Kaskadekoblet regulering

Kompetansemål:

- idriftsette og optimalisere regulatorer basert på prosessbehov

Læringsmål

- Kunne forklare hvordan en kaskadekoblet reguleringsstruktur virker.
- Kunne koble sammen to regulatorer i en ytre og indre sløyfe.
- Kunne optimalisere en kaskadekoblet reguleringsstruktur.

Forkunnskaper:

- Grunnleggende reguleringsteknikk

Teori

afgv.pdf - Basic process control strategies - Cascade control

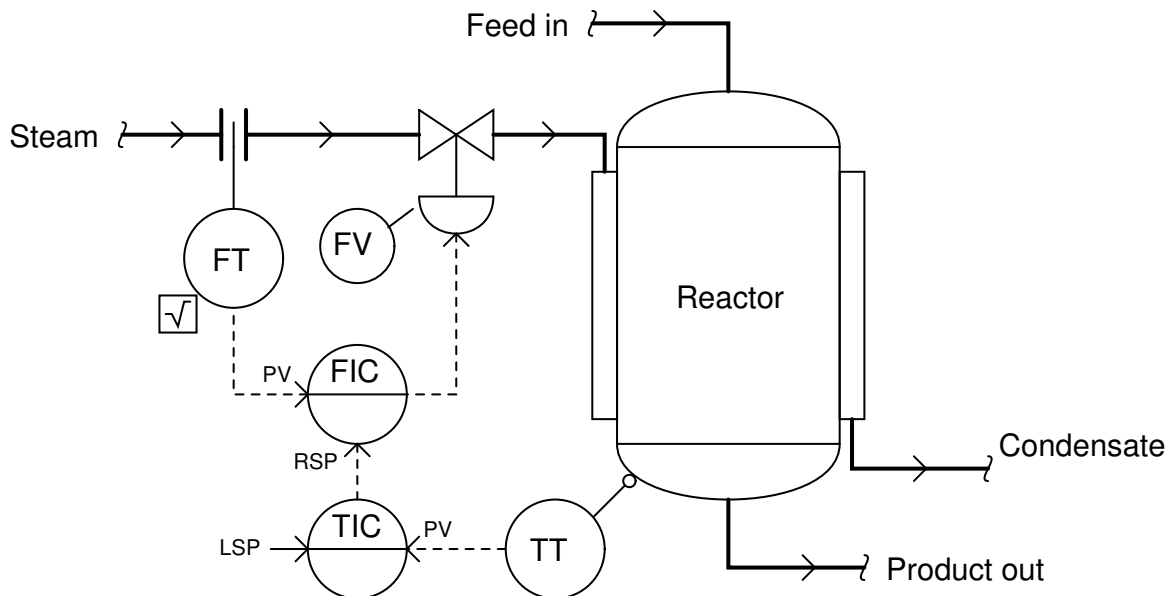Øvingsoppgaver til leksjon - følger neste side

Innlevering til leksjon - Det er ingen innlevering til leksjonen.

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Oppgaver

Oppgave 1

Forklar hvordan dette *kaskadekoblede* temperaturreguleringssystemet virker:

Kaskadekoblede reguleringsystemer har to sløyfer: en primær sløyfe og en sekundærsløyfe. Finn ut hvilke sløyfer som er primær og sekundær i regulerinssystemet. Finn også ut hvilken av sløyfene som må optimaliseres først og hvorfor den må det.

Finn ut hvilken retning styresignalet må ha på hver av regulatorene. Du kan anta direkte virkende ytransmittere og air-to-open ventil. Merk skjemaet med "+" og "−" symboler for å finne ut hvilken virkning PV og SP har på regulatoren.

| Suggestions for Socratic discussion |

- A useful problem-solving strategy for determining necessary controller actions in a cascade control system is to replace the ISA-standard "bubble" symbols for controllers with triangular opamp symbols, complete with "+" and "−" symbols at the inputs. One input of each "opamp" controller will be the PV, while the other input of each "opamp" controller will be the SP. The inverting and noninverting inputs standard to all operational amplifiers helps remind you that the PV and SP inputs of a loop controller always have opposite effects on the output signal.

- When tuning each loop controller (TIC, FIC), what should be done with the *other* controller? Should the other controller be in automatic mode or manual mode, and why?

