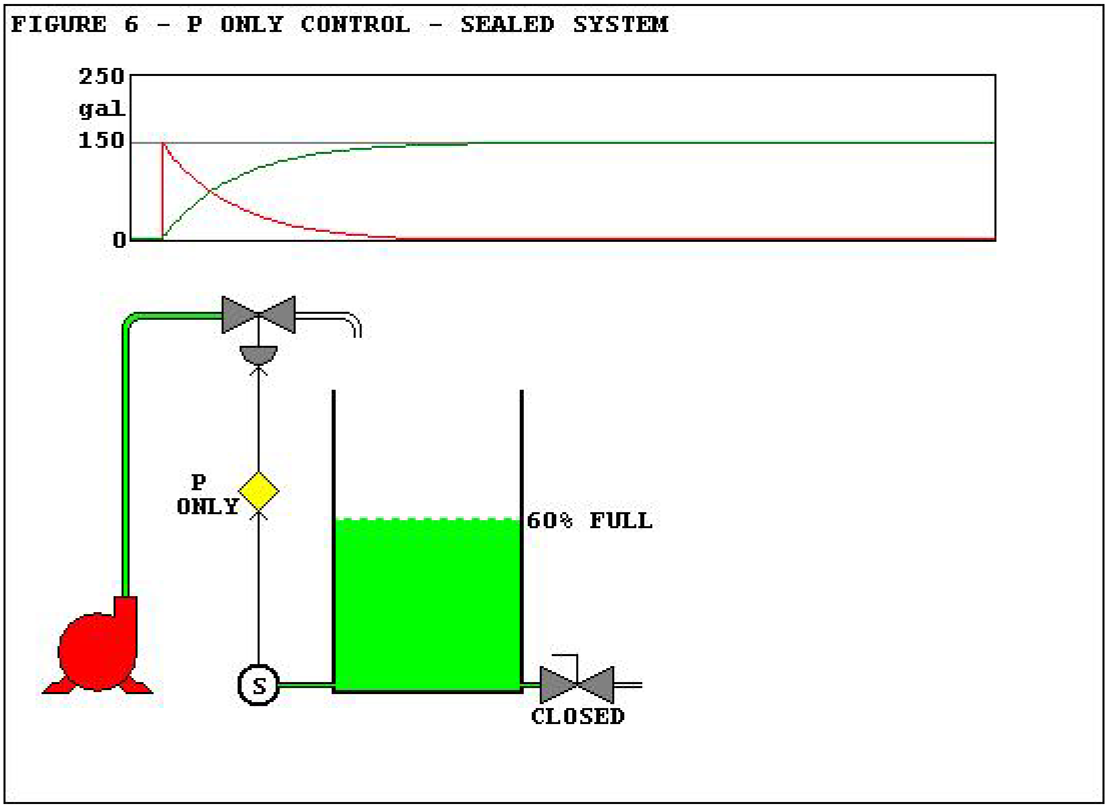


now keep in mind that the tank we’re using for our example is a straight-sided vessel and that we’re maintaining a constant rate of fill ... but under these conditions, basic common sense and life’s experiences are enough to convince us that, sooner or later, the tank will become full and then overflow ...

the main idea to come away with from this example is that the current level of the tank does NOT affect how fast the level continues to rise ... and so the characteristics of the “level control” system are different from those of our “pressure tank” example ... in the “pressure” example, the current amount of pressure in the tank DID indeed affect how fast the pressure could continue to rise ... and in our original “oven” example, the current temperature of the oven DID indeed affect how fast the temperature of the oven could continue to increase ... (remember that the DIFFERENCE between the oven and the surrounding air came into play in that example) ...

and so at this point we’ve looked at a few different types of processes and seen quite different responses from each one of them ... no wonder our student friend admits to being a little bit confused ... I can assure you that he is not the only student that I’ve ever met who finds all of this somewhat perplexing ... the basic idea is that different types of processes have different characteristics ... and when it comes to automatically controlling them, “one-size-fits-all” does NOT apply ...

in Figure 6 we have another type of “sealed system” ... again our controller is using only Proportional action ... and our Proportional gain has once again been given a setting of 1.00 ... and for consistency, our setpoint is once again dialed in at 60% (or 150 gallons) ...



