Foroverkoblet regulering Kompetansemål:

- idriftsette og optimalisere regulatorer basert på prosessbehov

Læringsmål

- Kunne forklare hvordan en foroverkoblet reguleringsstruktur virker.
- Kunne sette opp en foroverkoblet reguleringsstruktur i et PLS program.
- Kunne ta opp en foroverkoblingsfunksjon

Forkunnskaper:

- Grunnleggende reguleringsteknikk

Teori

afgv.pdf - Basic process control strategies - Feedforward Control

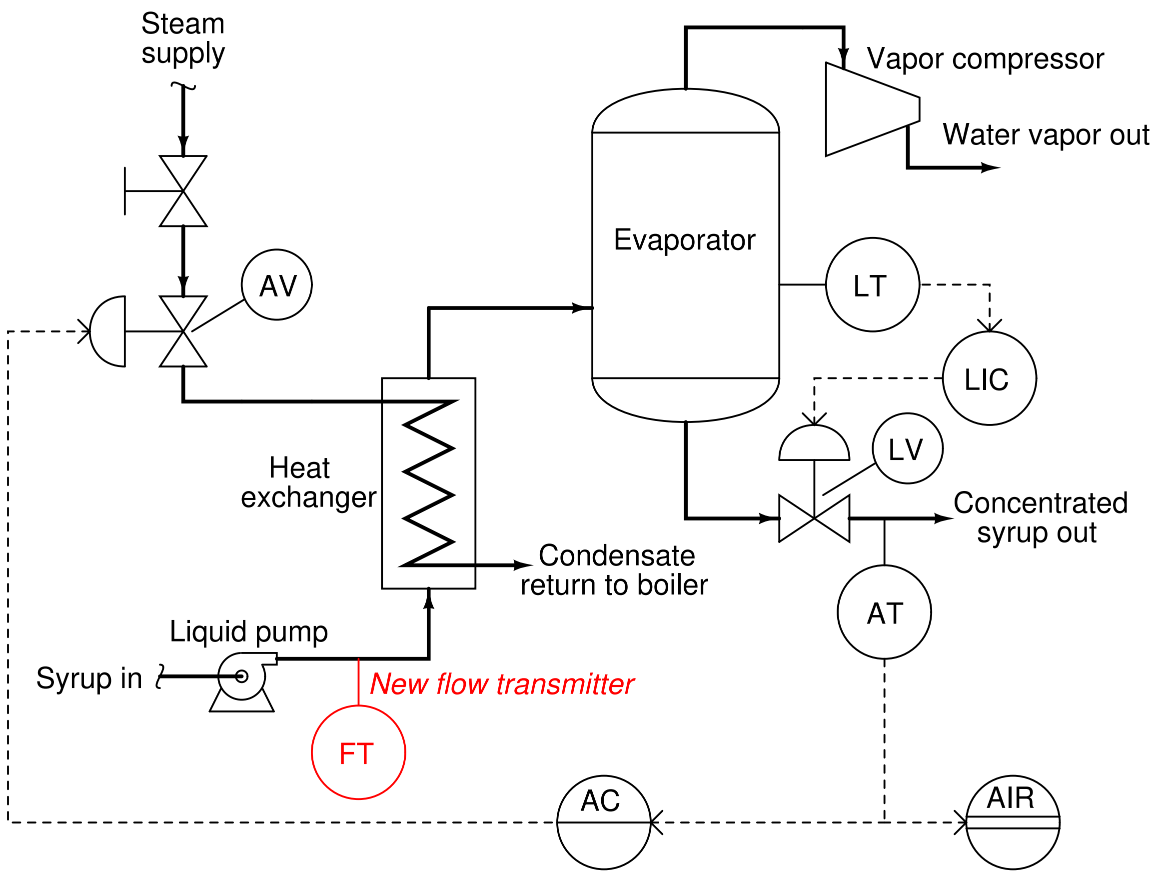
Øvingsoppgaver til leksjon - følger neste side

Innlevering til leksjon - Det er ingen innlevering til leksjonen.

Oppgaver

Oppgave 1

I denne prosessen blir sevje fra sukkerlønn oppvarmet for å gjøre den mer konsentrert. En sukkerkonsentrasjonsmåler måler konsentrasjonen på det ferdige produket som er lønnesyrup.



Et flowmeter er installert for å måle forandringer i strømmen av sevje. Prosessoperatører har funnet ut at variasjoner i strømmen av sevje har stor påvirkning på produktkvaliteten. Din oppgave er å implementere et reguleringssystem som holder produktkvaliteten konstand, selv med forandringer i strømmen av sevje.

Suggestions for Socratic discussion

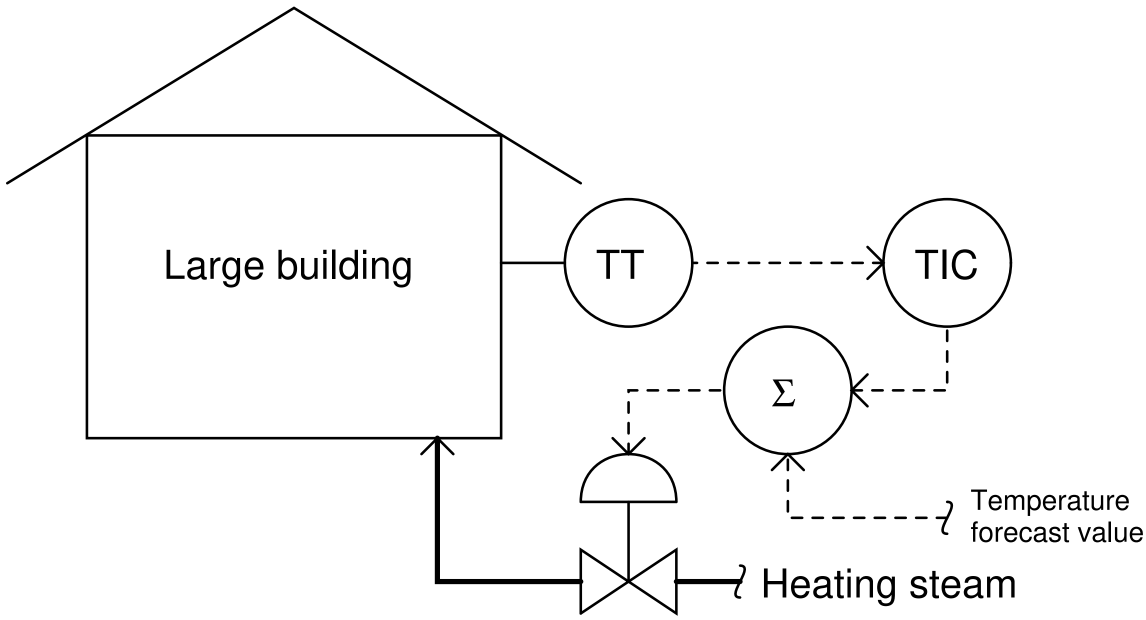
- A vitally important step to formulating a solution is to completely understand the problem. Perform some "thought experiments" to specifically determine what the adverse effects of feed flow changes are on the outgoing maple syrup quality.

- Perhaps the single most common mistake students make when planning a feedforward system is mis-placing the location of the *summing* function block, where the load signal adds to the feedback control signal. Explain why the load signal should always be added to the feedback controller *output* signal, and never to the feedback controller PV signal.

file i00424no

Oppgave 2

An energy-efficiency engineer decides to install an advanced temperature control system in a large building, which receives input from a weather prediction service to offset the effects of ambient temperature changes on the building's interior temperature:



Add polarity symbols (+, −) to the summing function to show how the forecast temperature should be combined with the controller output to effectively implement feedforward control to this system. Hint: you may find a "thought experiment" to be a helpful problem-solving technique here!

Suggestions for Socratic discussion

- Would this strategy be most useful on a *small* building or on a *large* building? Explain your answer.

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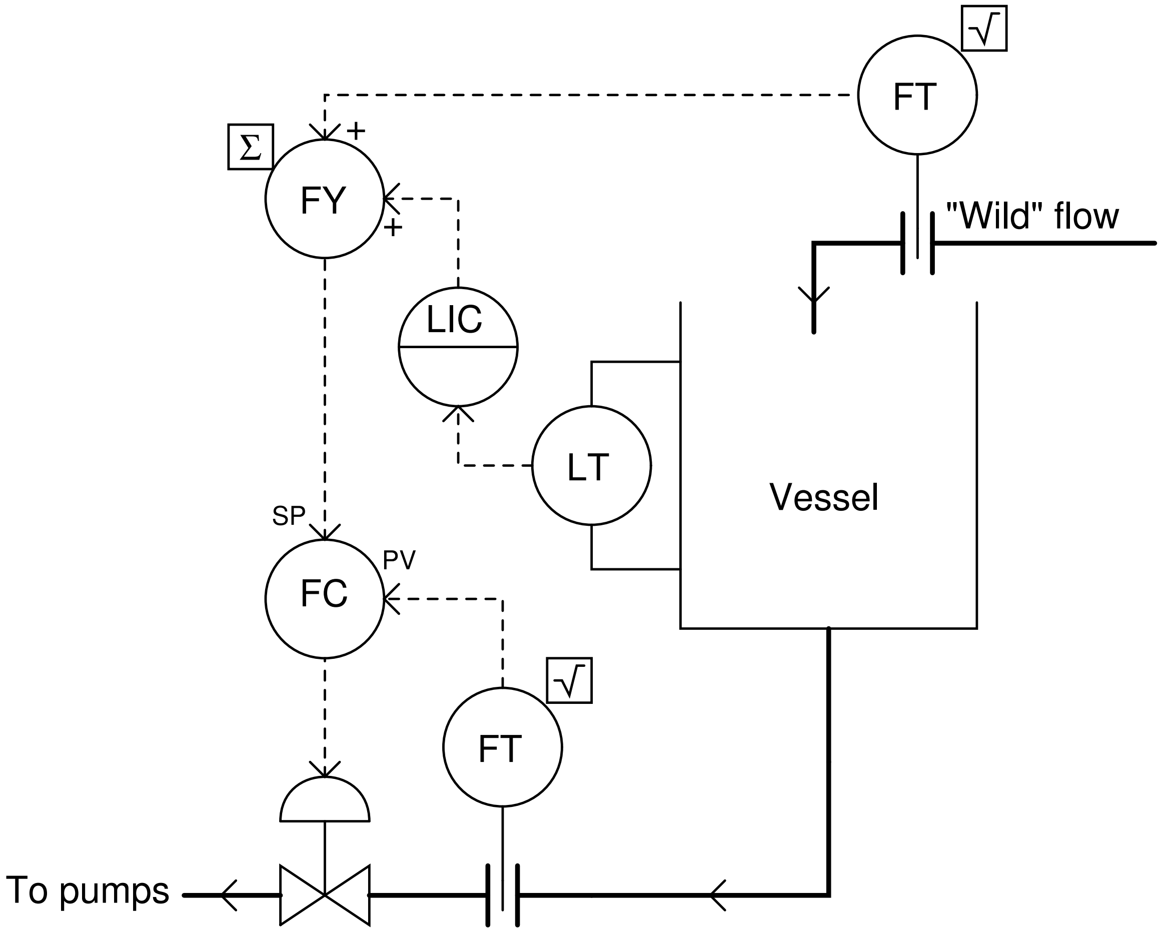
Oppgave 3

Denne reguleringsmetoden for nivåkontroll blir kalt treelements regulering.



Hva vil dette systemet gjøre for å holde konstant nivå hvis det er store variasjoner strømning inn i tanken.

Og hva vil systemer gjøre for å holde konstant nivå, om det oppstår en lekkasje i tanken?

Suggestions for Socratic discussion

- Explain why pure feedforward control is almost never used in industry. Instead, we almost always see feedforward used as part of a larger feedback control strategy.
- A problem-solving technique useful for analyzing control systems is to mark the PV and SP inputs of all controllers with "+" and "−" symbols, rather than merely label

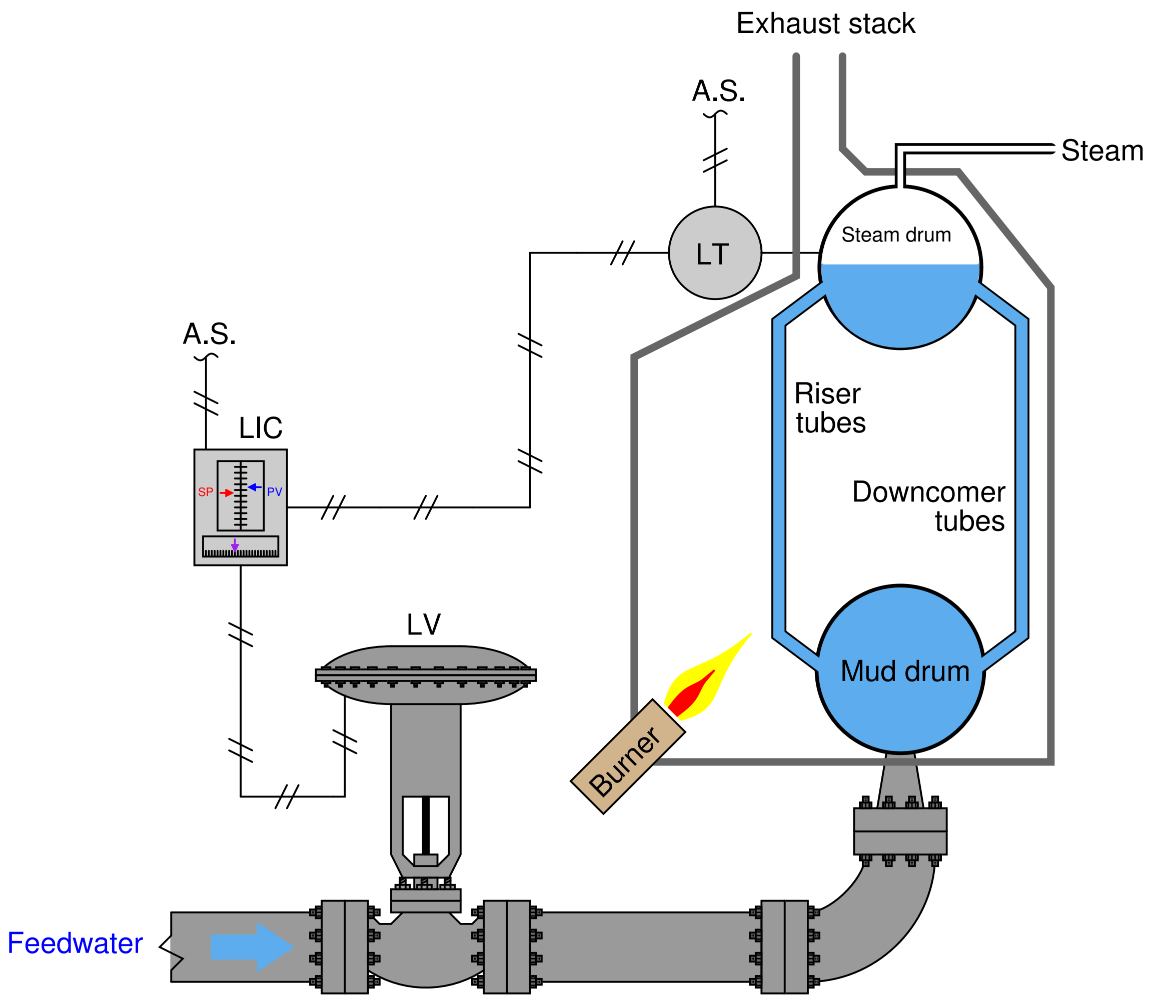
each controller as "direct" or "reverse" action. Apply this technique to the control strategy shown here, identifying which controller input(s) should be labeled "+" and which controller input(s) should be labeled "−".

- Explain what will happen if the level transmitter fails with a low signal.
- Explain what will happen if the level transmitter fails with a high signal.
- Explain what will happen if the summing relay fails with a low signal.
- Explain what will happen if the summing relay fails with a high signal.
- Explain what will happen if the flow controller is left in manual mode.
- Explain what will happen if the level controller is left in manual mode.
- Explain what will happen if the wild flow transmitter fails with a low signal.
- Explain what will happen if the wild flow transmitter fails with a high signal.
- Explain what will happen if the captive flow transmitter fails with a low signal.
- Explain what will happen if the captive flow transmitter fails with a high signal.

file i01750

Oppgave 4

Steam boilers are common in many process industries, and offer many challenges for process control. Let's begin with a simple, "single element" steam drum level control system:



This simplest type of drum level control is suitable only for boilers with very constant "loading" (steam demand). If the boiler is subjected to large fluctuations in steam demand, the drum level will be erratic, possibly leading to boiler tube damage.

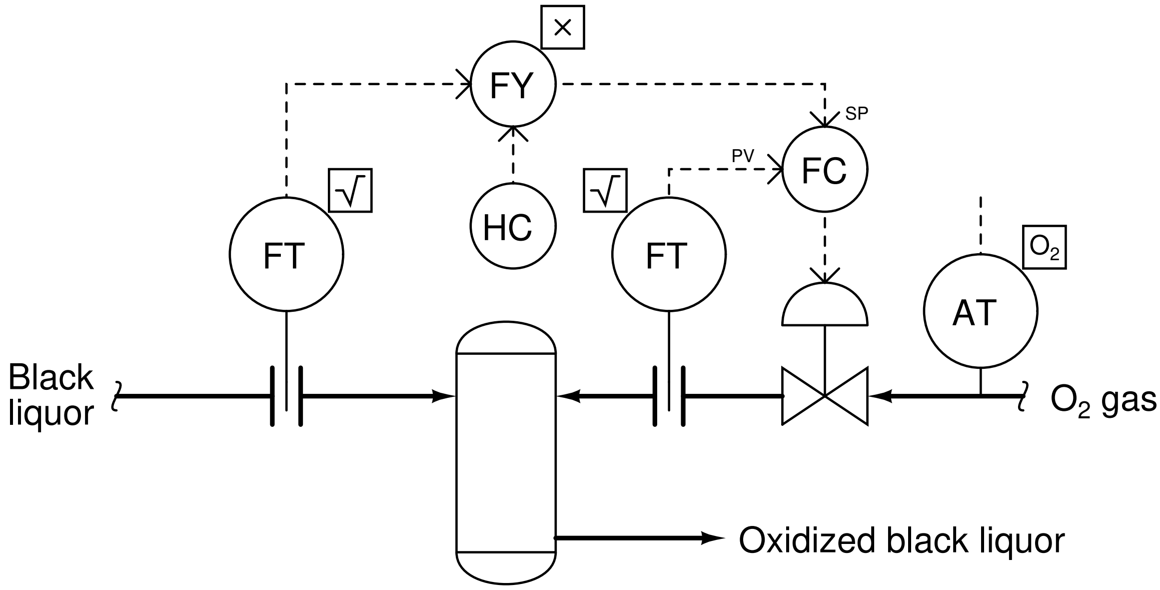
As you have seen though, *feedforward* control benefits processes with varying loads. Since steam demand is a type of load in a boiler system, determine how feedforward control could be added to this system to minimize the effects of changing demand (load) on drum level. Hint: this alteration to the control scheme will turn it from a "single-element" to a "two-element" level control system.

file i01788

Oppgave 5

A byproduct of the *kraft process* used in the paper industry for turning wood chips into pulp is a liquid called *black liquor*. This liquid contains many volatile sulfur compounds such as hydrogen sulfide (H_2S) and mercaptans, both of which are strongly scented, and if released to the atmosphere will constitute a hazardous (or at least strongly objectionable) emission. Loss of volatile sulfur compounds also constitutes a loss of sulfur, which is a raw material in the kraft pulping process.

These sulfur compounds may be stabilized for less volatility and easier recovery by a process of oxidation: exposing the black liquor to pure oxygen gas. To minimize consumption of oxygen, the gas flow is metered proportionately to liquor flow in a ratio control system:



One problem with this system, though, is that the purity of the oxygen gas varies over time. Some days it is near 95% pure, while other days it may sink down to 80% purity. The balance is made up of nitrogen gas, which does nothing to oxidize the liquor. Operations personnel discovered this problem when they had an oxygen analyzer installed on the O_2 line coming in to the oxidation reactor. Now they want a control system that takes this on-line measurement and automatically compensates the gas flow in to properly oxidize the liquor no matter what the oxygen concentration happens to be.

A useful problem-solving technique to apply here is a "thought experiment" where you imagine the oxygen purity changing between two easy-to-calculate values: suppose the purity begins at 100%, then suddenly changes to 50%. How should an automatic compensating system respond to the O_2 purity *being cut exactly in half*, in order to maintain proper oxidation of the liquor? Then, take that conclusion and implement it using one or more additional function blocks.