- Suppose the control valve were switched from air-to-open to air-to-close. Would *both* master and slave controller actions need to be reversed, or just one of the controllers? If just one, which one?

file i01690

Oppgave 2

I et kaskadekoblet reguleringssystem, hvilken sløyfe må *alltid* ha kortere tidskonstant og døtid, den primære eller den sekundære? forklar hvorfor.

Suggestions for Socratic discussion

- Explain how the lag and dead times of each loop may be quantitatively measured in a live process.

file i01692

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Oppgave 3

Dette temperaturreguleringssystemet for en ovn, virker ikke så bra som operatørene skulle ønske. Temperaturen driver rundt settpunktet, til tross for flere forsøk på optimalisere regulatoren ved å justere P, I og D parameterene.
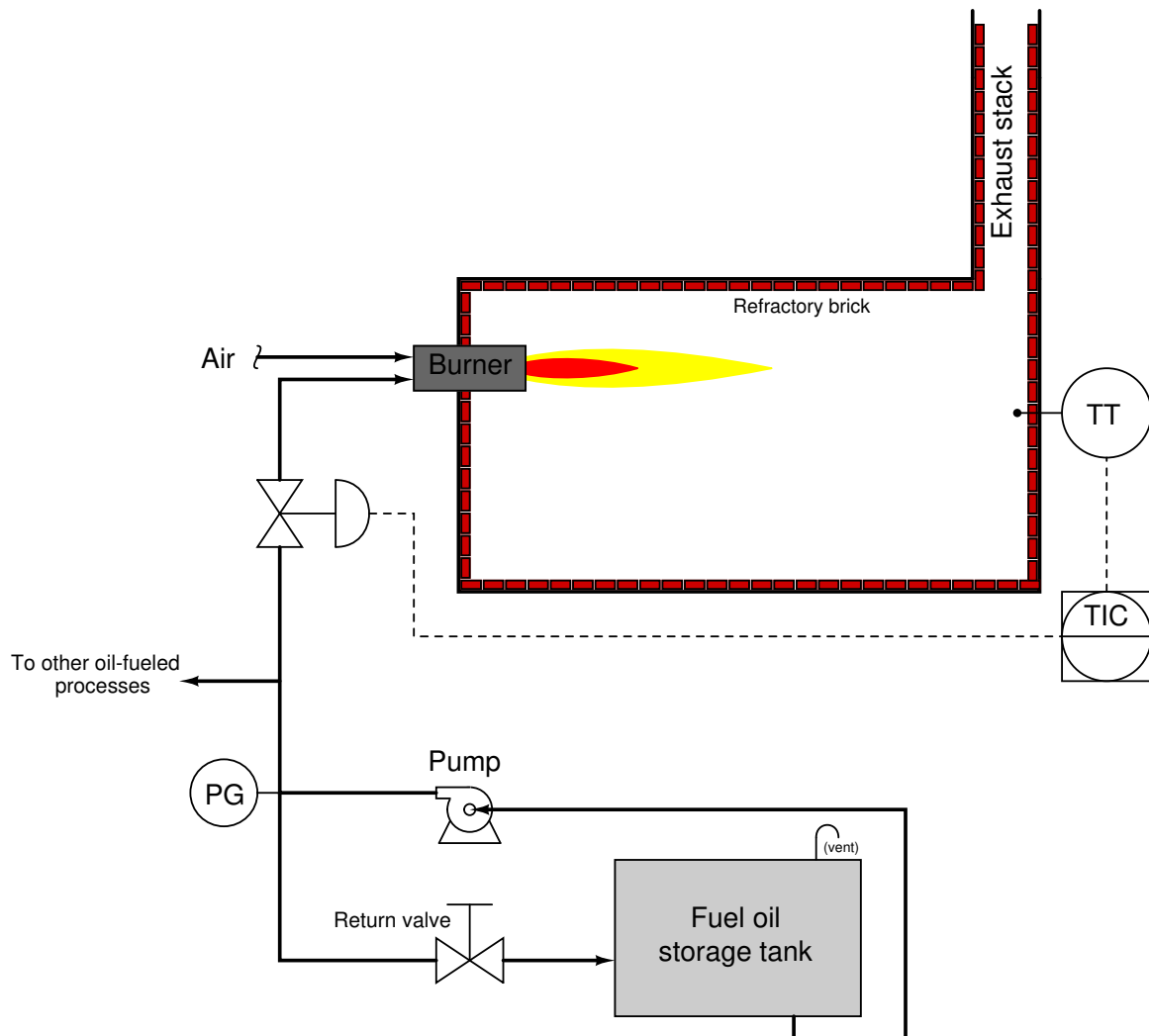
Til slutt ser en instrumentteknikker at trykkindikeringen på utaket av oljepumpen indikerer et ustabilttrykk. Det ser ut til å øke og minke helt tilfeldig.