and once again, we seem to be violating the popular textbook “rule” that says that “Proportional-only control will not maintain a setpoint” ... but by now you should be getting used to the trick involved in violating that particular “rule” ... specifically, we’re “cheating” just a little bit by keeping the drain valve closed ... under these special “sealed system” conditions, ANY amount of water entering the tank will raise the level ... and since the Proportional-only controller will not completely close off the fill valve until the setpoint is finally reached, then SOME amount of water will continue to flow into the tank until we’ve finally reached the target ... it might take a VERY long time, but eventually the target will be reached ... and the error will become zero ... and then the controller will finally completely close the inlet valve ...

but once again, this “sealed system” isn’t going to prove very useful in the real world ... someday somebody is going to open that drain valve ... we’ll cover that situation in just a little while ... but first ...

warning! ... trick question coming up ... this next part has little if anything to do with the topic at hand but I find it mildly entertaining ... and maybe we can learn something useful from it ... and so a side-trip just for fun ...

suppose that we temporarily turn off our automatic controller for awhile ... and suppose that we start out with an empty tank ... and suppose that we open the fill valve SOME amount and then leave it at that setting ... and suppose that we also open the drain valve SOME amount and then leave

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it at that setting ... suppose that we see the level in the tank start to rise ... now ...

since the level is definitely rising, we CAN say with assurance that “the water is coming IN faster than it is going OUT” ... but (and here’s the trick question) can we also say with absolute assurance that the tank will eventually fill all the way up and then overflow? ... at first glance we might think “yes, eventually that will surely happen” ... because (as we said before) “the water is coming IN faster than it is going OUT” ... and so an overflow must be inevitable ...

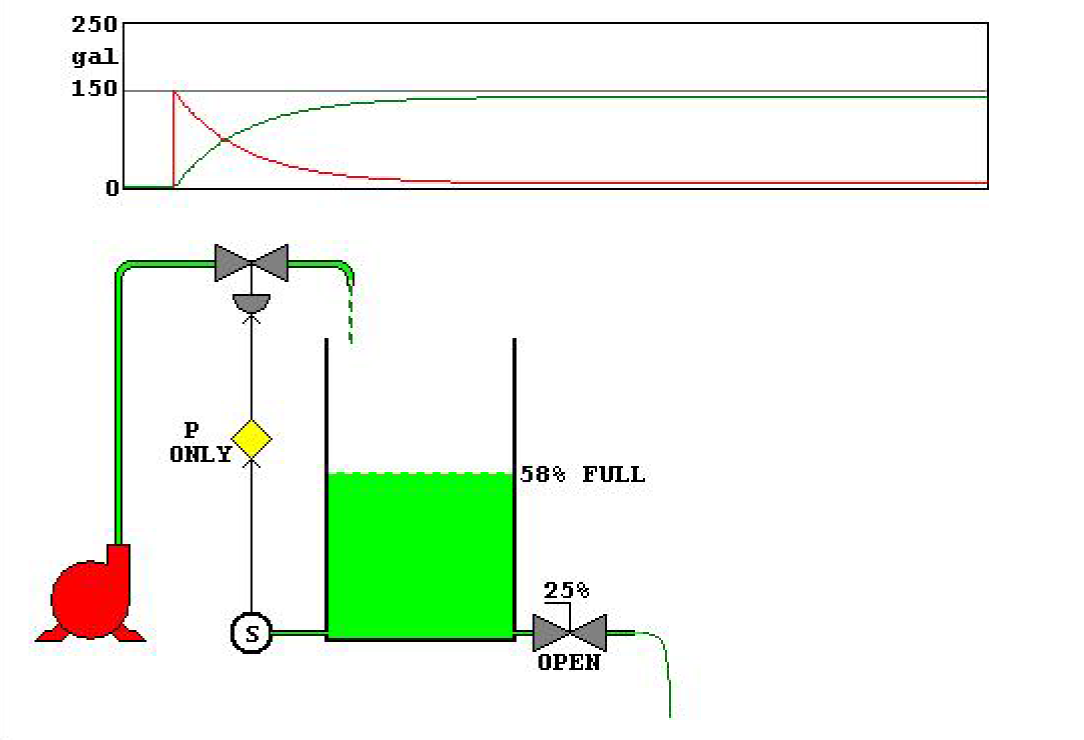
but the correct answer is “the tank MIGHT NOT overflow – we can’t be sure without more information” ... why? ...