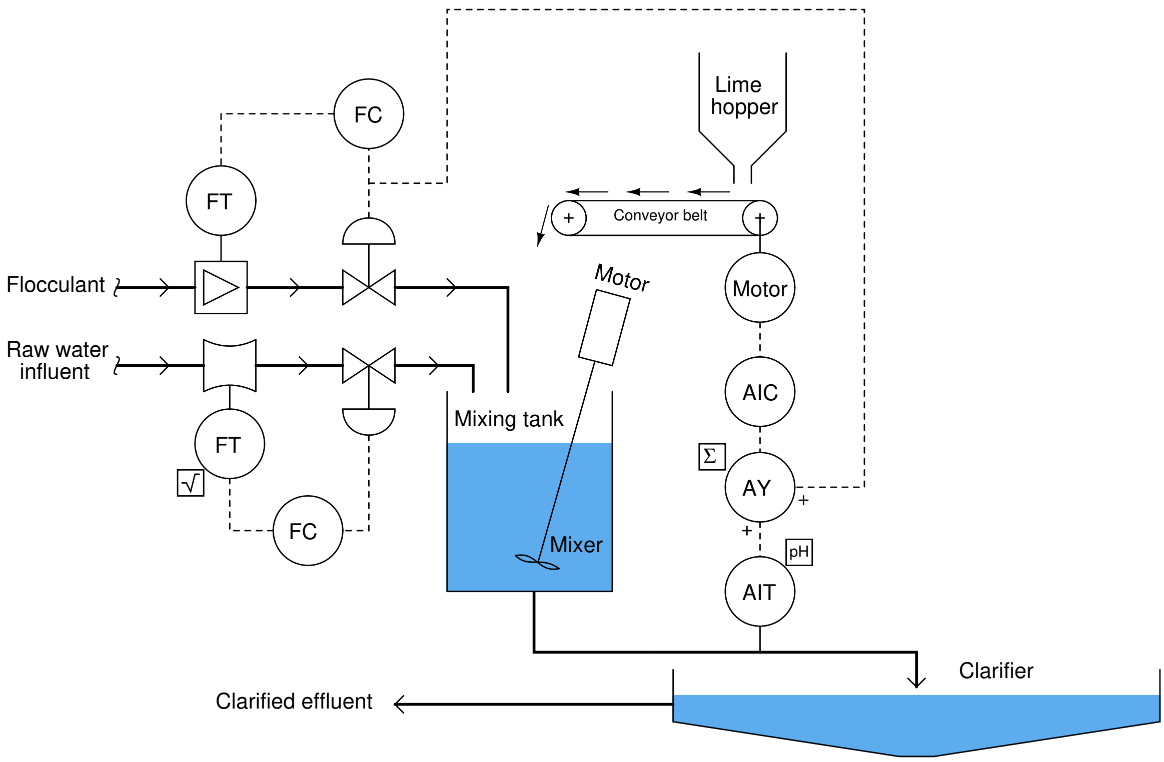
Suggestions for Socratic discussion

- Explain how the suggested thought experiment makes this a relatively easy problem to solve.
- For those who have studied flow measurement, explain why each flow transmitter has *square root* characterization.

file i00435

Oppgave 6

Water treatment processes use chemicals called *flocculants* to force suspended solids to clump together and readily fall out of suspension. Some flocculants such as polymers have the undesirable effect of lowering the water's pH value, which not only poses problems for further use of the water but also (ironically) minimizes flocculation efficiency. In order to counter-act this decrease in pH, powdered lime may be added to the water in addition to flocculant to raise the pH level back to a more neutral value.
One way to make this counter-acting lime addition more responsive to changes in flocculant flow is to use a *feedforward* control strategy to pre-emptively alter lime feed rate before the change in flocculant rate has an opportunity to affect the water's pH value. Unfortunately, someone implemented the feedforward incorrectly, as shown in this P&ID:



First, identify the mistakes you see in this P&ID, explaining how the system *would* behave if it were actually built and operated like this. Then, correct all the mistakes you see in this control strategy so that the feedforward strategy will work as it should.

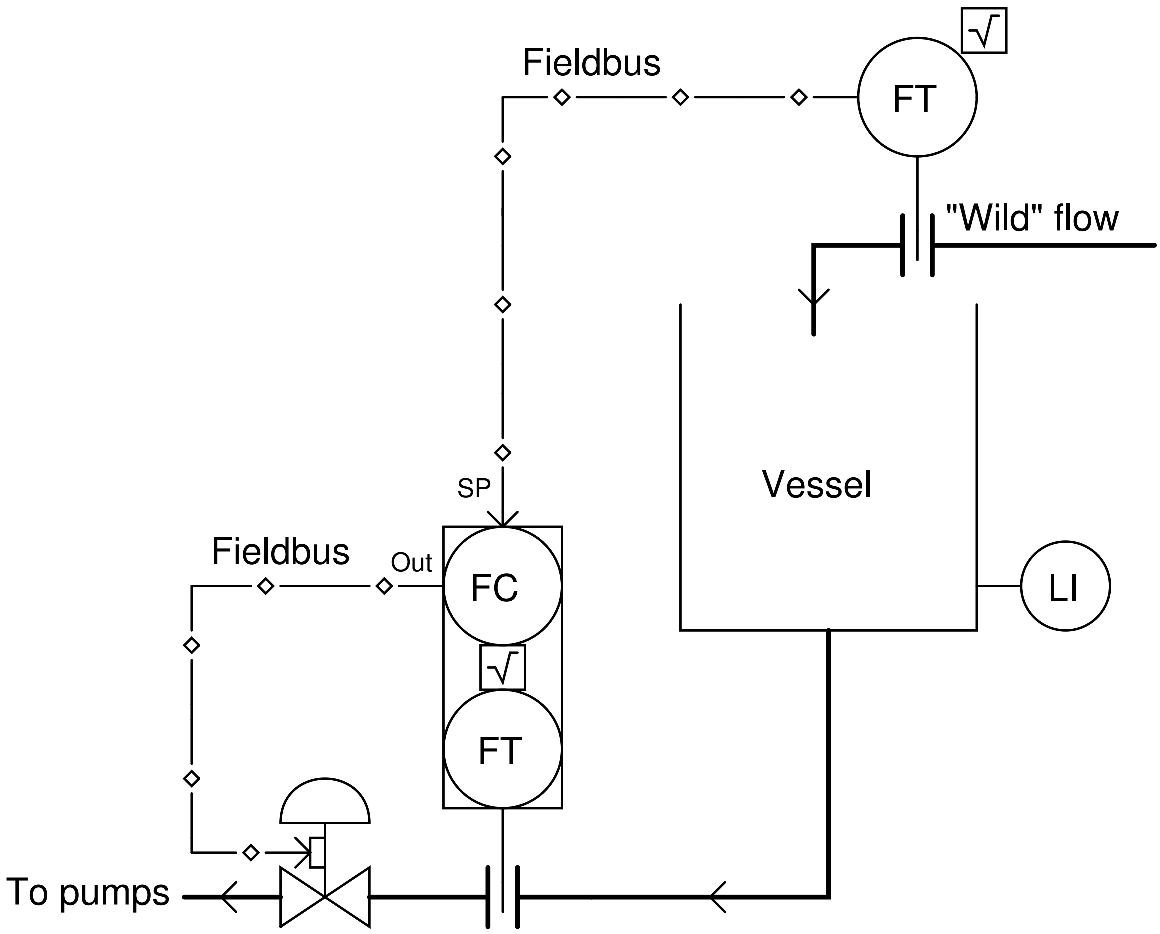
Suggestions for Socratic discussion

- Explain why someone might be inclined to sketch the control strategy in this (incorrect) manner. The mistakes shown here are quite common, and so there is likely a logical explanation for why they are so often made!
- Identify where you think *dynamic compensation* might best be applied in this system, after correcting the errors in this proposed feedforward control strategy.

file i00436

Oppgave 7

Since liquid level can only change in a vessel if there is an imbalance of inlet and outlet flow rates, would this system be practical to achieve steady liquid level control? Explain why or why not.



Note: the philosophy behind this control system is a principle known as *mass balance*, and it is a very valid principle. Explain what the principle of "mass balance" is, and how it is implied in the design of this control system.

Also, mark the SP and PV inputs of the controller in this system with "+" and "−" symbols as appropriate to show the correct controller action.

Suggestions for Socratic discussion

- Explain why the control system as shown is impractical for real-life use, despite the fact that it does represent a very effective and important control strategy frequently used in industry.
- Explain what "Fieldbus" instruments are, and how they differ from traditional instrumentation.
- How will this control system respond if the "wild" flow transmitter fails with a high signal?
- How will this control system respond if the "drain" flow transmitter fails with a high signal?
- How will this control system respond if the control valve's air supply fails?
- How will this control system respond if the "wild" flow line becomes partially plugged?
- How will this control system respond if the "drain" flow line becomes partially plugged?
- Are there any loads unaccounted for in this feedforward control strategy?

file i01749

Oppgave 8

In the United States of America, where the Superbowl is a very popular sporting event to watch from home, water and wastewater treatment plant operators have learned to pay attention to the game in order to improve process control. They know that a significant percentage of the population in any metropolitan area will simultaneously use the bathroom during breaks in the game, particularly the half-time break. This places unusual demands on both the water supply and the wastewater handling systems at very specific times.

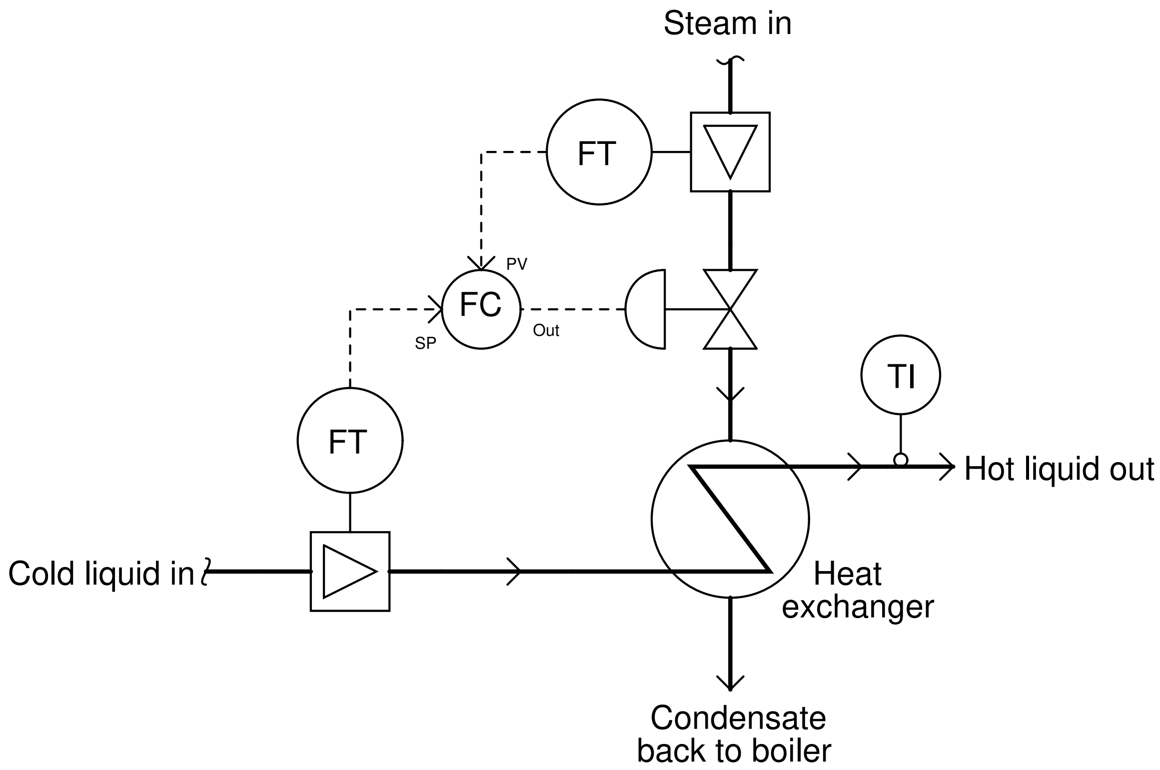
So, when a break begins, these operators at the water and wastewater treatment facilities preemptively turn on spare pumps to handle the impending flow rates, so that the systems do a better job maintaining setpoint. There is a technical term for this sort of control strategy: *feedforward*. Explain what "feedforward" control is, in your own words, and compare it against the more customary "feedback" control philosophy.

A practical example of feedforward control on a grand scale is the control of reservoir water level at hydroelectric dams. The dam must use or "spill" excess water when the reservoir is nearing full capacity, in order to avoid over-filling of the reservoir. A feedforward variable relevant to this control problem is ambient air temperature in the high mountain regions surrounding the reservoir. Explain how mountain temperature relates to reservoir level, and how such a feedforward control strategy might work in a hydroelectric dam.

file i01751

Oppgave 9

Since the outlet temperature of a heat exchanger can only change if there is an imbalance of inlet and outlet heat rates (assuming constant liquid inlet temperature and constant liquid composition), would this system be practical to achieve steady liquid outlet temperature control? Explain why or why not.



Note: the philosophy behind this control system is a principle known as *energy balance*, and it is a very valid principle. Explain what the principle of "energy balance" is, and how it is implied in the design of this control system.

Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question.
- Explain why the control system as shown is impractical for real-life use, despite the

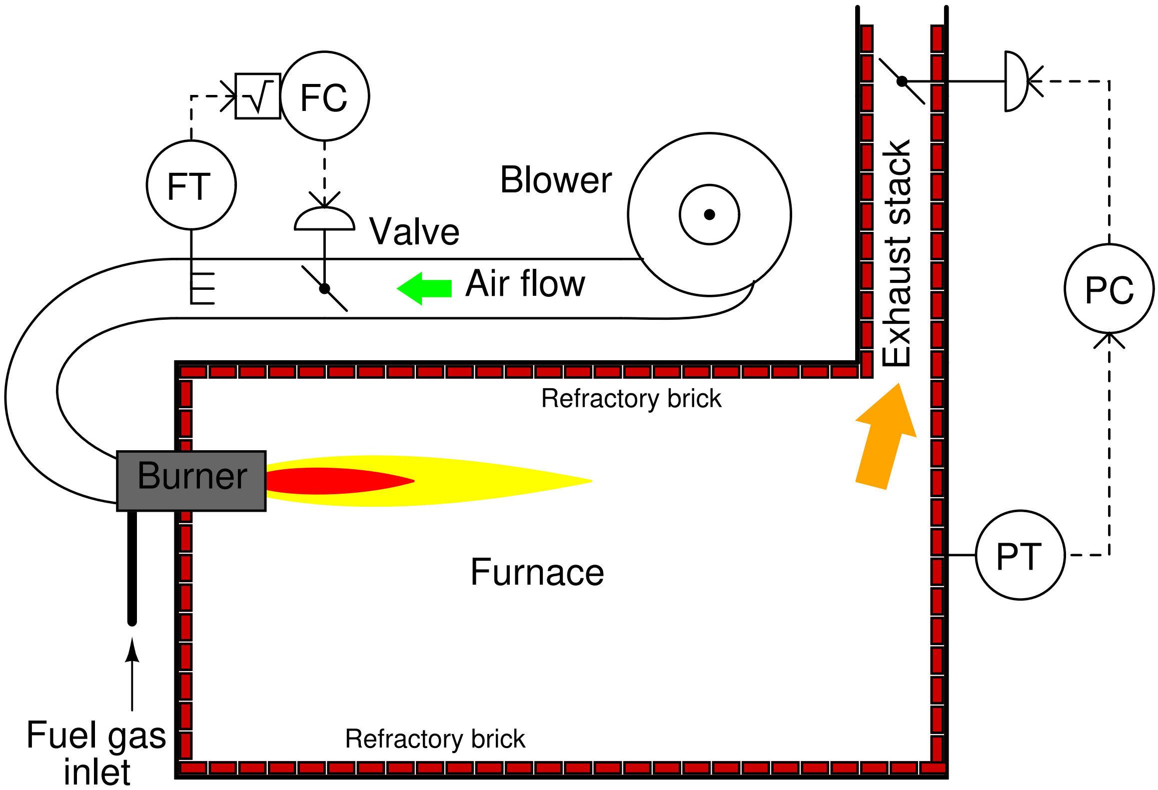
fact that it does represent a very effective and important control strategy frequently used in industry.

- Determine whether the controller needs to be *direct* acting or *reverse* acting.
- A problem-solving technique useful for analyzing control systems is to mark the PV and SP inputs of all controllers with "+" and "−" symbols, rather than merely label each controller as "direct" or "reverse" action. Apply this technique to the control strategy shown here, identifying which controller input(s) should be labeled "+" and which controller input(s) should be labeled "−".
- Modify this control strategy to incorporate "feedback trim" in addition to the feedforward action it currently possesses.
- Are there any loads unaccounted for in this feedforward control strategy? If so, see if you can modify this control strategy to account for them as well.

file i01770

Oppgave 10

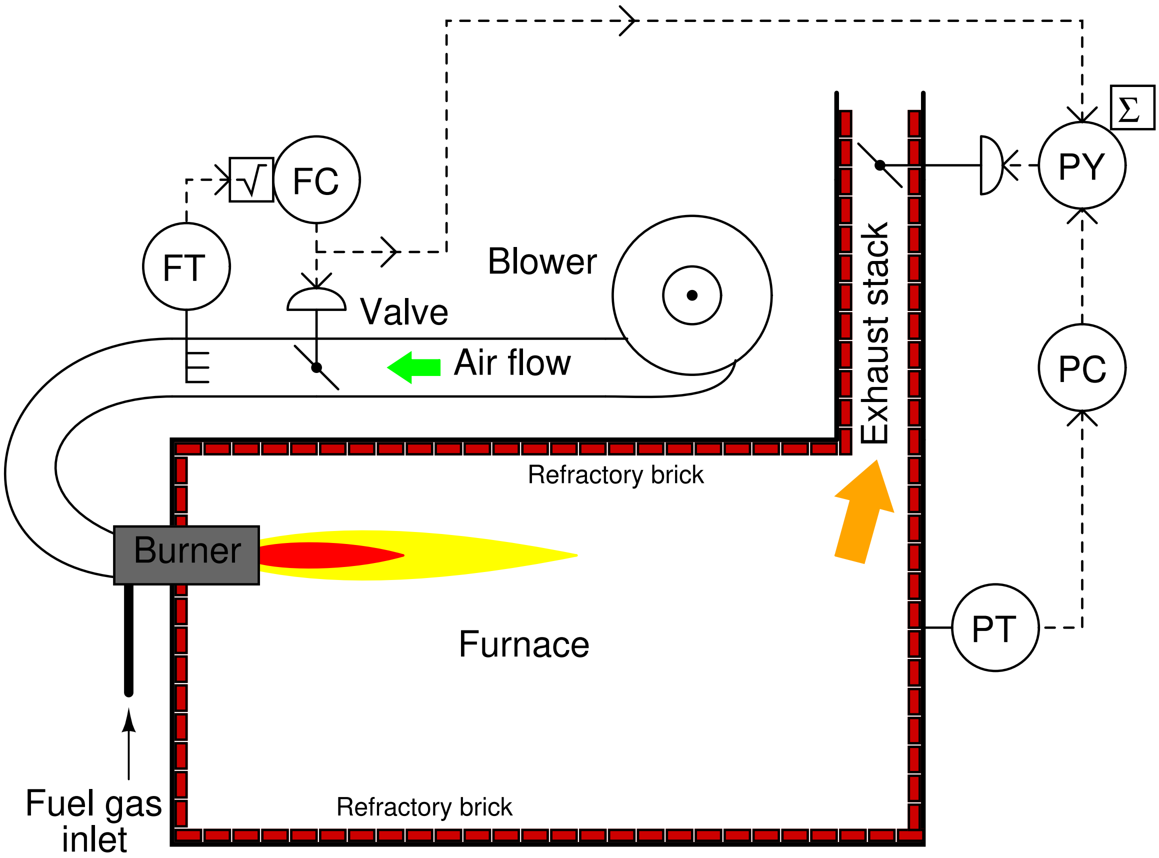
Sometimes two or more separate control loops interact with one another by way of the process being controlled. When this happens, the loops are said to be *coupled*. An example of this is air flow and air pressure control on a large combustion furnace:



The flow controller (FC) works to maintain a set air flow into the furnace for combustion, in order to precisely control the firing rate of the burner. The pressure controller (PC) works to maintain a constant furnace box pressure, to ensure minimal leakage of cold air into the furnace, or hot air out of the furnace.

A simple "thought experiment" illustrates the problem of coupling: suppose the setpoint to the flow controller is suddenly increased, calling for more air (to fuel a larger fire). What happens to furnace pressure as the inlet air flow damper opens up? What does the pressure controller tell the exhaust stack damper to do in order to maintain constant furnace pressure? How does the stack damper's motion consequently affect the air flow into the furnace? Unless one of these controllers is tuned much faster than the other, the two control systems will tend to "fight" one another through coupling.

A solution to this control problem is *decoupling*, illustrated in the next diagram:

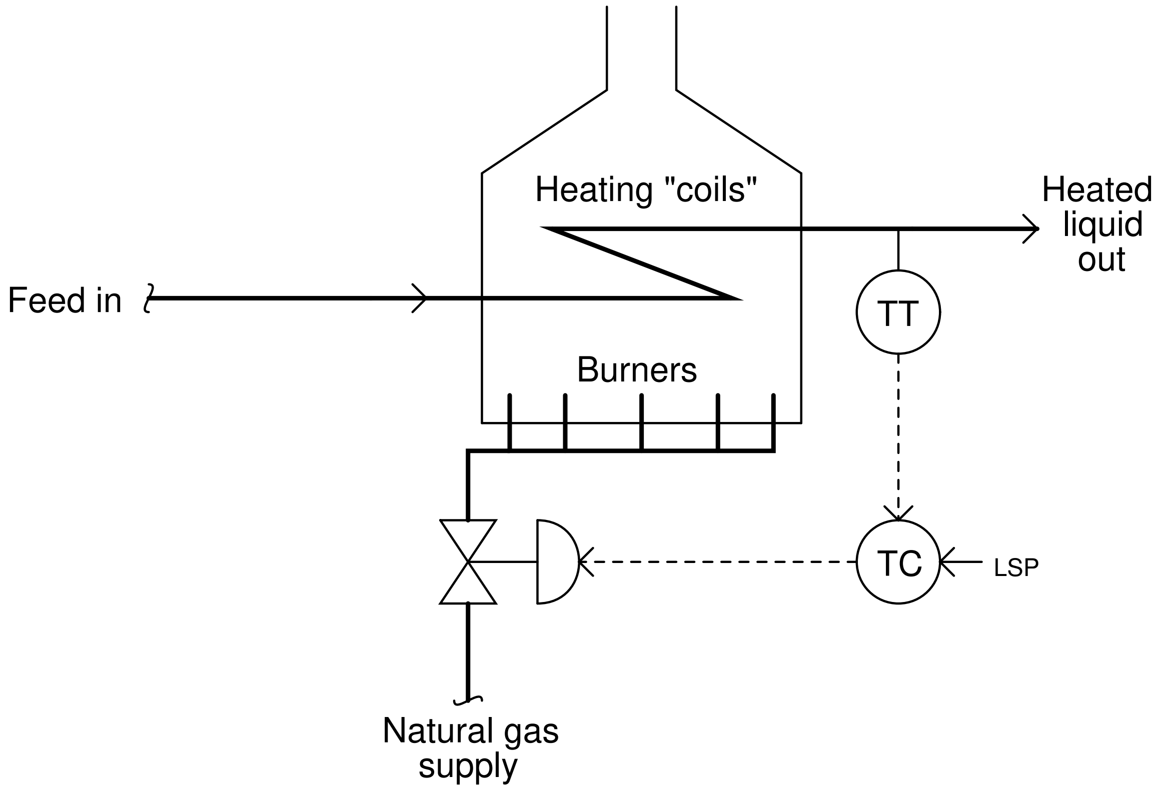


Explain how this control system modification solves the problem of coupling, and also explain how it is similar to *feedforward control* in its design.

file i01771

Oppgave 11

En gassfyrt varmeovn brukes til å varme opp en veskestrøm. En regulator brukes for å styre pådraget slik at temperauren på utgangen holdes konstant.



Denne måten å sette opp et reguleringssystem er i de fleste tilfeller god nok, men det finnes bedre løsninger. Hva vil f.eks. skje om væskestrømmen som skal oppvarmes raskt stiger i temperatur? Regulatoren vil gjøre justeringer når denne forandringen har nådd utgangen av varmeovnen og temperaturtransmitteren (TT) har registrert det.

En måte å forbedre dette systemet på er å innføre *foroverkoblet* regulering. Modifiser systemet ved å bruke en temperaturtransmitter på væskestrømmen inn og koble denne som en foroverkoblng på systemet.

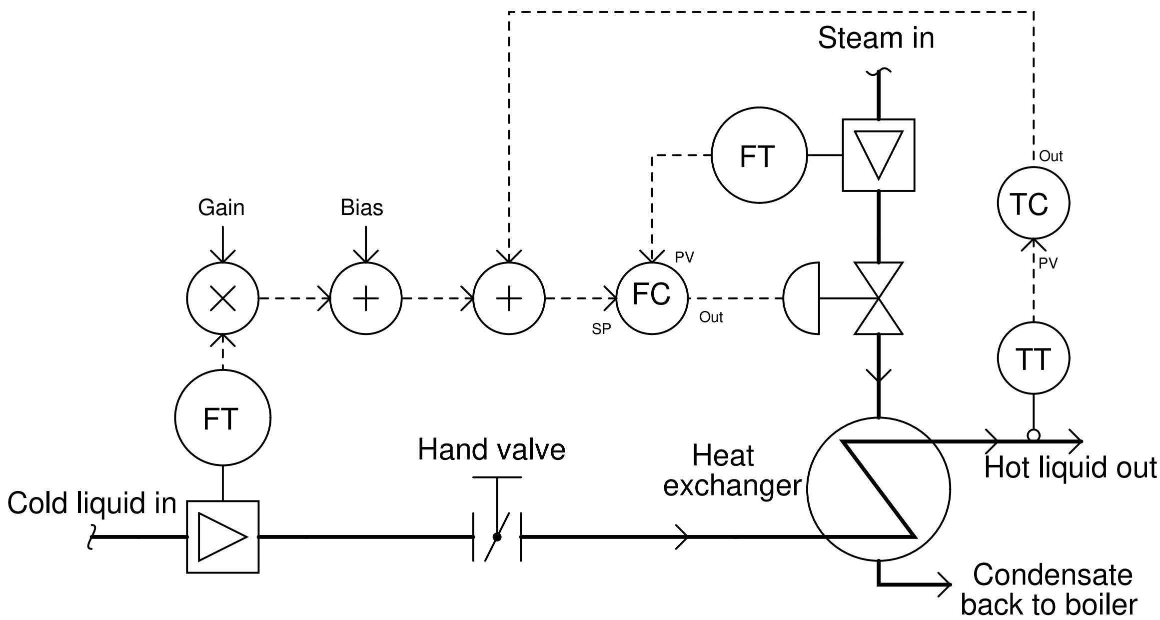
Suggestions for Socratic discussion

- Perhaps the single most common mistake students make when planning a feedforward system is mis-placing the location of the *summing* function block, where the load signal adds to the feedback control signal. Explain why the load signal should always be added to the feedback controller *output* signal, and never to the feedback controller PV signal.
- What do you suppose the heating "coils" look like in real life?
- For those who have already studied temperature measurement, what kind(s) of temperature-sensing elements do you think could be used in this application?
- Are there any loads unaccounted for in the requested feedforward control strategy? If so, see if you can modify this control strategy to account for them as well.

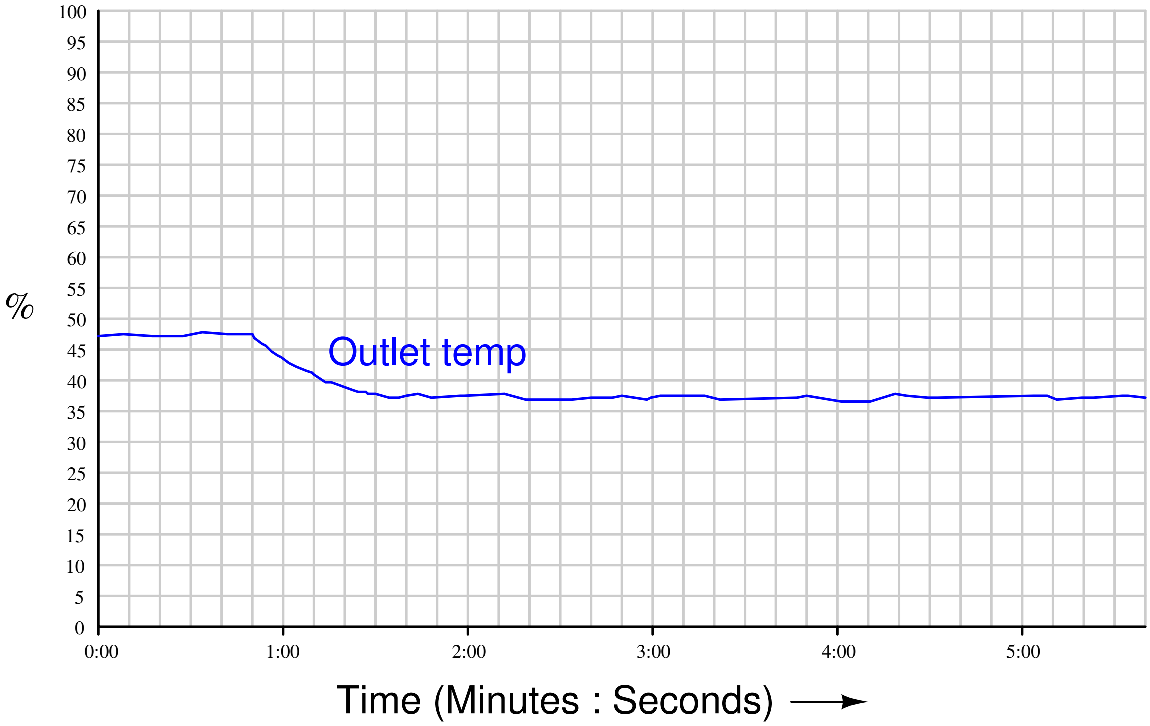
file i01776

Oppgave 12

Suppose this feedforward control system was just recently installed on a heat exchanger, complete with "gain" and "bias" functions to allow the feedforward action to be adjusted:



After tuning the flow and temperature controllers (in that order), the instrument technician's next step is to place the temperature controller in manual mode, then slightly close the hand valve leading into the heat exchanger in order to introduce a load change. The result is this trend of outlet temperature:



What should be adjusted in the feedforward system in order to achieve better load compensation? Why was it important for the technician to first place the temperature controller in manual mode before attempting the load change test? Would it have been equivalent to place the flow controller in manual mode instead?

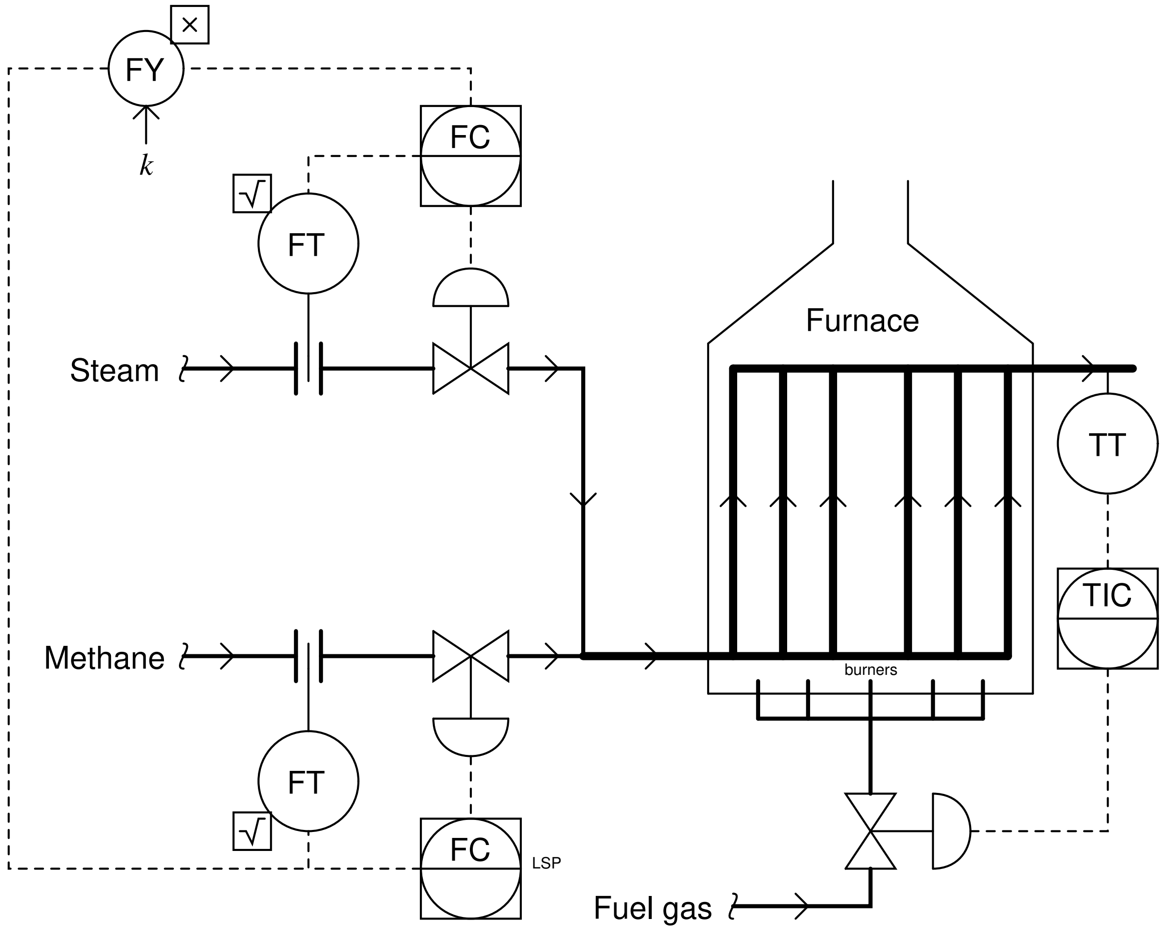
Suggestions for Socratic discussion

- Predict the effects resulting from one of the transmitters in this system failing with either a *high* or a *low* signal.
- Can we tell from the results of this test whether the feedforward system requires *lead* or *lag* dynamic compensation? If so, which form of dynamic compensation do you think this system requires?

file i02462

Oppgave 13

Reforming furnaces are special process furnaces used to generate pure hydrogen gas from a hydrocarbon feed gas, such as methane. Methane gas (CH_4) added to steam (H_2O) at high temperatures forms hydrogen gas (H_2) and carbon monoxide gas (CO), the latter converted into CO_2 and more hydrogen gas in subsequent reactions. The chemical reaction is highly *endothermic*, meaning that it requires energy input rather than liberating energy (as what happens in an *exothermic* process such as combustion). This required heat comes from a set of gas burners at the bottom of the reaction furnace:



The rate of hydrocarbon feed greatly "loads" the control of temperature inside the reaction furnace, making it more challenging to maintain setpoint temperature as the feed rate varies. Design a solution for this temperature-stability problem using a *feedforward* control strategy, explaining the reasoning behind your solution.

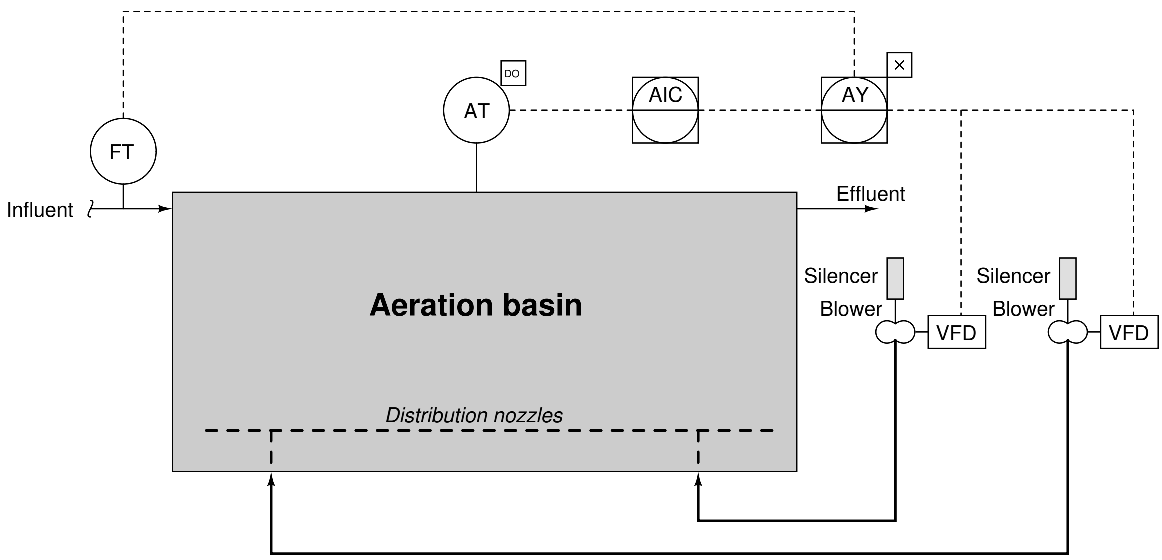
Suggestions for Socratic discussion

- How would your design solution be affected if the chemical reaction inside the furnace were mildly *exothermic* rather than endothermic?
- Predict the effects resulting from one of the transmitters in this system failing with either a *high* or a *low* signal.
- Predict the effects resulting from an operator increasing the steam-to-methane ratio value (k).
- Devise a test by which you could determine whether *dynamic compensation* is needed in your proposed feedforward control strategy. Be specific, identifying how you can tell whether you will need to incorporate *lead* or *lag* into the feedforward loop to optimize its performance.

file i02504

Oppgave 14

One of the major processes used to treat municipal wastewater is *aeration*, where the dissolved oxygen concentration of the wastewater is enhanced by bubbling air through the water in an *aeration basin*. A dissolved oxygen ("DO") analyzer measures the oxygen concentration in the wastewater, and a controller varies the speeds of blowers pumping air into the basins using AC motors powered through variable-frequency drives (VFDs):



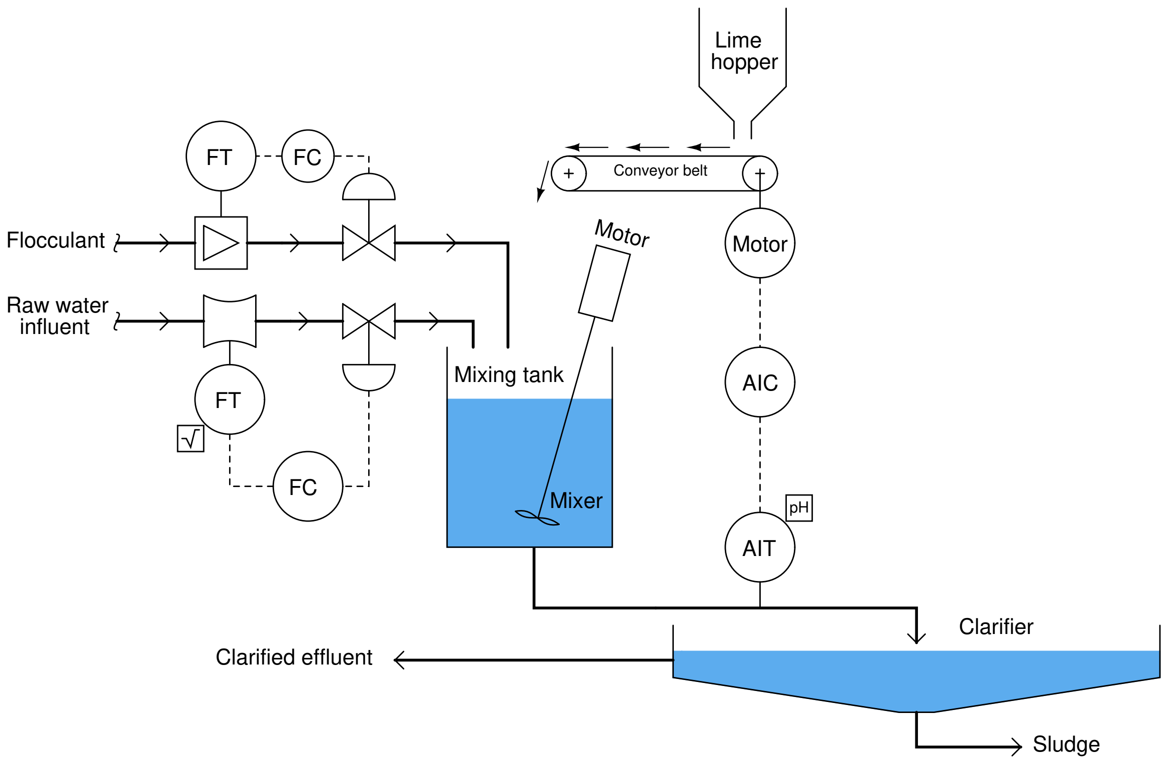
The control strategy used here is called *adaptive gain*. While similar in configuration to feedforward – where a load variable (in this case, influent flow rate) is used to alter the MV signal going to the final control element(s) of a feedback control loop – the relay used in this case is a *multiplier* rather than the more customary *summer* seen in conventional feedforward strategies.

Explain why a multiplying relay really is the most appropriate for this kind of application, "demonstrating" your explanation by posing a thought experiment of your own design.

file i03291

Oppgave 15

Water treatment processes use chemicals called *flocculants* to force suspended solids to clump together and readily fall out of suspension. Some flocculants such as polymers have the undesirable effect of lowering the water's pH value, which not only poses problems for further use of the water but also (ironically) minimizes flocculation efficiency. In order to counter-act this decrease in pH, powdered lime may be added to the water in addition to flocculant to raise the pH level back to a more neutral value:



A pH transmitter measures the pH level of the water exiting the mixing tank, on its way to the clarifier where the floc will settle to the bottom over time and cleaner water is collected at the outer rim.

If someone happens to change the setpoint on the flocculant flow controller, the flow of powdered lime into the mixing tank will not change until the pH controller (AIC) sees a change in pH, which by then may be too late to make a swift correction. The result will be a "bump" in pH over time that may take a while to correct.
Modify this control system to include feedforward, so that any change in flocculant flow rate will *immediately* alter the flow rate of lime, in order to help stabilize pH and thereby improve water treatment quality.

Suggestions for Socratic discussion

- Perhaps the most common mistake made in this problem is to place the feedforward summing function block at the PV input to a controller, when it should actually be located at the output of a controller instead. Explain how we may determine the correct location for the summing block in the control scheme of this process, and/or explain why the other location is wrong.
- For those who have previously studied chemistry, explain what *pH* is and why it is important.
- Why is a *mixing tank* important to have in a system like this where pH is being continuously controlled?