remember that the amount of water draining from the tank under the force of gravity relies on the level (the height in feet and inches) of the water level in the tank ... and so the amount of water draining from the tank will constantly be increasing as the tank continues to fill ... and so, depending on exactly how much water is coming in, and depending on the setting of the drain valve, and depending on the depth of the tank, then there COULD be a point (a specific level) at which the rate of draining would exactly equal the rate of filling ... big idea: the “rate of fill” is a straight line as shown in Figure 5 ... but the “rate of drain” is a curving line as shown in Figure 4 ... and so without further information, we can NOT say with assurance that the tank will eventually overflow ... regardless of the fact that at the start of the test the water is indeed coming in faster than it is going out ...

as I said earlier, this doesn’t really have a lot to do with the subject at hand ... but I thought that I’d bring this discussion up just to show that you have to keep your wits about you when you’re trying to determine the characteristics of any particular system that you’re planning to control ... specifically, one size does NOT fit all ... and your mileage may vary ... and first impressions are not always correct ...

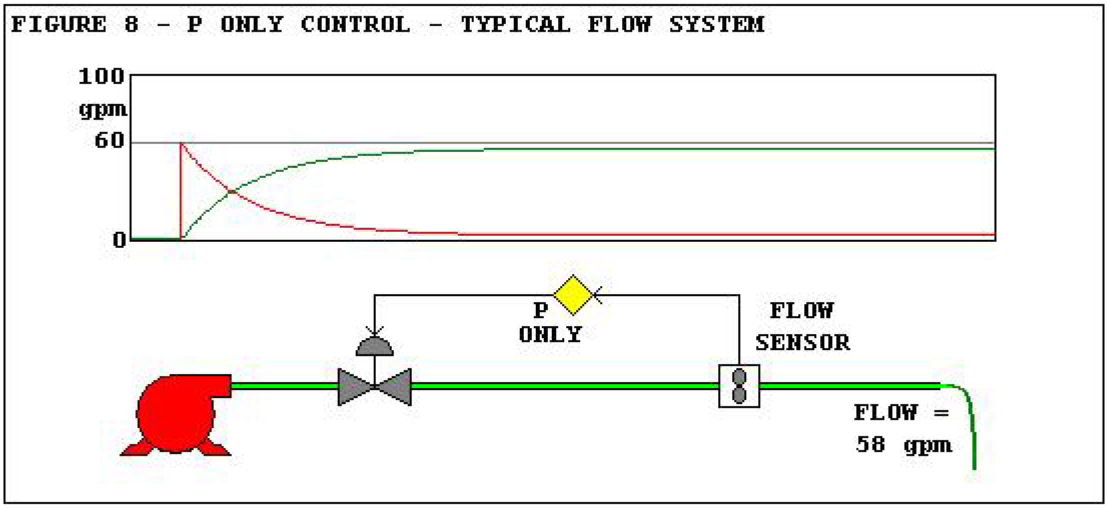
in Figure 7 we’ve finally opened the drain valve on our tank ...

FIGURE 7 - P ONLY CONTROL - WITH LOAD



so now we no longer have a “sealed system” ... the “load” represented by the water draining away from the tank produces the classic “droop” or position slightly below the setpoint that we normally associate with a Proportional-only controller ... and so instead of the 60% target which we desire, something more along the lines of about 58% is the best that our Proportional-only controller is able to give us ...

in Figure 8 we'll take just one quick look at a typical flow system ...



and by now you should have the idea that a "sealed system" would allow a Proportional-only controller to actually achieve and then maintain a desired setpoint for our flow application ... but think ... how on earth would we go about designing a "sealed system" for a flow process? ... by definition, a "flow" cannot be "sealed" ... and so when you get right down to it, the more we try to increase the flow ... then the more we increase the turbulence in the system ... and the more we increase the turbulence, then the more we increase the resistance to an increase in flow ... hint: that's why we need the pump in the first place ... SOMETHING has to overcome the inevitable resistance to the flow ...

I hope that this material helps with the basic question: "why won't a Proportional-only controller maintain a setpoint?" ...

best regards,
Ron