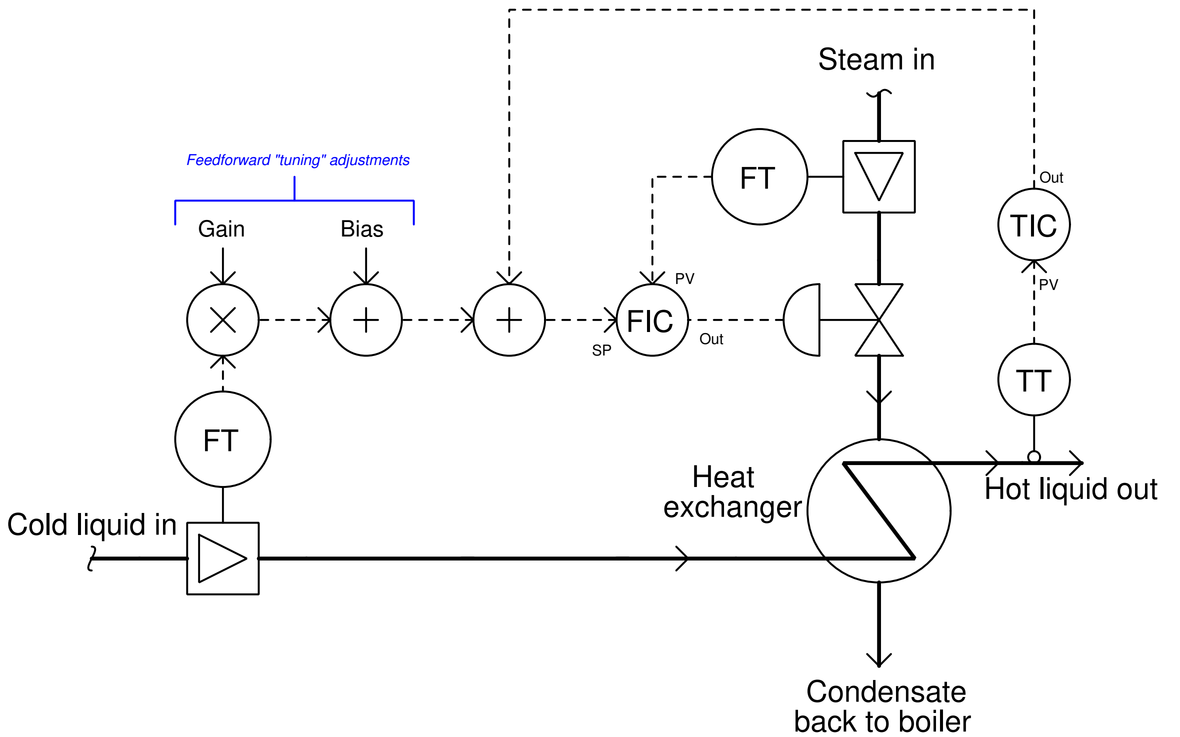
file i03445

Oppgave 16

When the loop controller in a *feedback* control system is tuned too aggressively, it will result in process oscillations. This is a well-known fact of loop tuning, and indeed is regarded as a reliable indication of overly-aggressive controller action.

Feedforward control loops, by contrast, cannot create oscillations. However, it is still possible to have "too much" feedforward action in a loop, so that process control quality suffers.

Examine the following P&ID of a practical feedforward control system on a heat exchanger, complete with "gain" and "bias" functions to allow the feedforward action to be adjusted:



How would this feedforward control system respond to load changes if it were "over-tuned" so that it took *too much* corrective action? What could you do to this system to test the feedforward control response, in order to tell whether or not the magnitude of its corrective action was appropriate? Identify the specific adjustments that you would make to this feedforward system so that its action was more appropriate, if it were discovered that the feedforward action was too aggressive.

Suggestions for Socratic discussion

- Determine the appropriate actions (*direct* acting or *reverse* acting) for each controller shown in this system, labeling all inputs with either "+" or "−" symbols as appropriate to show the correct action for each controller.
- What types of flowmeters are shown in this P&ID, and how do they work?
- Identify the individual effects of improper *gain* adjustment, versus improper *bias* adjustment in the feedforward loop. Are the effects the same for both? Why or why not?
- Explain what would happen in this process if the liquid flow transmitter failed with a low signal.
- Explain what would happen in this process if the liquid flow transmitter failed with a high signal.
- Explain what would happen in this process if the steam flow transmitter failed with a low signal.
- Explain what would happen in this process if the steam flow transmitter failed with a high signal.
- Explain what would happen in this process if the temperature transmitter failed with a low signal.
- Explain what would happen in this process if the temperature transmitter failed with a high signal.
- Explain what would happen in this process if the flow controller were switched from "Cascade" mode to "Automatic" mode.
- Explain what would happen in this process if the flow controller were switched from "Cascade" mode to "Manual" mode.
- Explain what would happen in this process if the temperature controller were switched from "Automatic" mode to "Manual" mode.

file i04339

Oppgave 17

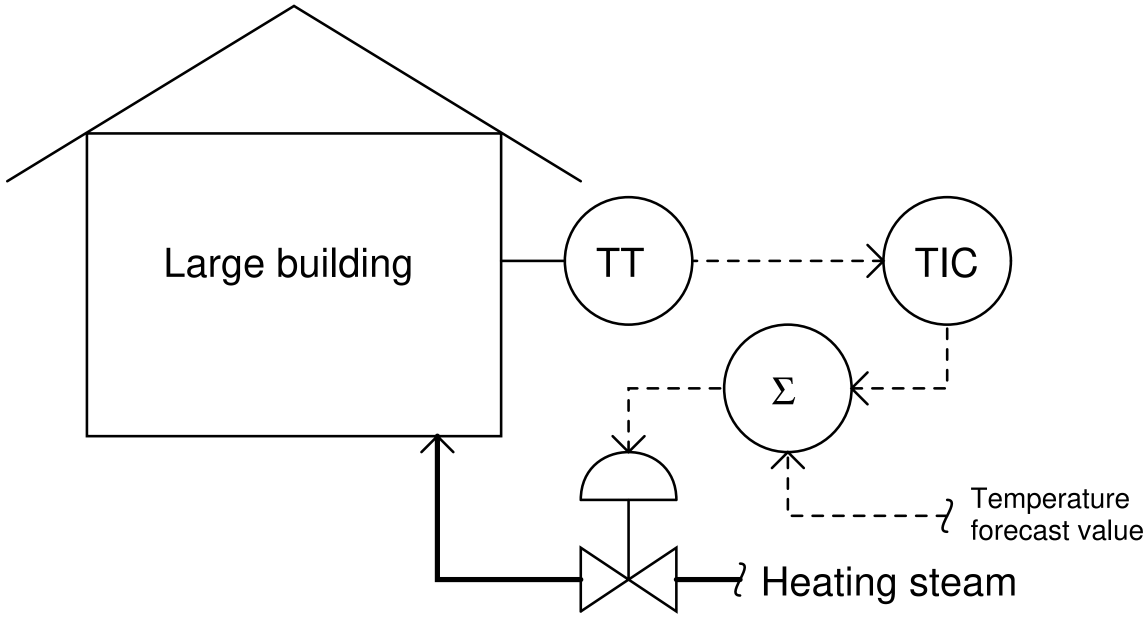
Perform the following numeration system conversions:

- 110011 (unsigned binary) into decimal: ________
- 139 (decimal) into octal: ________
- 8C (hexadecimal) into binary: ________

file i04340

Oppgave 18

An energy-efficiency engineer decides to install an advanced temperature control system in a large building, which receives input from a weather prediction service to offset the effects of ambient temperature changes on the building's interior temperature:



Add polarity symbols (+, −) to the summing function to show how the forecast temperature should be combined with the controller output to effectively implement feedforward control to this system. Hint: you may find a "thought experiment" to be a helpful problem-solving technique here!

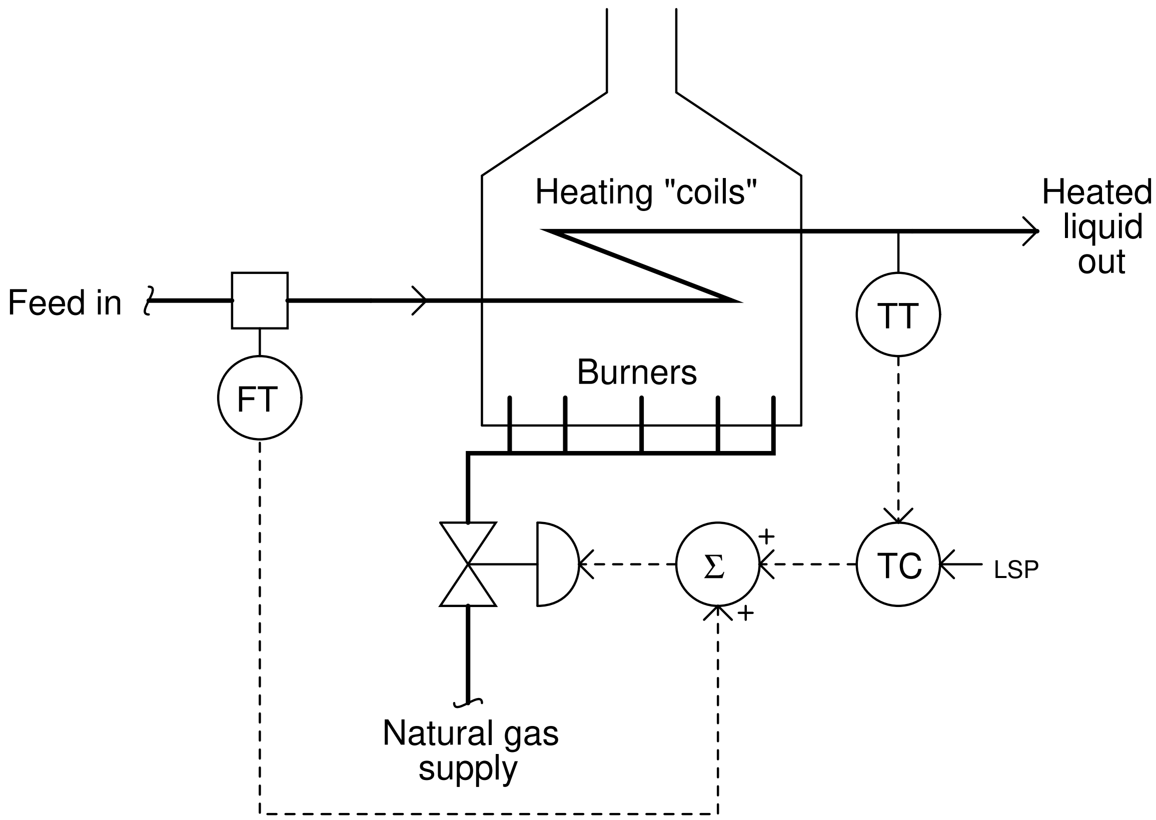
Suggestions for Socratic discussion

- Would this strategy be most useful on a *small* building or on a *large* building? Explain your answer.

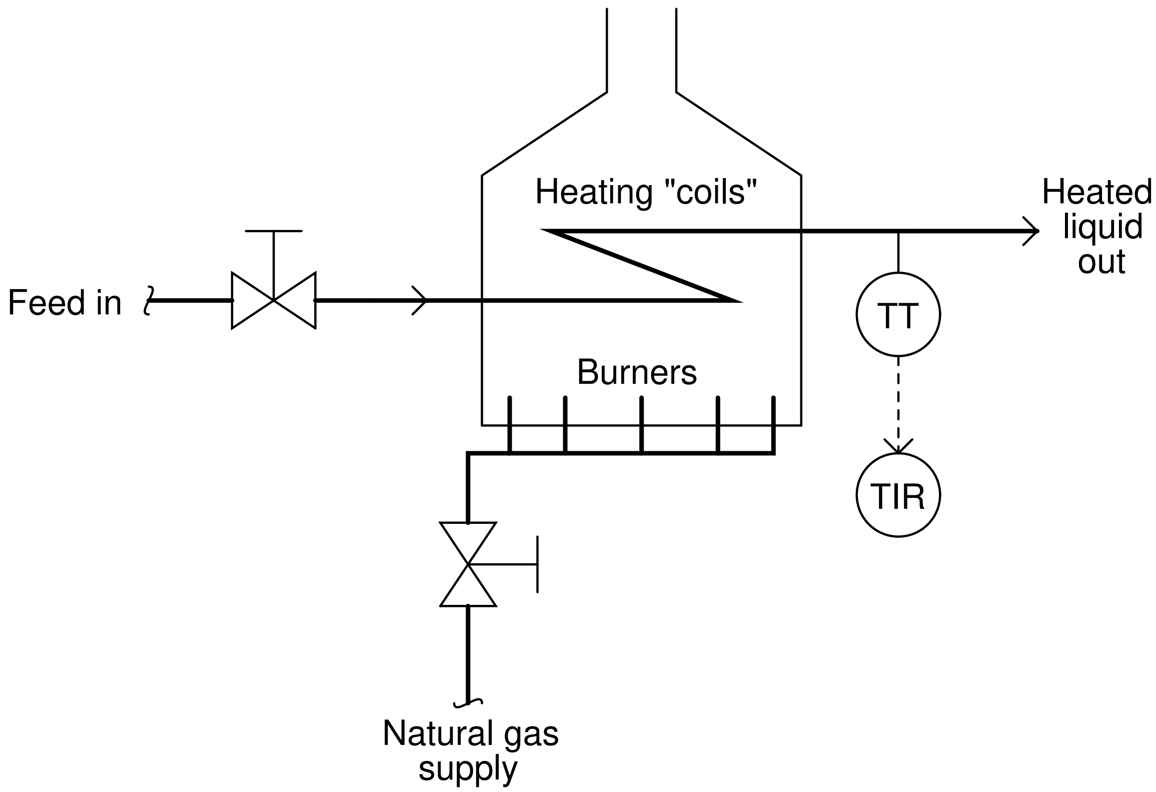
file i04345

Oppgave 19

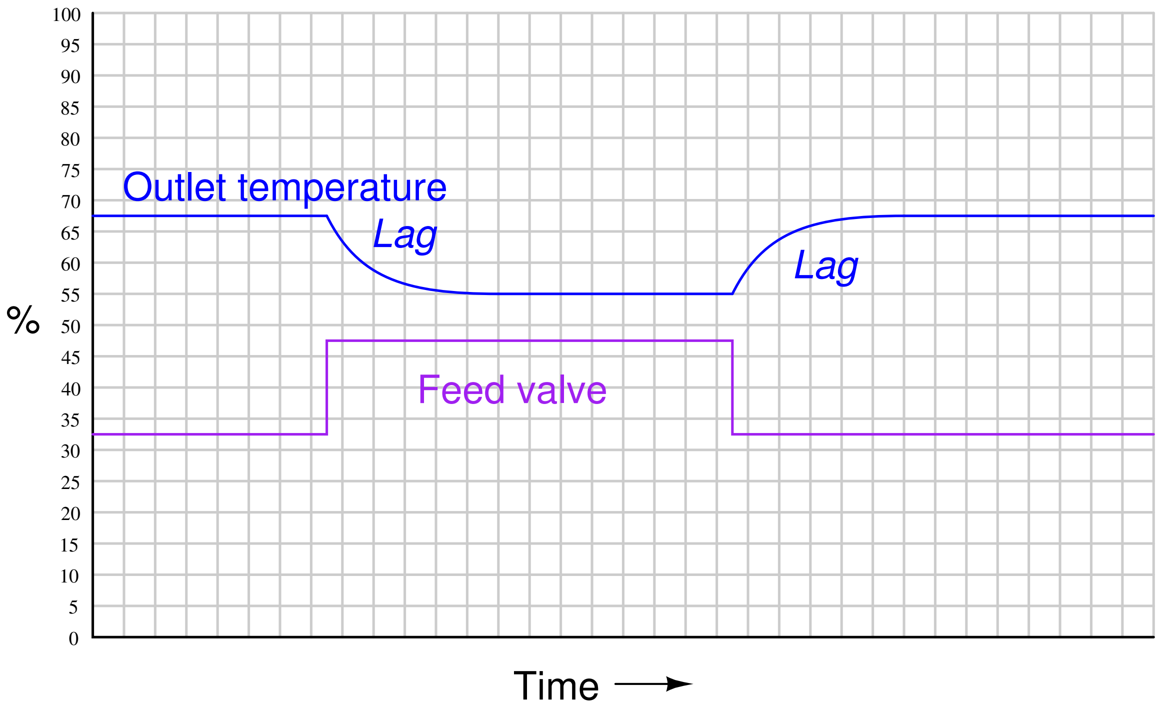
Shown here is a simple feedforward control system (with trim), which attempts to compensate for changes in cold feed flow by immediately adjusting fuel flow to the burners proportionately (*before* the outlet temperature has time to change):



A problem lurks within this process, however, which is not very obvious. The problem is *lag time*. Imagine removing all automatic controls from the process, and replacing them with hand valves so we could have manual control over feed flow and fuel flow while we graphed outlet temperature on a trend recorder:



Now, imagine introducing a step change in feed flow, and a step change in fuel gas flow, in two separate tests: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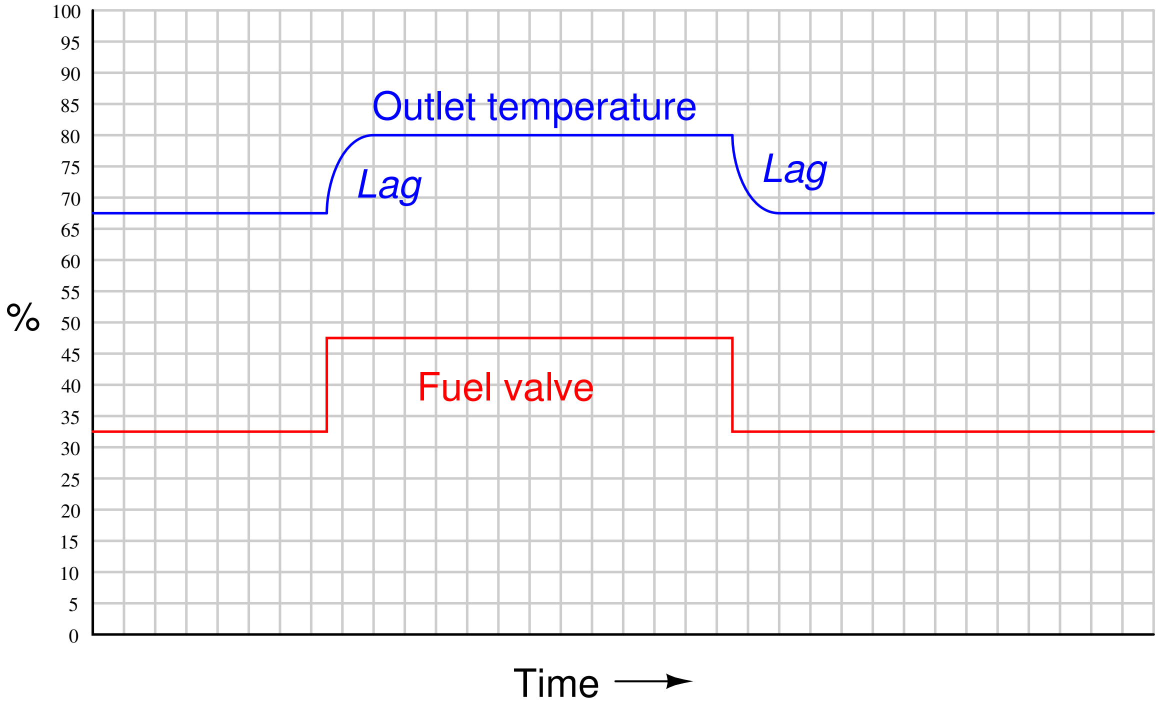
60
55
50
45
40
35
30
25
20
15
10
5
0
%
Outlet temperature
Lag
Lag
Feed valve
Time

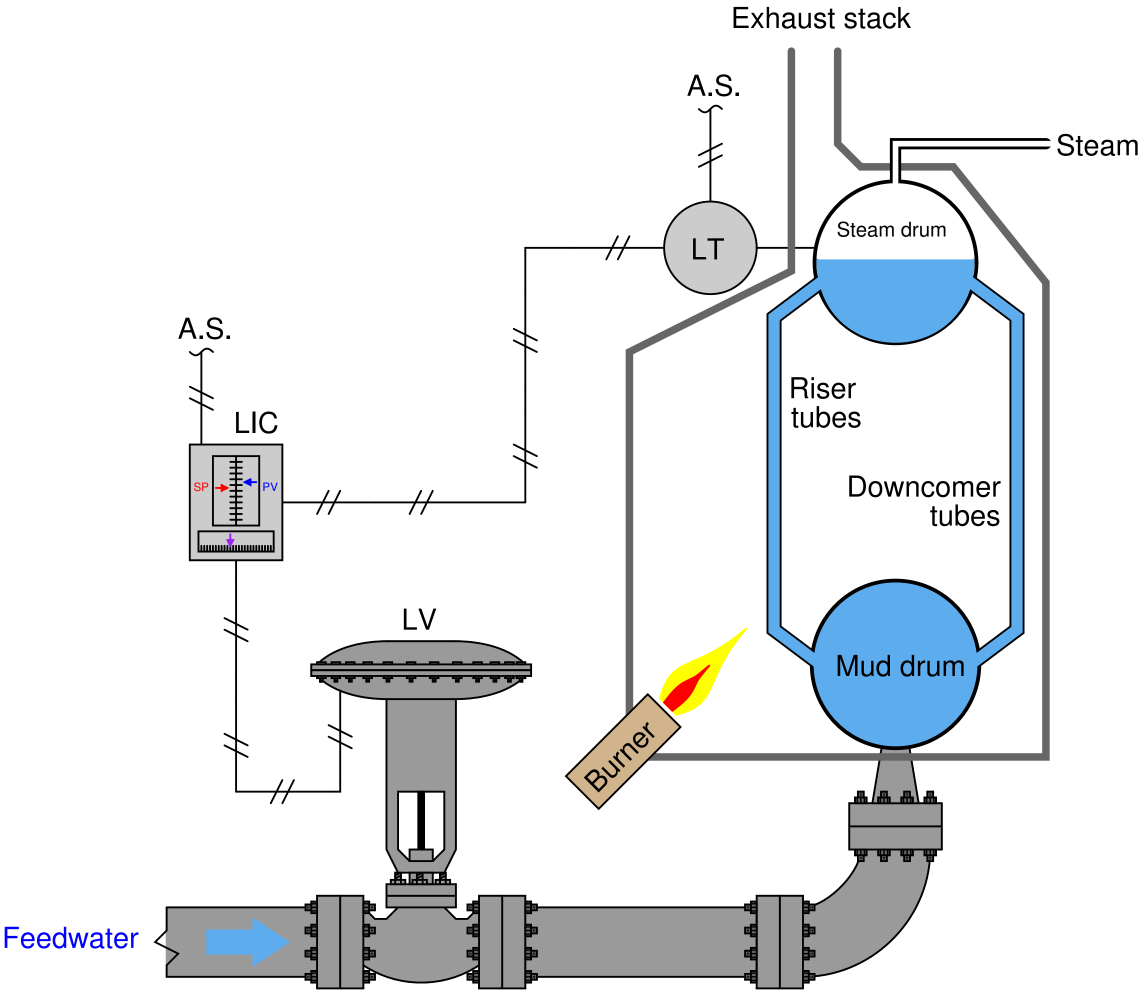

100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
%
Outlet temperature
Lag
Lag
Fuel valve
Time

If these two lag times (one for feed flow and one for fuel flow) are exactly the same, then a simple feedforward compensation system such as that shown at the beginning of the question will work just fine. However, if these lag times are *not* equal, as shown in above trends, a simple feedforward system will not perfectly compensate for changes in feed flow. Explain why.

file i01779

Oppgave 20

Steam boilers are common in many process industries, and offer many challenges for process control. Let's begin with a simple, "single element" steam drum level control system:



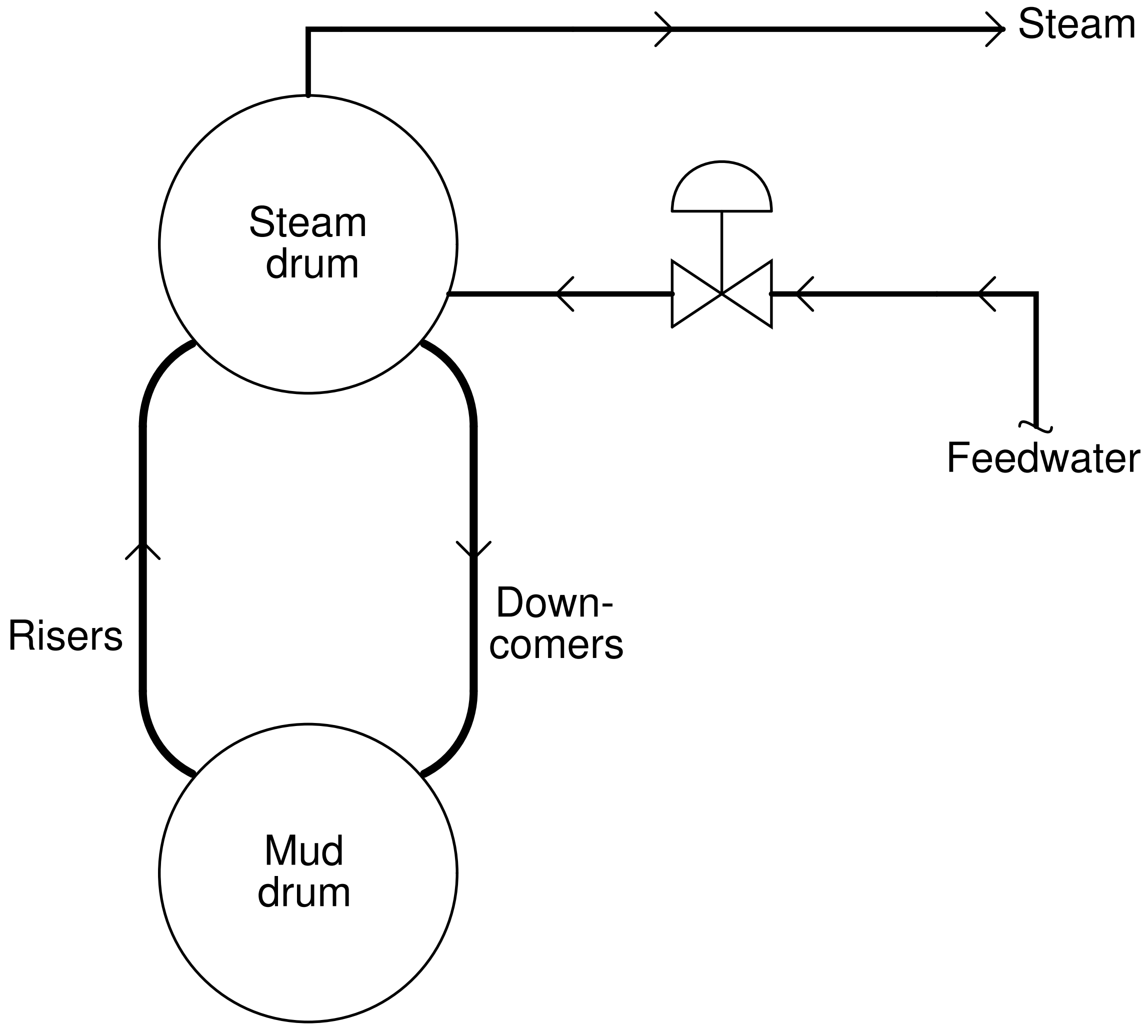
This simplest type of drum level control is suitable only for boilers with very constant "loading" (steam demand). If the boiler is subjected to large fluctuations in steam demand, the drum level will be erratic, possibly leading to boiler tube damage.

As you have seen though, *feedforward* control benefits processes with varying loads. Since steam demand is a type of load in a boiler system, determine how feedforward control could be added to this system to minimize the effects of changing demand (load) on drum level. Hint: this alteration to the control scheme will turn it from a "single-element" to a "two-element" level control system.

file i01788

Oppgave 21

Most large power boilers use a *three-element* control strategy to control the level of water in the steam drum. Explain what "three-element" means, and illustrate the control strategy in the form of a P&ID:

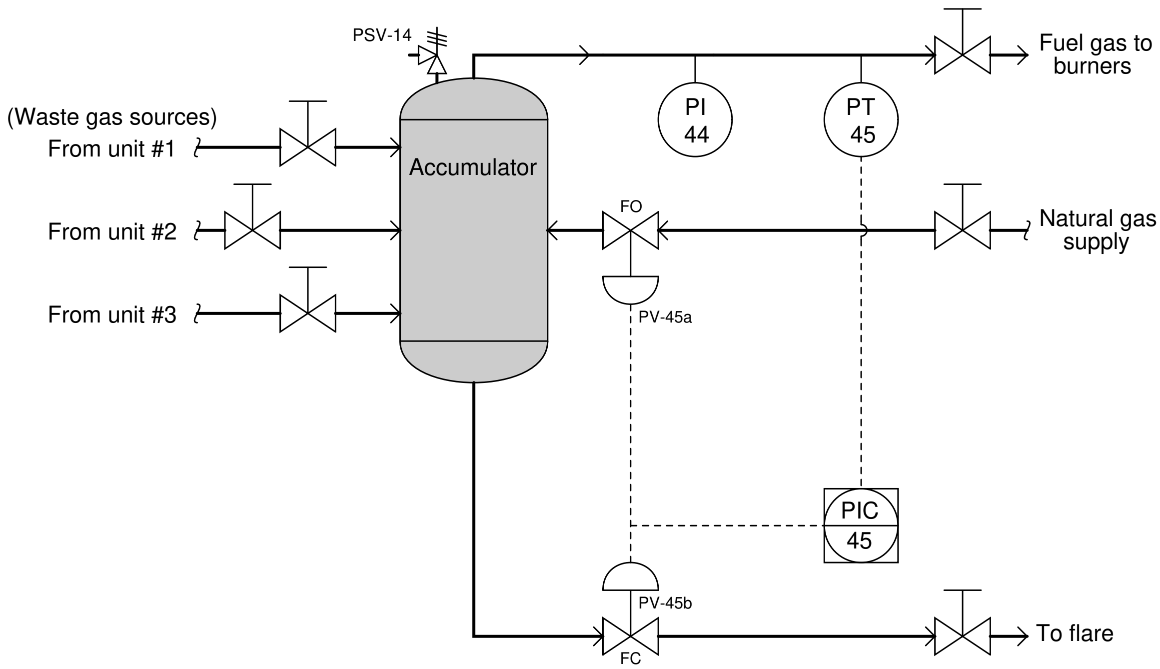


file i01789

Oppgave 22

Many flammable gases are produced in chemical processing and oil refineries as “waste” products. These “waste” gases may be used as fuel for steam boilers and combustion heaters in other parts of the refinery. The problem is, “waste” fuel gas production is often unsteady, and the demand for fuel gas in boilers and heaters is unsteady as well. There are times when there will be a surplus of waste gas (more than can be used), and times when there will not be enough.

The following pressure control system works to maintain constant fuel gas pressure in the accumulator vessel despite changes in waste gas flows and fuel gas demands:

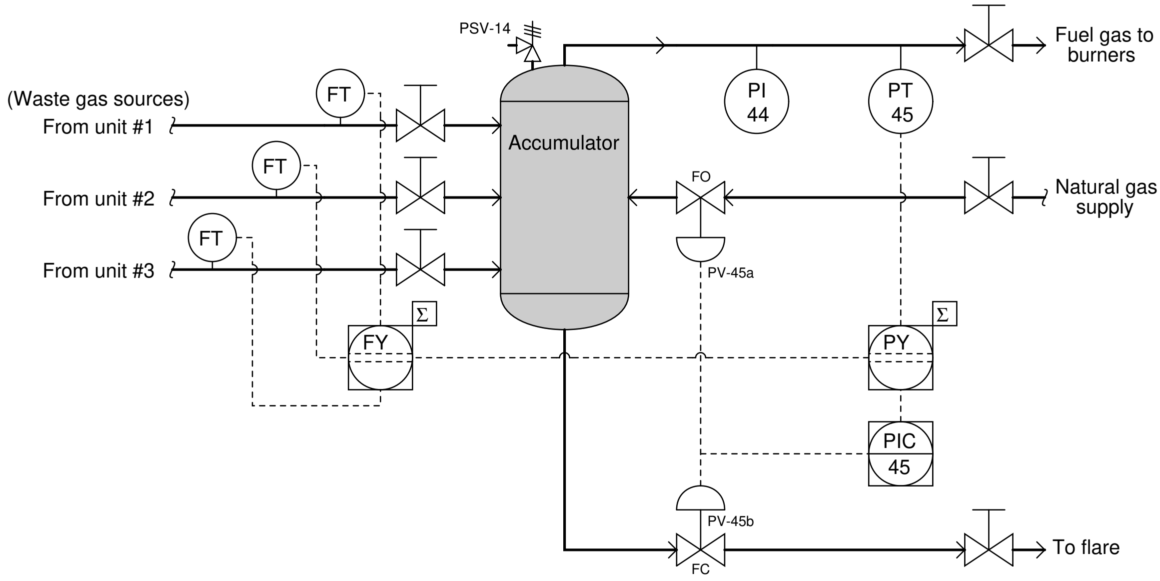


A pair of split-ranged control valves (PV-45a and PV-45b) work together to either admit natural gas into the accumulator (when the gas pressure is too low) or release excess gas to the flare (when pressure is too high).

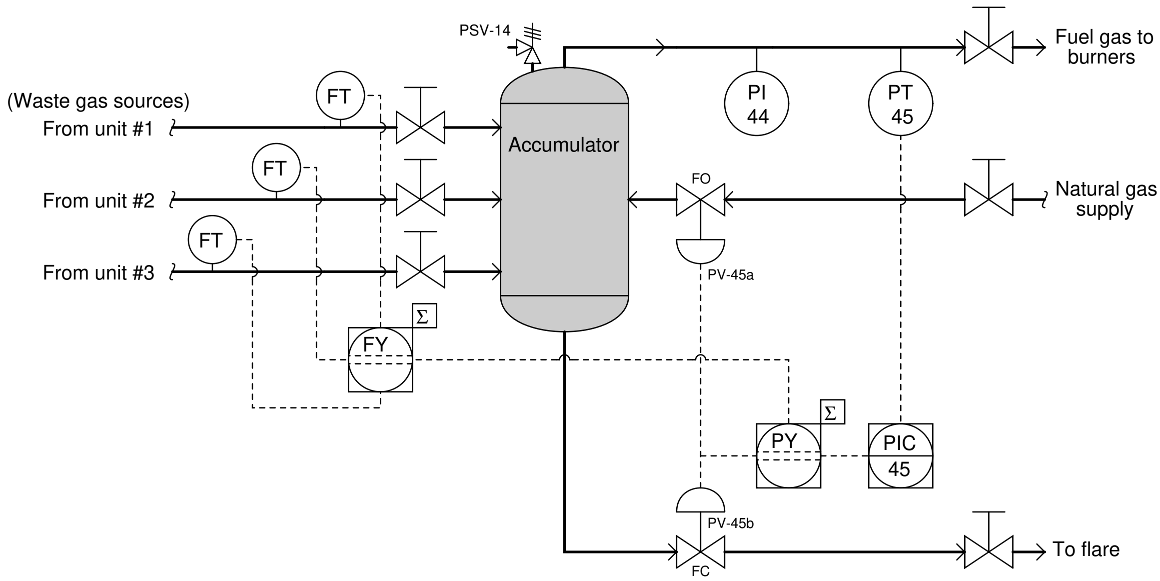
Operations personnel have determined that the pressure inside this accumulator is not steady enough for their operational needs. They have also determined that fast-changing waste gas flows are the source of the instability, and so they ask instrumentation personnel to implement a solution. The instrumentation personnel, in turn, decide to implement a *feedforward* control strategy to meet this need.

The first step, of course, is to install flowmeters on each of the waste gas lines entering the accumulator, the signals of which will be used in the feedforward strategy to proactively compensate for changes in waste gas flows. A controversy erupts between instrumentation personnel, however, regarding how to implement the feedfoward strategy.

One team says the strategy should look like this:



Another team says the strategy should look like this:

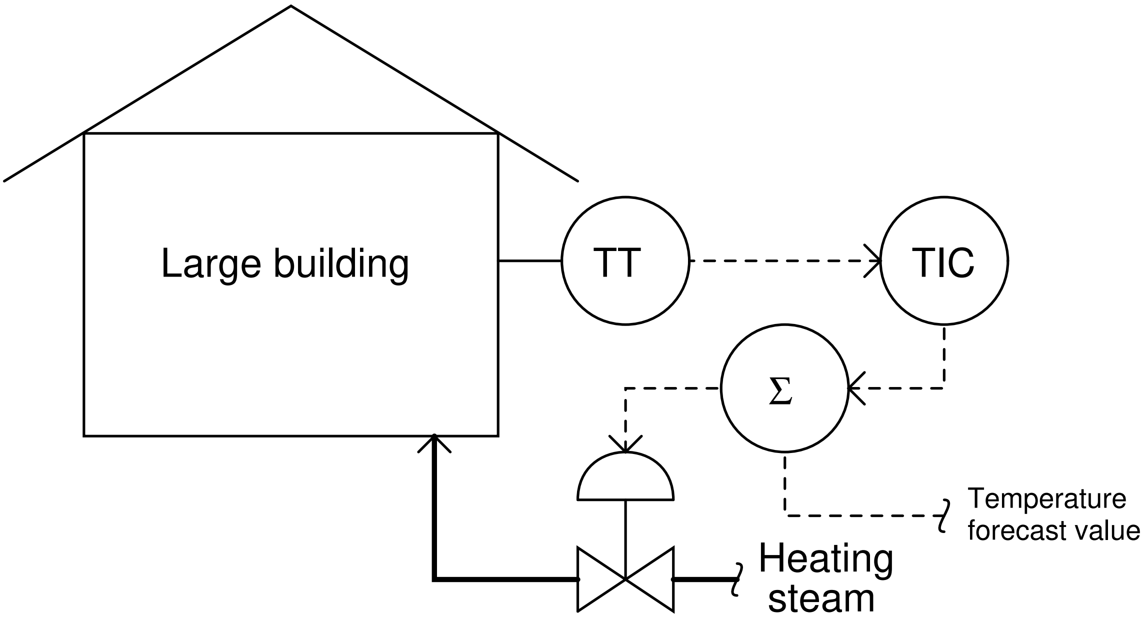


Which team do you agree with, and why? Note: *this is a very important concept to grasp in feedforward control strategies, and in fact is one of the most commonly mis-understood concepts associated with feedforward!*

file i01263

Oppgave 23

An energy-efficiency engineer decides to install an advanced temperature control system in a large building, which receives input from a weather prediction service to offset the effects of ambient temperature changes on the building's interior temperature:



The only problem with this system as it stands is that the forecast temperature causes the building's temperature to rise and fall prematurely, since the forecast is predicted much longer in advance than the building takes to heat up or cool down.

Identify what type of dynamic compensation function you would install in this control system to correct this problem, and where exactly in the strategy (function block diagram) you would choose to install it.

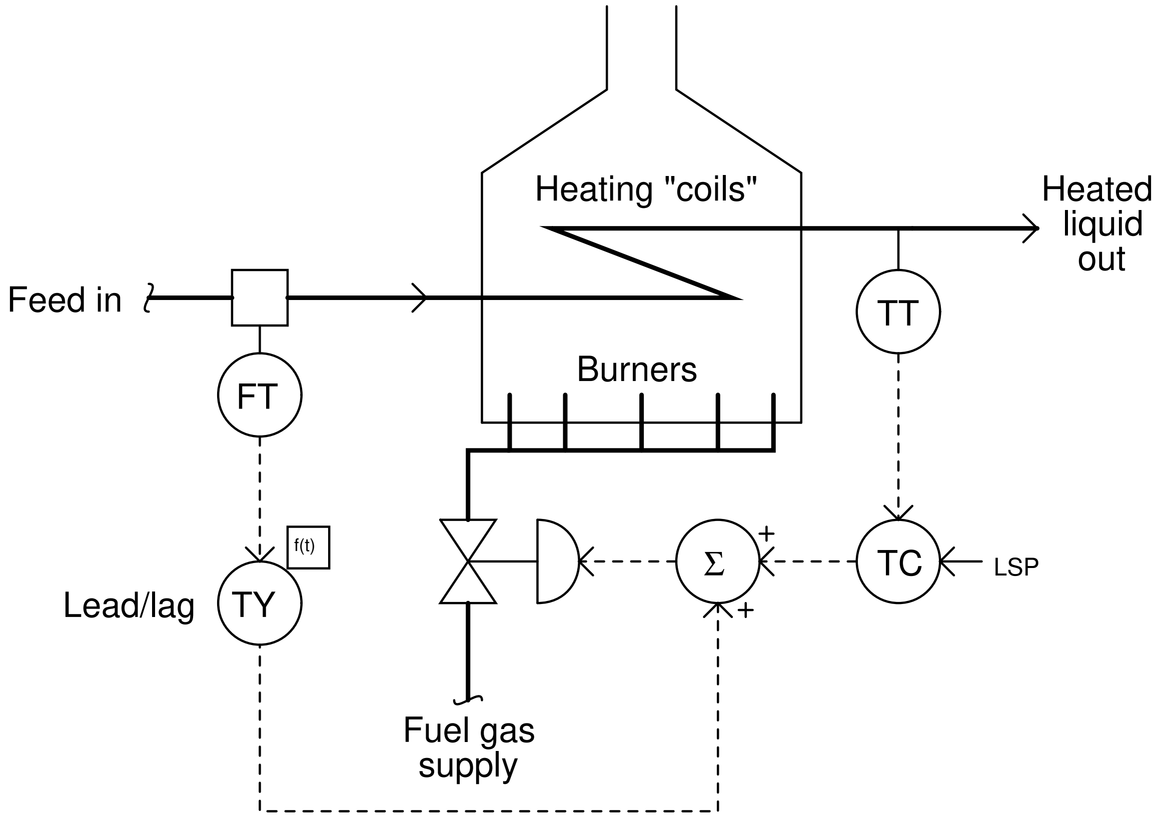
Suggestions for Socratic discussion

- Would the amount of dynamic compensation needed in this system vary with the range of the forecast, the size of the building, or both?

file i04346

Oppgave 24

Explain the purpose of the *lead/lag* unit installed in this feedforward system:



Hint: this control strategy is usually called *dynamic compensation.*

Determine whether the lead/lag unit should be set for *lead* or for *lag* if we happen to know that the process temperature naturally responds to load changes faster than to fuel gas valve changes (i.e. a sudden decrease in feed flow causes a quicker rise in outlet temperature than a sudden increase in fuel gas flow to the burner assembly).

Suggestions for Socratic discussion

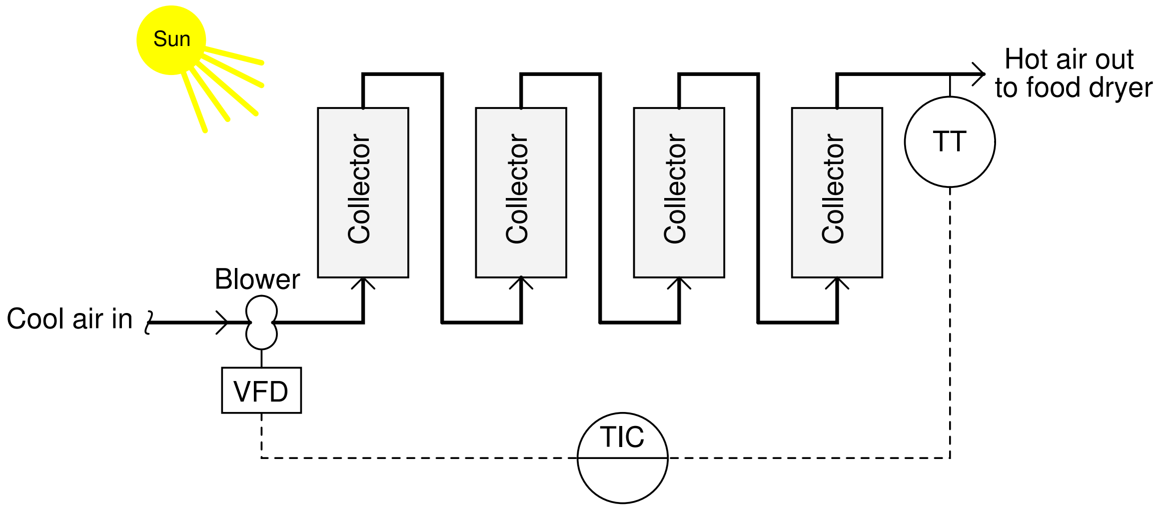
- Explain the significance of the "+" symbols next to the summer input lines. How well would the system work if one or more of these inputs were inverting ("−") rather than non-inverting?
- Explain the consequence(s) of not having any dynamic compensation at all in this feedforward system.

- Describe the test you would perform to determine whether or not this feedforward system required *lead* compensation or *lag* compensation, prior to introducing the lead/lag function block to the control strategy.
- Explain why you suppose the load (feed flow) has a faster effect on temperature than the compensation (fuel gas flow), based on the physics of heat transfer in this process.
- Explain what would happen in this process if the flow transmitter failed with a low signal.
- Explain what would happen in this process if the flow transmitter failed with a high signal.
- Identify what process characteristic(s) would dictate the lead/lag time ratio in the function block.
- Identify what process characteristic(s) would dictate the lag time value in the function block.

file i01780

Oppgave 25

This solar hot-air collector bank uses a variable-speed fan as the final control element, the temperature controller commanding the fan to blow air at different rates in order to maintain a relatively constant discharge temperature. The hot air is being used to dehydrate food, and so precise temperature control is important:



The single most significant load in this process is sunlight intensity. As the sun becomes covered by clouds, the heat output of the collector bank rapidly drops. This, of course, affects the temperature of the air going to the food dryer. Even though the feedback controller will eventually get the temperature back to setpoint, there are moments of deviation (error).

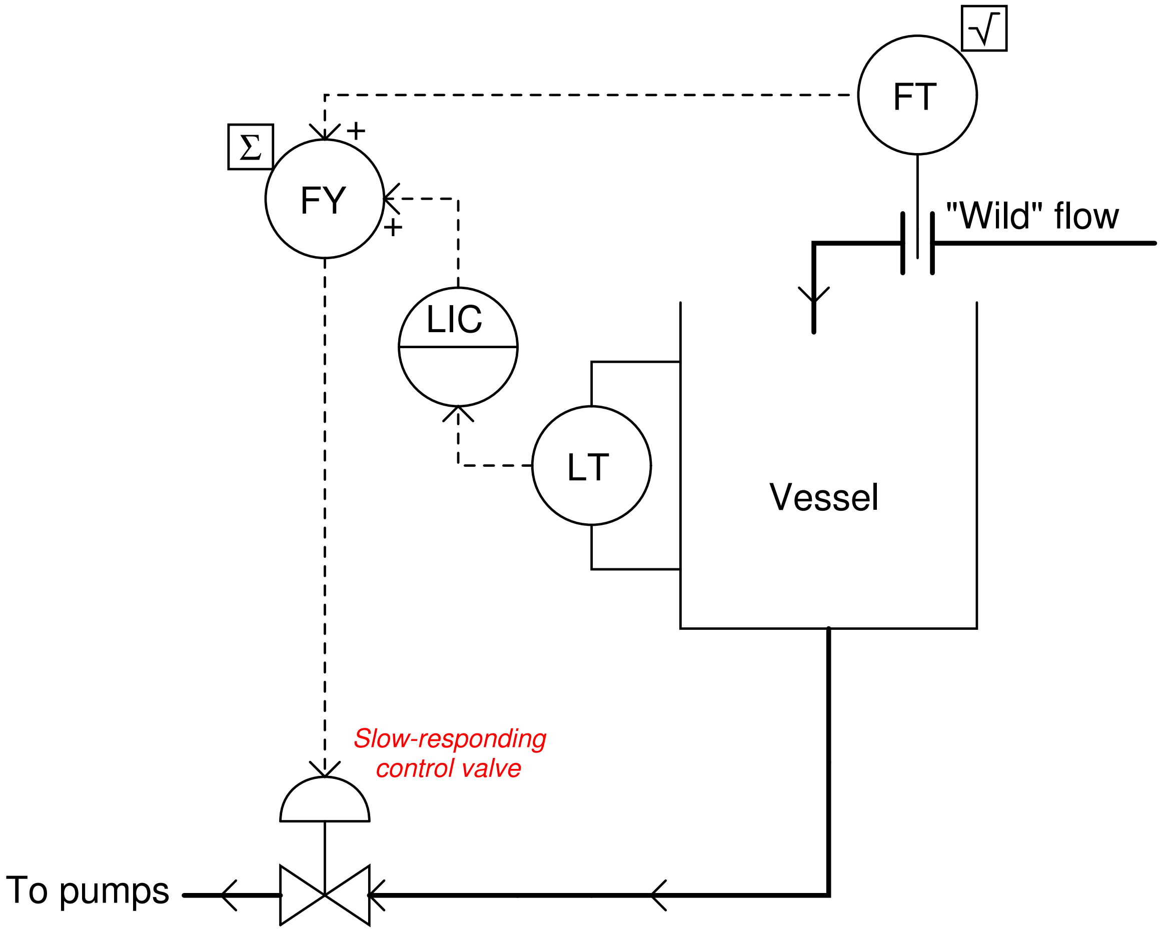
Suppose a sunlight radiation transmitter (RT) were installed to detect incident sunlight intensity. Sketch how this RT could be connected to the rest of the control system components to form a *feedforward* loop.

Also, describe a real experiment you could do with this process to determine whether or not *dynamic compensation* (i.e. lead/lag) is necessary in the feedforward signal path for optimal control.

file i02474

Oppgave 26

Suppose the flow control valve in this three-element control system is slow to respond because it does not have a volume booster to help actuate it quickly:



Perform a "thought experiment" illustrating how this slow valve response compromises the feedforward control quality. After that, explain how the proper addition of a lead/lag (I'll let you determine which!) function block could help address this problem.

Next, explain how the judicious use of *cascade* control would be a better solution to the problem.

Suggestions for Socratic discussion

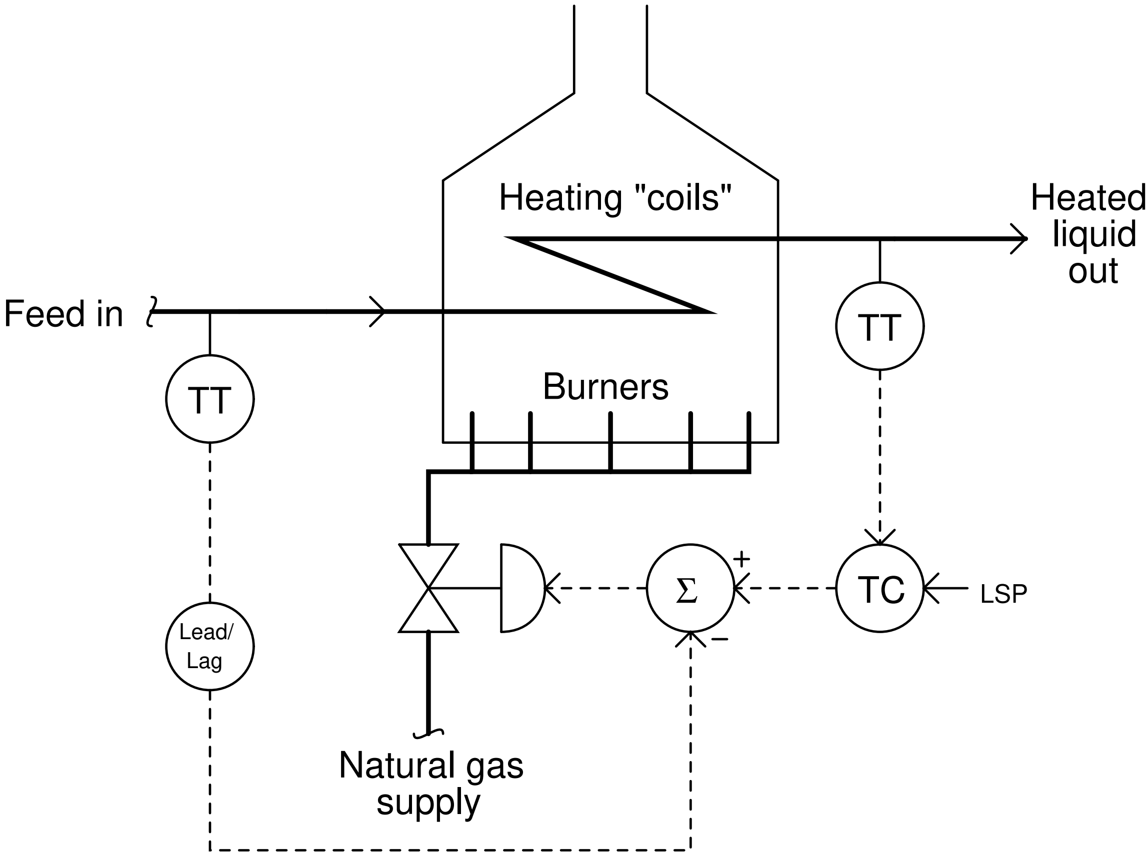
- Identify at least one *mechanical* solution to this problem.

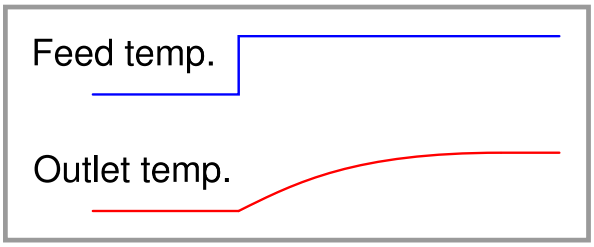
- Explain the significance of the "+" symbols next to the summer input lines. How well would the system work if one or more of these inputs were inverting ("−") rather than non-inverting?
- Suppose the suction produced at the discharge line by the pumps proved to be a significant load in the system (i.e. starting or stopping pumps caused excursions in the vessel's level). Explain how you might incorporate feedforward control to stabilize liquid level against that load.

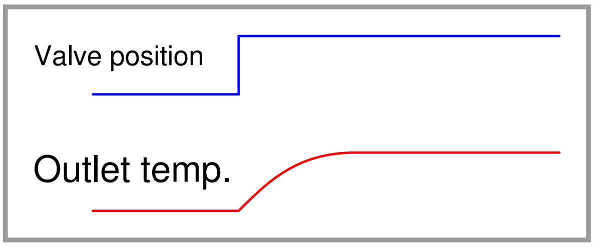
file i04344

Oppgave 27

Identify whether the lead/lag function block needs to be configured for *lead* behavior or for *lag* behavior, based on the open-loop (i.e. control valve fixed at one position) step-change responses shown below, and also explain your answer in detail:


Heating "coils"
Heated liquid out
Feed in
TT
TT
Burners
TC
LSP
Σ
+
−
Lead/ Lag
Natural gas supply


Feed temp.
Outlet temp.


Valve position
Outlet temp.

Suggestions for Socratic discussion

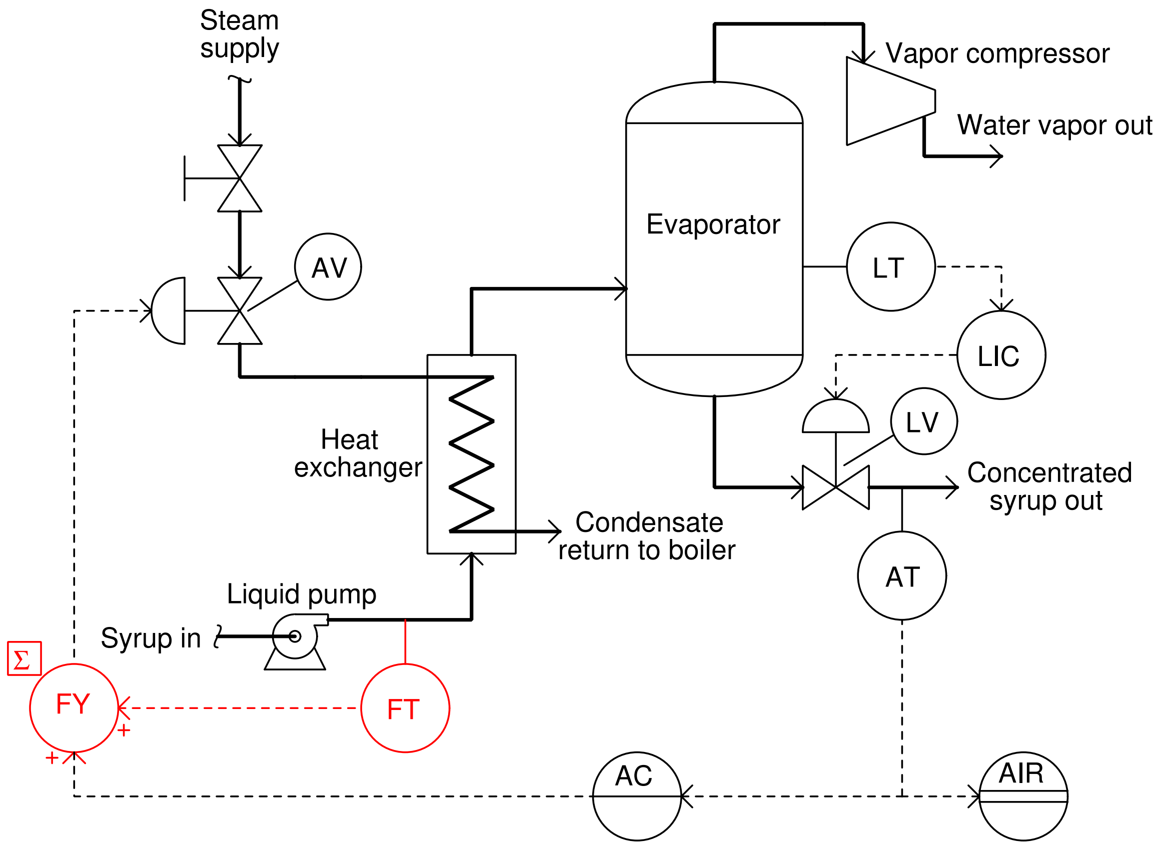
- Explain why it is critically important that the natural gas control valve *not move* during these tests.
- Explain the significance of the "+" and "−" symbols next to the summer input lines. How well would the system work if both of these inputs were non-inverting ("+")?
- How would this control system function if the summer function were moved to a location between the TT and TC?
- How would this control system function if the lead/lag function were moved to a location between the TT and TC?
- How would this control system function if the lead/lag function were moved to a location between the summer and the control valve?

file i04511

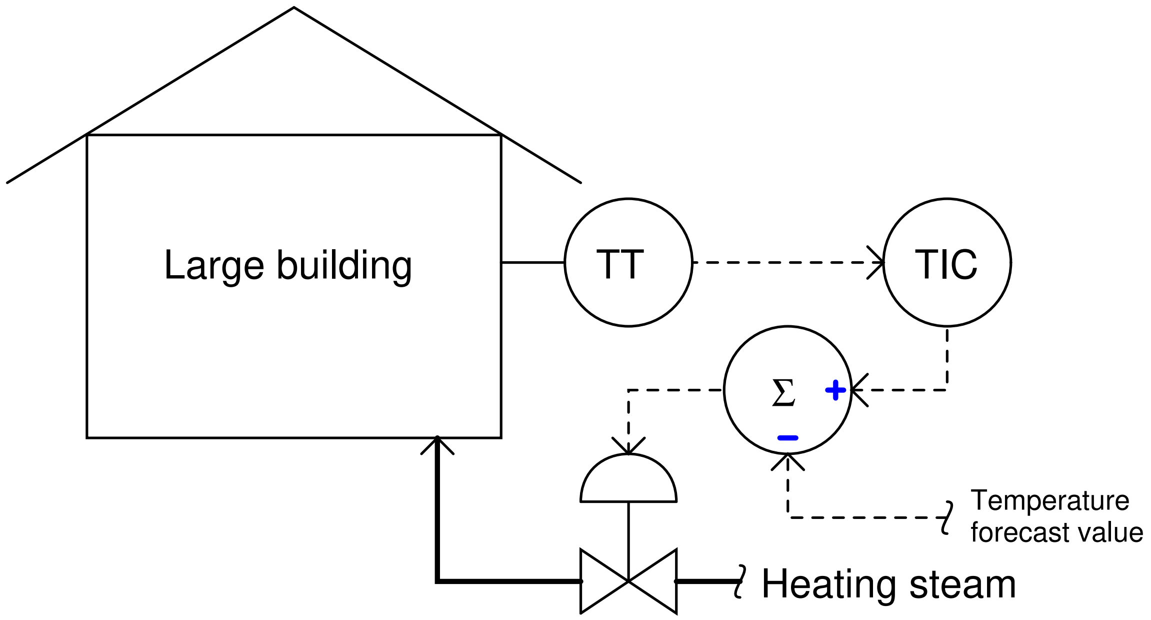
Svar

Svar 1

Feedforward action from the feed flow transmitter to the steam valve is one solution to this problem:



Svar 2



Svar 3

If the wild flow increases, the flow transmitter on that line will send an increased signal to the summer (FY), which will increase the setpoint to the outlet flow controller (FC), which will open the flow valve appropriately to handle the extra incoming flow, with no "bump" to the liquid level.

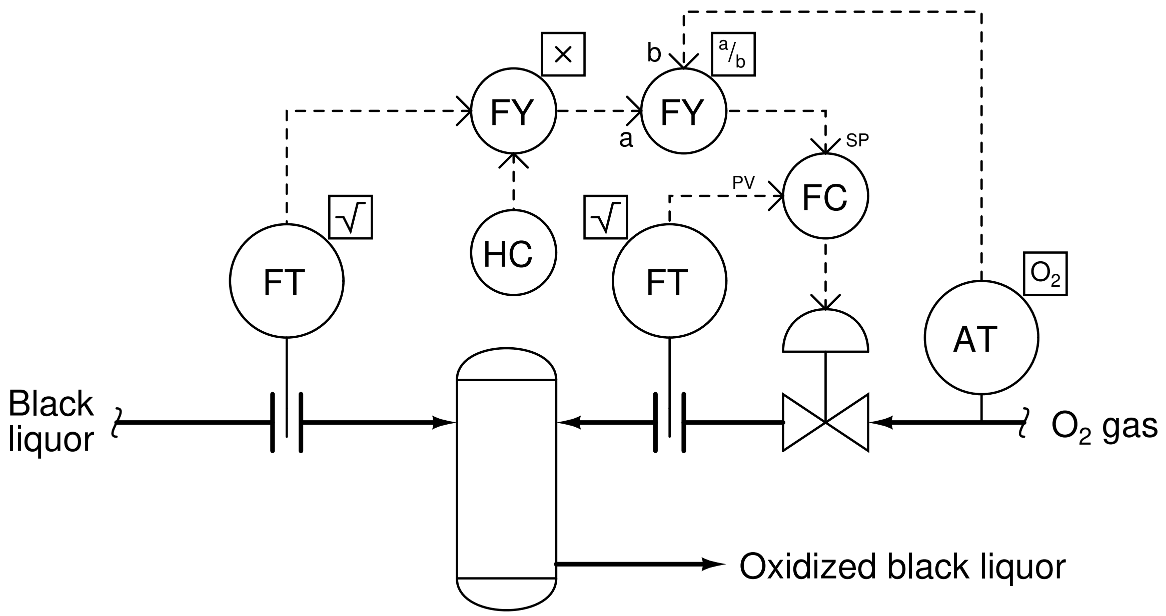
If the vessel springs a leak, the level transmitter will register a decrease in liquid level, the level indicating controller (LIC) will output a lesser signal to the summer (FY), decreasing the setpoint sent to the flow controller (FC) and compensating for the extra load on the process.

Svar 4

Place a steam flow transmitter on the outgoing steam line, then feed that steam flow signal "forward" to combine with the level controller's output to drive the feedwater valve.

Svar 5

The optimal solution uses a *divider* function block rather than a summer, so that the feedforward oxygen analyzer's signal will have the proper multiplicative effect on oxygen flow to the reactor if the oxygen purity becomes weakened:



If oxygen concentration were to fall from 100% to 50% (for example), we would need *twice* the flow rate of oxygen to the reactor than previously, not just an additional sum of oxygen flow.

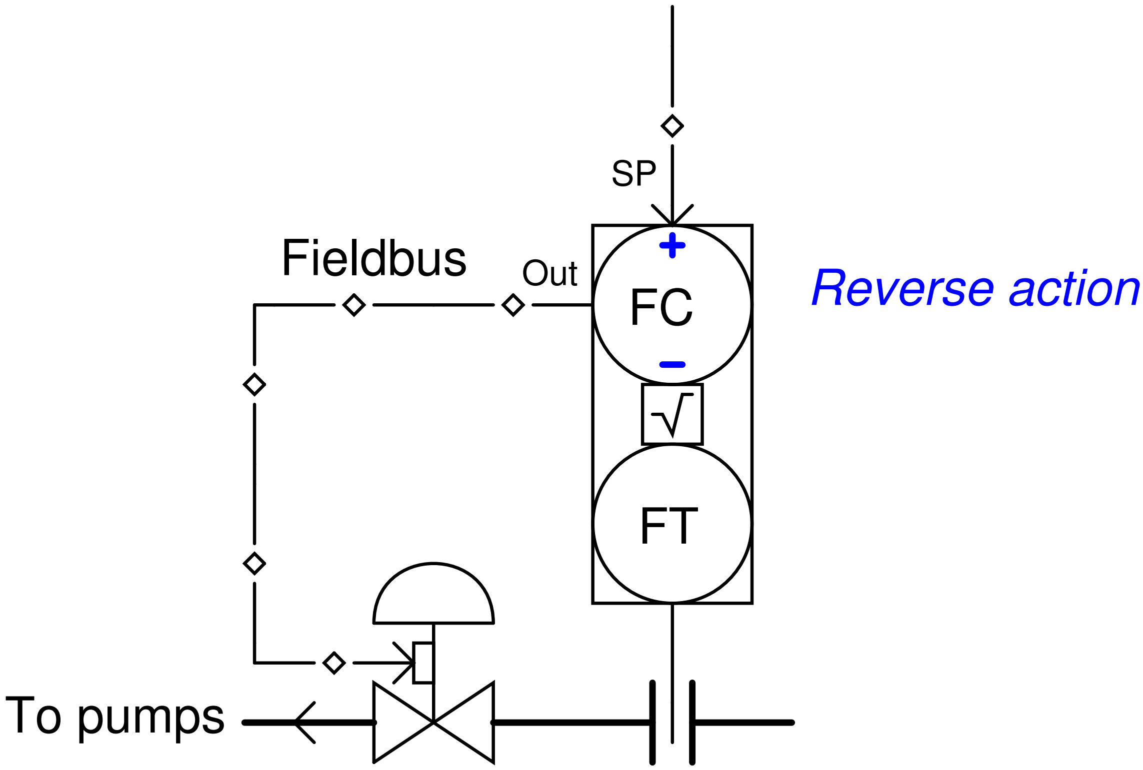
Svar 6

In this faulty system, the flocculant *valve position* is being used as the feedforward signal rather than the actual flocculant *flow rate*. Plus, there is one more (major) error which I will leave to you to find!

Svar 7

In theory, this *feedforward* system would work to hold the liquid level absolutely constant, because it will try to maintain flow out equal to flow in (mass out *balances* mass in). However, there are some practical reasons why it would not work.

The controller needs to be *reverse action*, assuming a signal-to-open control valve:



The "+" symbol at the SP input of the controller tells us there is a non-inverting relationship between the SP input and the controller output. The "−" symbol at the PV input of the controller tells us there is an inverting relationship between the PV input and the controller output. Both of these characteristics are consistent with what we call "reverse" action in a loop controller.

Svar 8

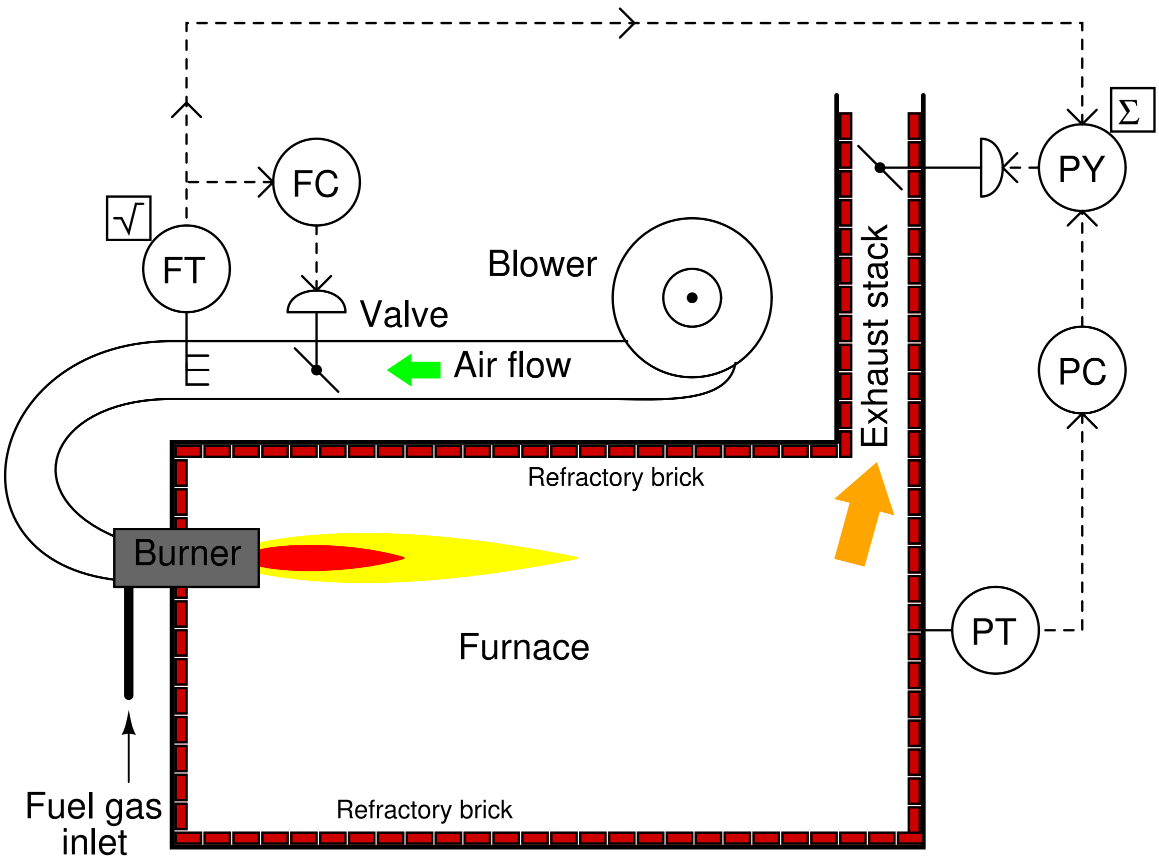
Svar 9

In theory, this *feedforward* system would work to hold the liquid outlet temperature absolutely constant, because it will try to maintain heat flow out equal to heat flow in (energy out *balances* energy in). However, there are some practical reasons why it would not work (even if the liquid inlet temperature and composition were held constant).

Svar 10

Since the stack damper is actuated by the flow controller's output in addition to the pressure controller's output, it will move in tandem with the inlet air damper to minimize the effect on furnace pressure. The pressure controller then merely serves a "trim" function.

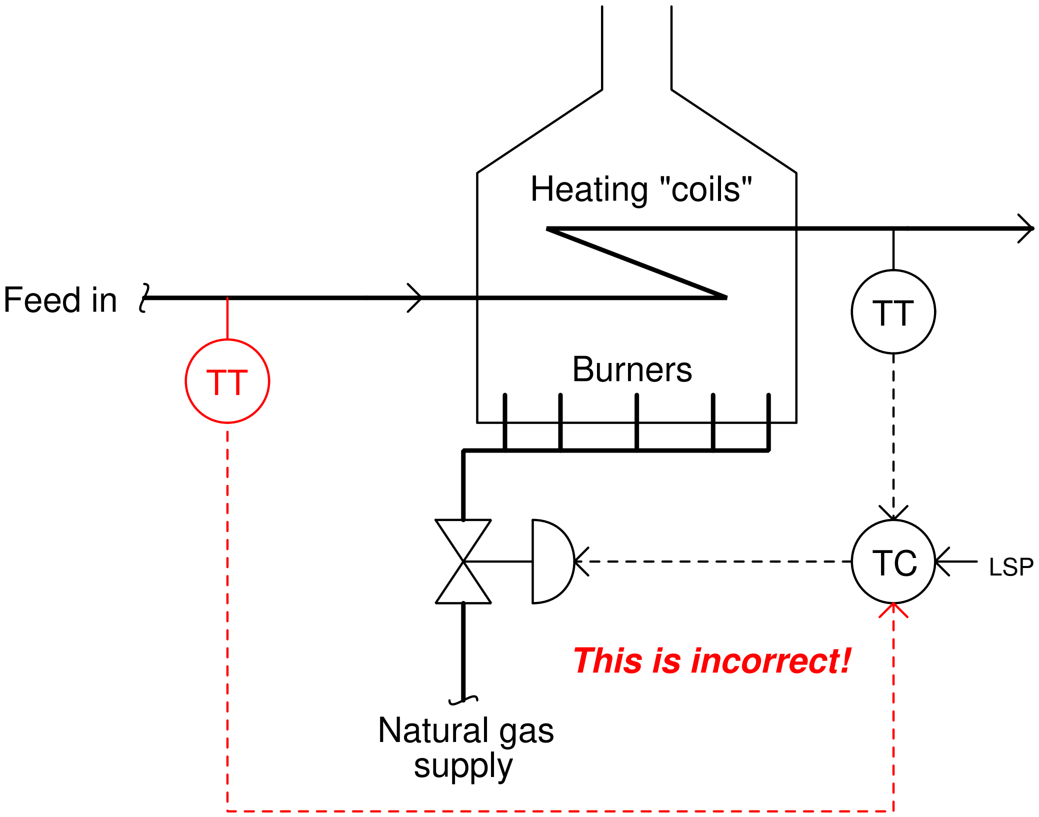
Challenge question: true feedforward control would look something like this, but it would *not* fix the coupling problem. Explain why:



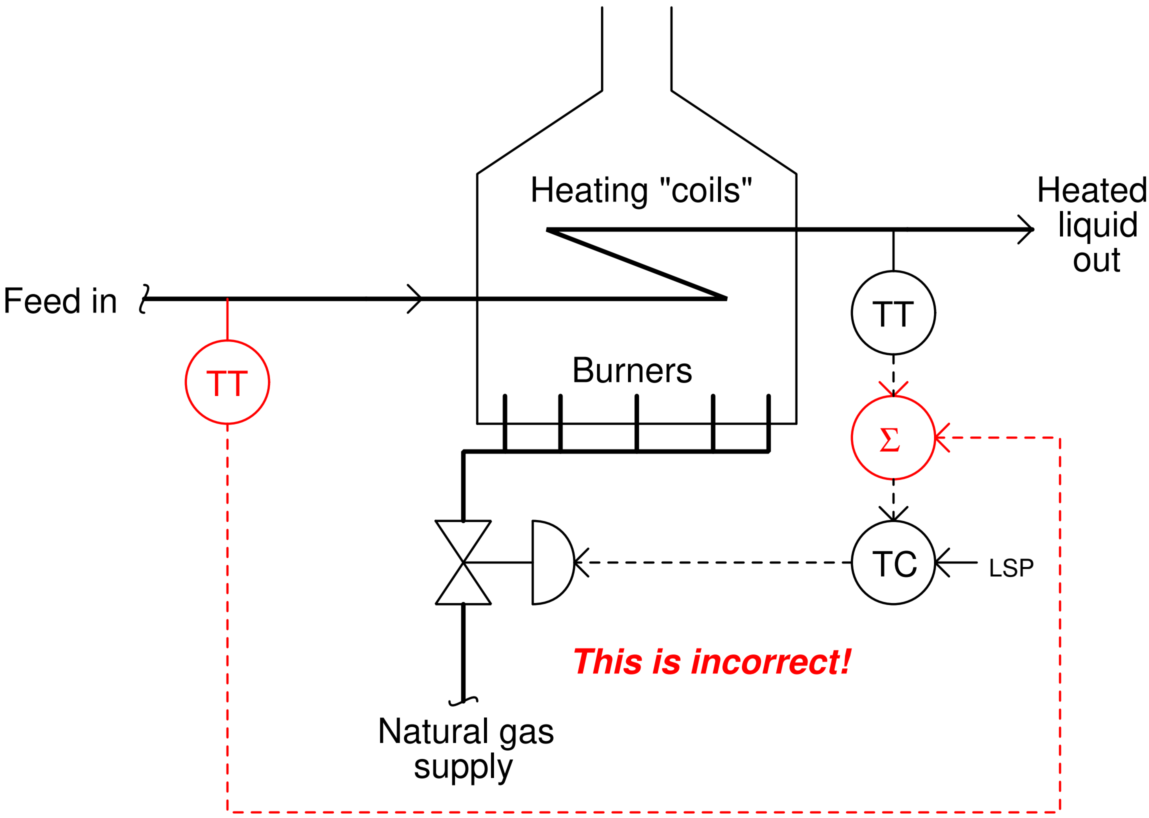
Svar 11

The following P&IDs show *incorrect* implementations of feedforward to this process. All of these incorrect solutions are commonly seen among students first learning about feed-forward control.

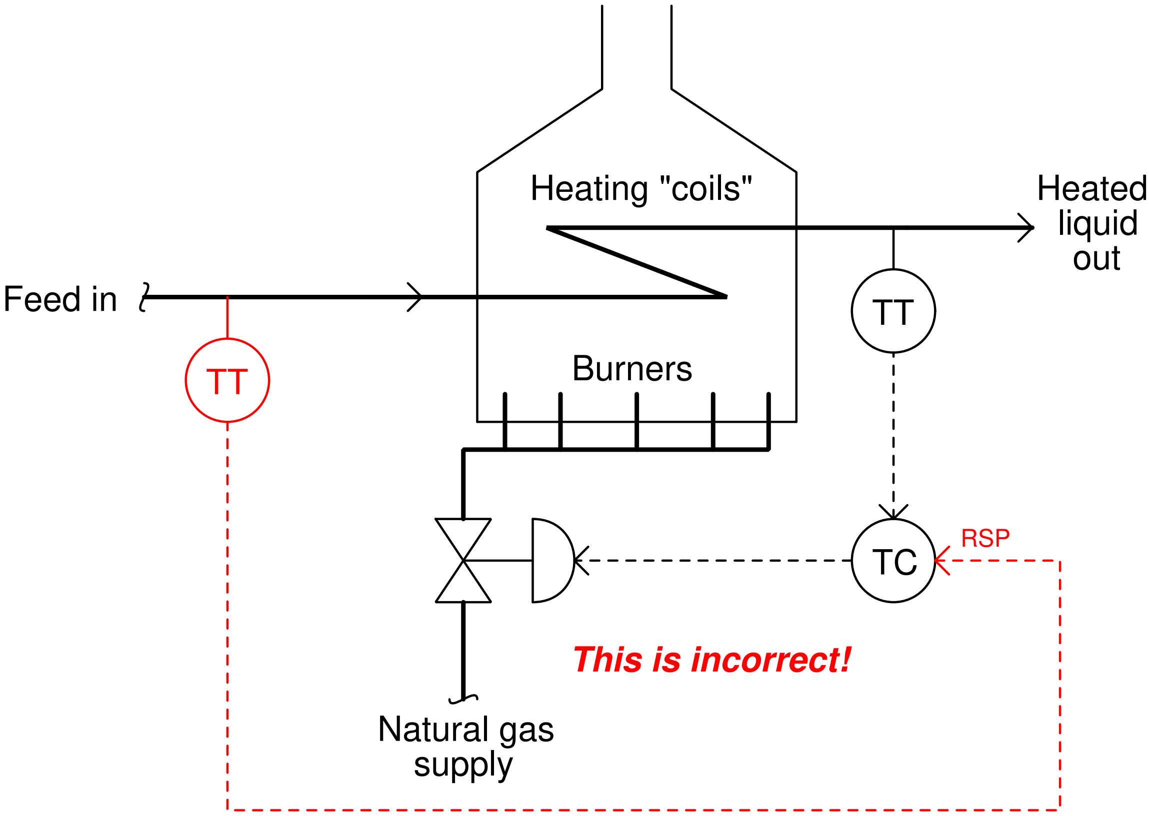
Incorrect solution #1: A mysterious third input on the temperature controller (TC) is being used here. Although some loop controllers do provide an input for a feedforward transmitter's signal, to sketch this as a solution does not demonstrate understanding of the feedforward strategy. What needs to be shown is a more explicit function-block strategy whereby it is clear to see what the feedforward signal actually does to achieve its ends.



Incorrect solution #2: Here we see the feedforward signal being summed with the process variable signal before it enters the controller. The reason this won't work has to do with the purpose of the temperature controller (TC) – to maintain the outgoing product temperature at some operator-determined setpoint (local setpoint, or LSP). If that controller isn't able to directly and accurately sense the product temperature (because that temperature signal is being added to a different temperature signal) then there is no way the controller will ever be able to hold the product temperature to setpoint. In other words, summing the two temperature signals together effectively "lies" to the controller such that it never sees the real process variable, and therefore can never hold the real process variable stable at setpoint because it's operating on false information.

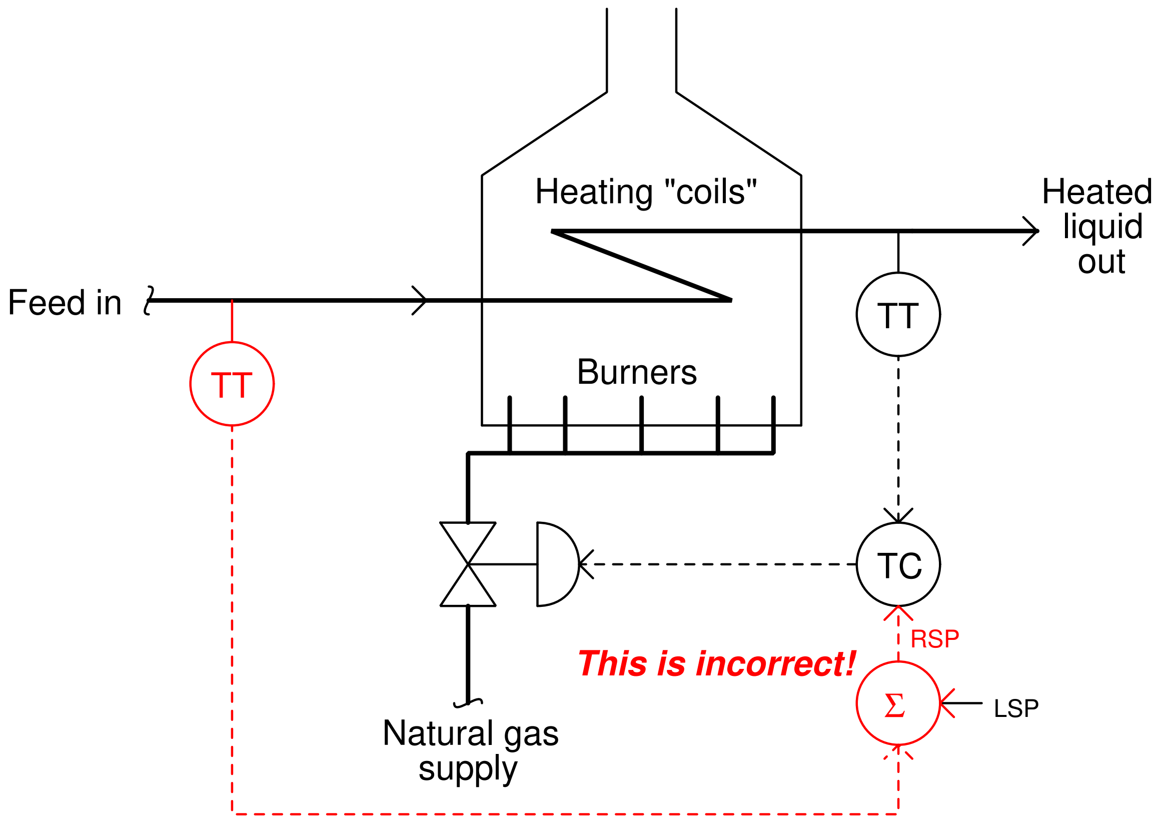


Incorrect solution #3: In this solution the feedforward signal is being used as a remote setpoint (RSP) to the temperature controller (TC), much like you would expect to see in a *ratio* control system. The trouble with this solution is again related to the purpose of the temperature controller – to maintain the outgoing product temperature at some operator-determined setpoint. Here there is no operator-determined setpoint at all, but rather a setpoint determined solely by the incoming feed temperature.

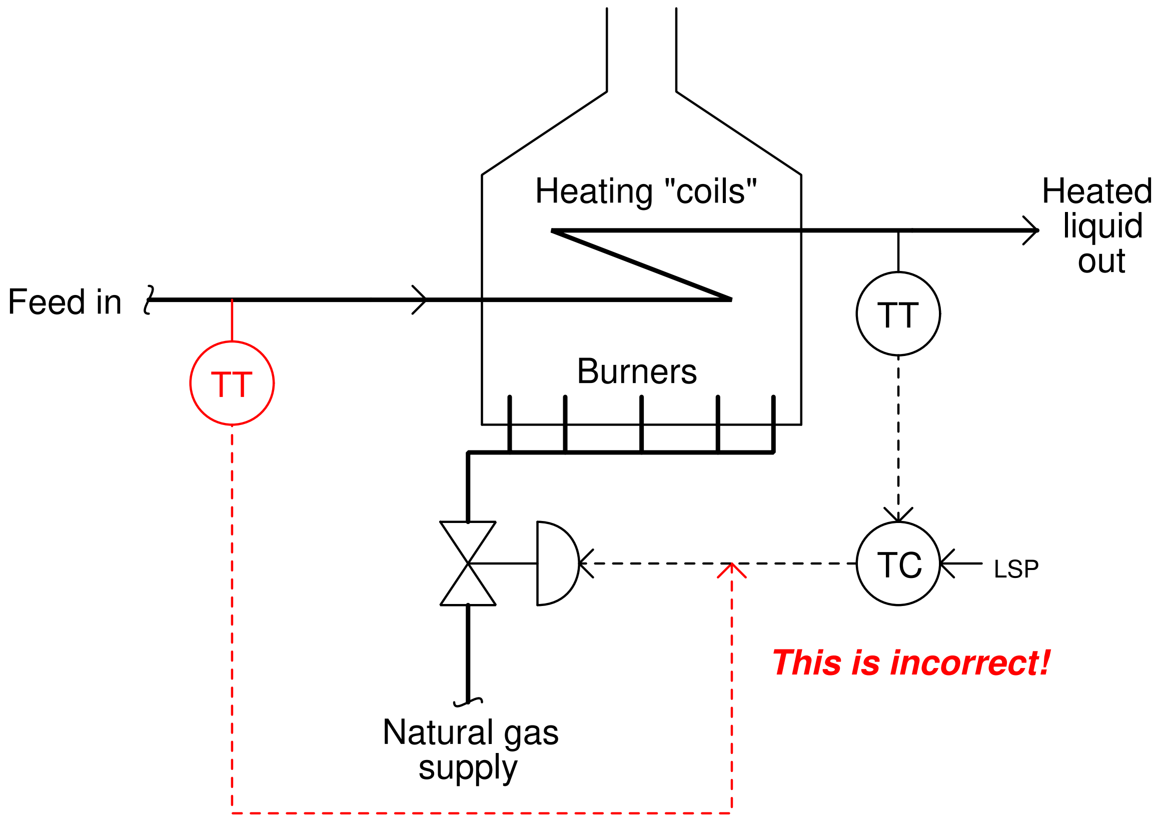


Furthermore, it makes absolutely no sense at all to have the controller's setpoint made equal to the incoming feed temperature. If we tried this strategy, the controller would maintain a closed-valve condition at all times, because the surest way to maintain the outgoing product temperature at a setpoint value equal to the incoming feed temperature is to not heat it up at all!

Incorrect solution #4: Similar to the last incorrect solution (#3), this one attempts to use the feedforward signal as *part* of a remote setpoint value (RSP) to the temperature controller (TC), while still maintaining an operator-determined local setpoint (LSP). Here we still have the same fundamental problem as before – so long as the feedforward signal modifies either the controller's view of the process variable (the outgoing product temperature) or its setpoint, the controller will be unable to perform its most basic function, to maintain the outgoing product temperature at some operator-determined setpoint.



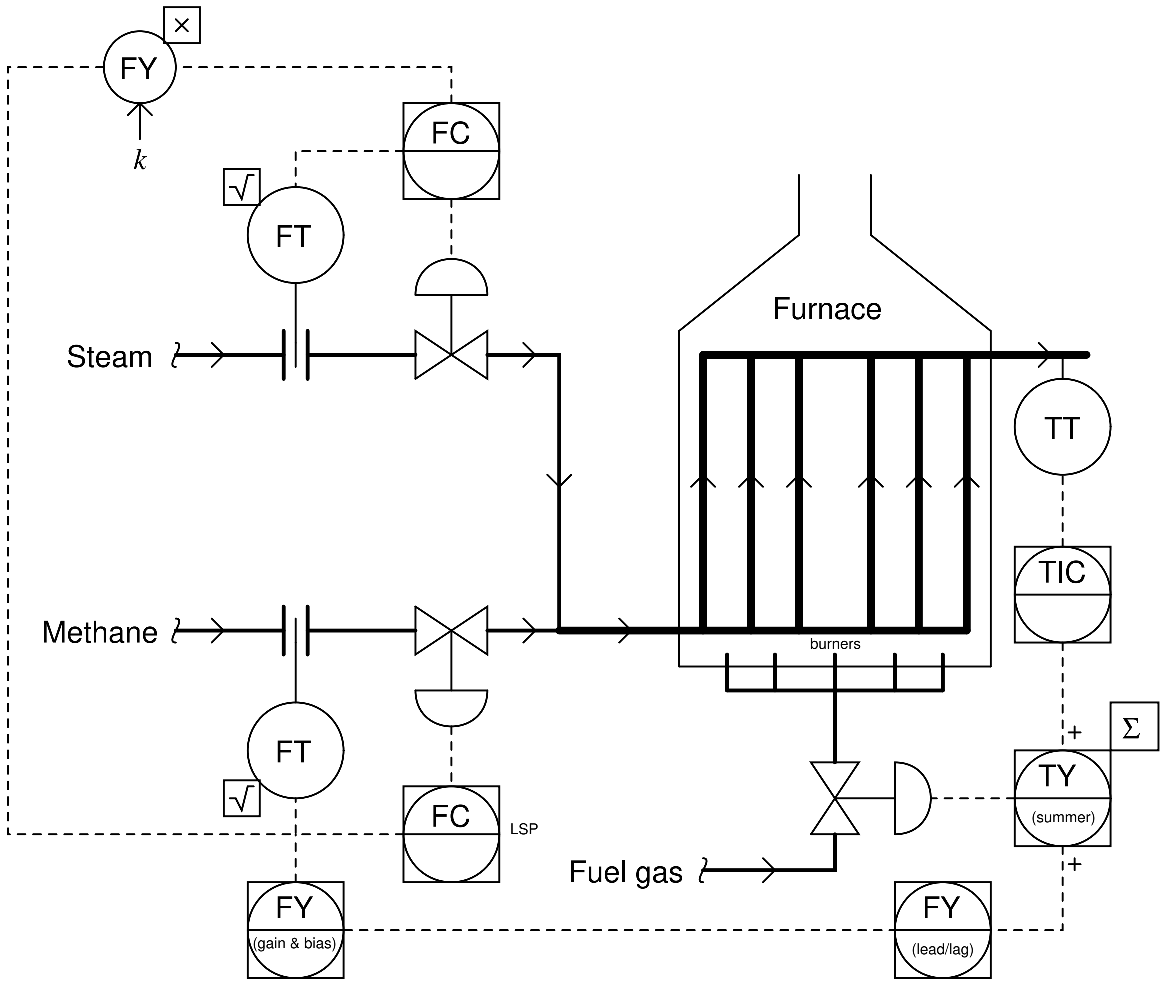
Incorrect solution #5: This solution comes closer than all the others with regard to conceptual correctness, but there is no way for it to be practically implemented. One cannot simple merge two different control signals together (i.e. the temperature controller's output signal somehow joining together with the feedforward signal). Whether these signals are physical (e.g. two 4-20 mA DC currents or two digital fieldbus messages), or virtual (e.g. binary values inside of a control system such as a DCS), we need some sort of algorithm to combine them together. The two signals will simply not merge together in any sensible way on their own.



Svar 12

Right now there is too much *gain* in the feedforward signal path, which means the feedforward control is *overcompensating* for changes in feed flow.

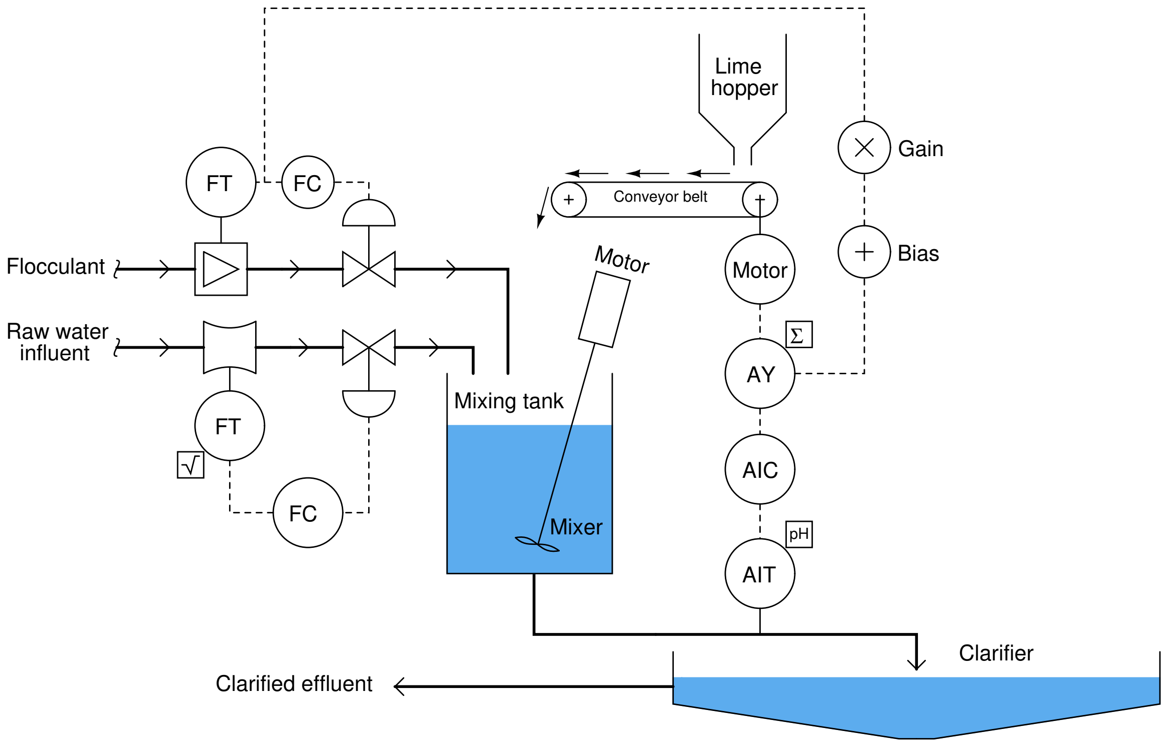
Svar 13



Svar 14

This is a graded question – no answers or hints given!

Svar 15



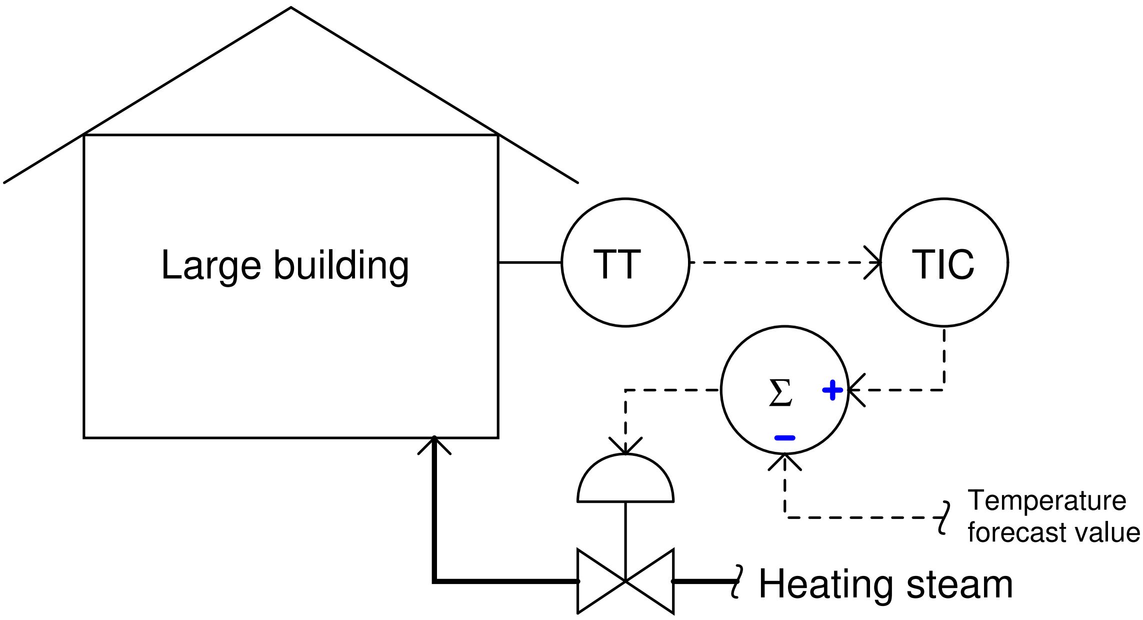
Svar 16

In order to test the effectiveness of feedforward control, we need to perturb the wild variable (in this case, feed flow rate) and watch the PV's response over time on a trend graph, *all with the feedback controller in manual mode so that we are only looking at the effects of feedforward.* If the feedforward action is "tuned" properly, there will be little or no effect on the process (controlled) variable.

Svar 17

- 110011 (unsigned binary) into decimal: **51**
- 139 (decimal) into octal: **213**
- 8C (hexadecimal) into binary: **10001100**

Svar 18



Svar 19

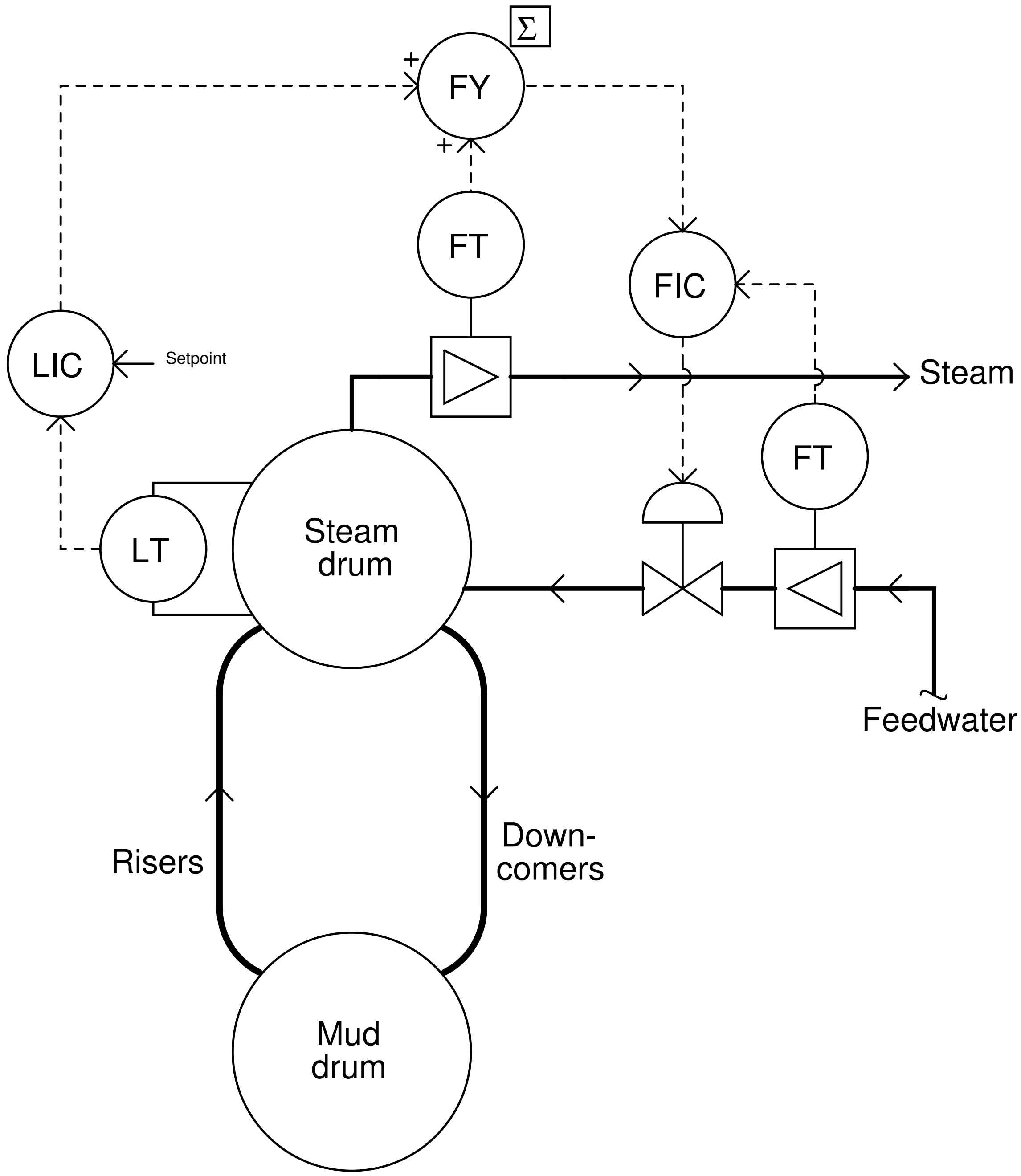
If the two lag times are unequal, the feedforward response to a change in feed flow may either be too soon, or too late.

Follow-up question: given the lag times shown in the "manual test" trends, would the fuel gas adjustment be too soon or too late to compensate for a change in feed rate?

Svar 20

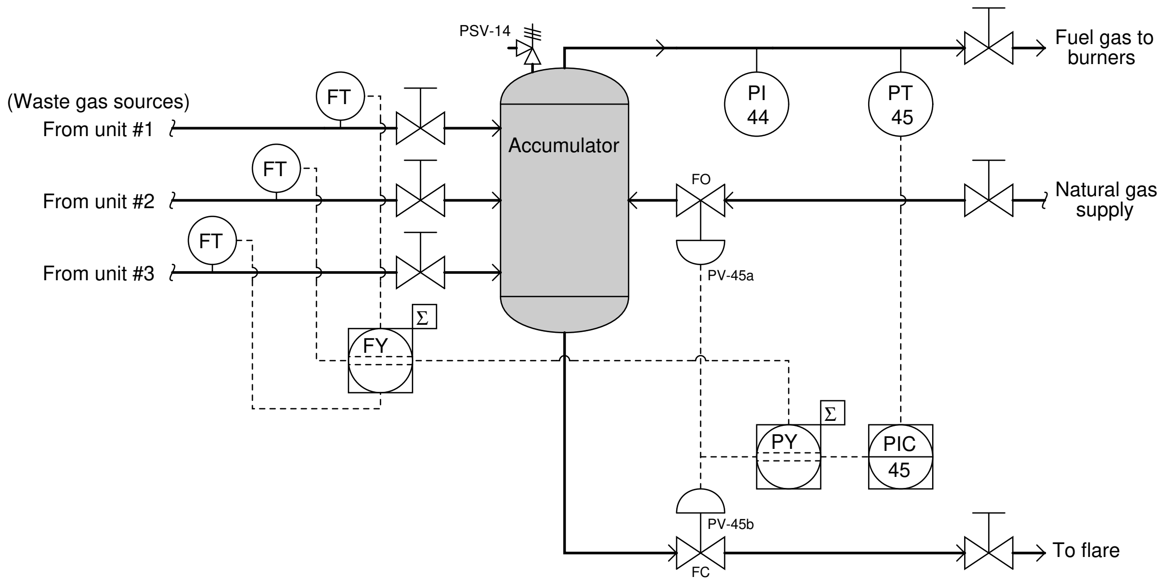
Place a steam flow transmitter on the outgoing steam line, then feed that steam flow signal "forward" to combine with the level controller's output to drive the feedwater valve.

Svar 21


Σ
+
FY
+
FT
FIC
LIC
Setpoint
Steam
FT
LT
Steam
drum
Feedwater
Risers
Down-
comers
Mud
drum

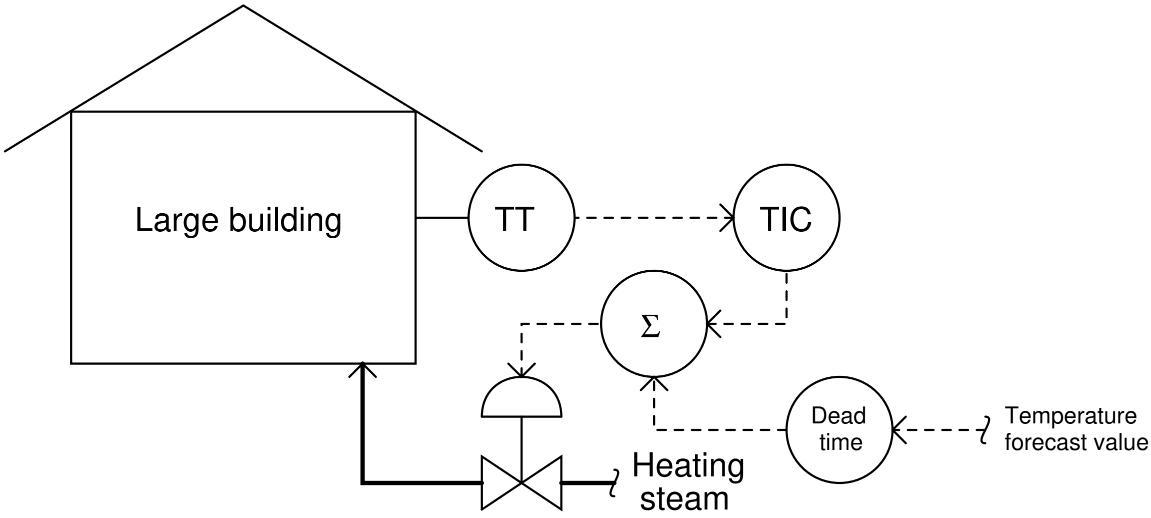
Svar 22

This is the correct solution, where the total load flow signal gets added to the *output* of the pressure controller, not to its *PV input*:



The reason for this is quite straightforward: we want the feedforward signal to directly contribute to the positions of the control valves, so that any change in waste gas flow immediately biases the control valves in order to proactively compensate. If the feedforward signal were to be added to the pressure controller's PV signal, it would cause the pressure controller to incorrectly see changes in pressure that were really changes in waste gas flow. Not only would this not achieve the desired effect, but it would also "lie" to the pressure controller, the result of which being it could never properly hold to setpoint!

Svar 23



Svar 24

The *lead/lag* relay introduces an adjustable lead or an adjustable lag into the feedforward signal, the purpose being to equalize the fuel flow's lag time with the feed flow lag time. By advancing or delaying the fuel flow response to changes in feed flow, we can make sure that the feedforward effect "arrives" at the process variable (outlet temperature) at just the right time to compensate for the change in feed.

Svar 25

This is a graded question – no answers or hints given!

Svar 26

Svar 27

If your problem-solving included the thought, *"We need to speed up the feed temperature's effect to bring it into step with the valve's effect"* then you have made a very common mistake. I will leave it to you to determine why it is impossible for us to speed up the feed temperature's effect on the process using dynamic compensation in the control system.