Vis hvordan vi kan forbedre temperaturstabiliteten ved å innføre en kaskadekoblet regulering.

Suggestions for Socratic discussion

- Can you think of any solutions to this control dilemma other than cascade?

- Why do you suppose there is a return valve in the fuel oil plumbing?

- Explain what will happen in this system if someone suddenly shuts off the return valve, from its normal position.

- Explain what will happen in this system if someone suddenly opens up the return valve, from its normal position.

file i00714

Oppgave 4

The following ammonium nitrate production process was shut down for an extended period of time (typically, this kind of event is called an "outage" or a "turnaround") to perform maintenance on components that could not be worked on while the unit was running:
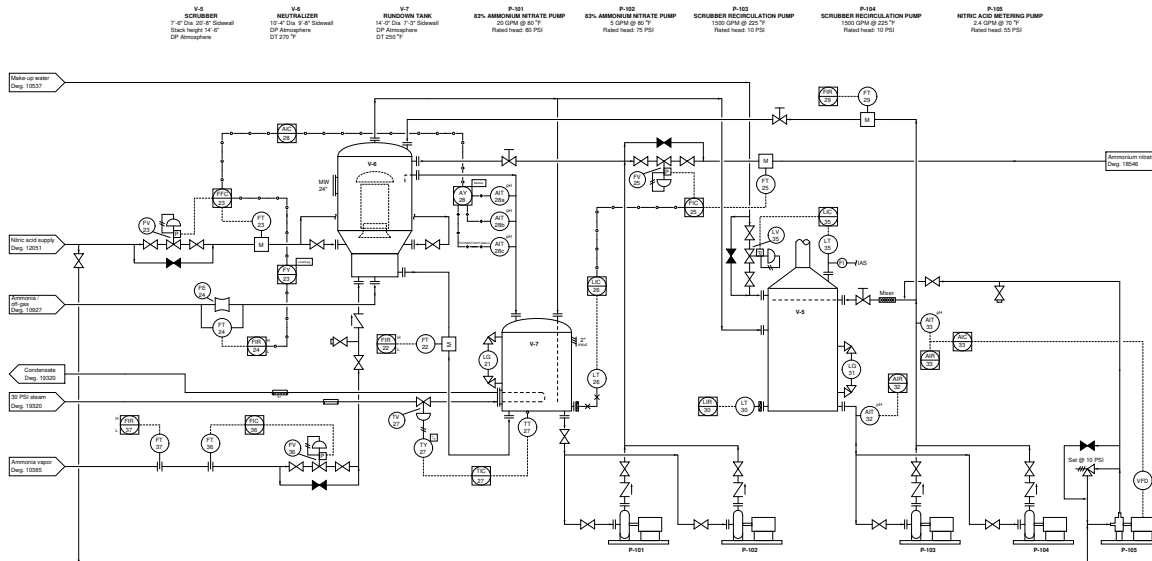
Unfortunately, the purchasing agent for the company mistakenly ordered the wrong type of valve trim on all the control valves being rebuilt. Instead of ordering equal-percentage trim for each of the valves as originally specified, the purchaser accidently ordered *linear* trim.

When the work was completed and the unit re-started, operations personnel began to notice the scrubber level control loop behaving poorly: the scrubber liquid level would not remain stable at setpoint the way it used to before the outage.

An instrument technician sent to diagnose this problem noticed that valve LV-35 was sporting a fresh coat of paint, suggesting it had been rebuilt during the outage, and following this clue the technician was able to discover the trim misconfiguration as being the cause of the instability.

After fixing this problem, the same technician decided to investigate other control valves in the unit that had been rebuilt. FV-25 was another one of the valves that had the wrong characterization of trim installed, and yet the rundown tank level control system was not misbehaving: LIC-26 was able to maintain liquid level at setpoint regardless of load changes or setpoint changes.

Explain why a change of valve trim characteristic caused problems for the scrubber's level control system, but not for the rundown tank's level control system.
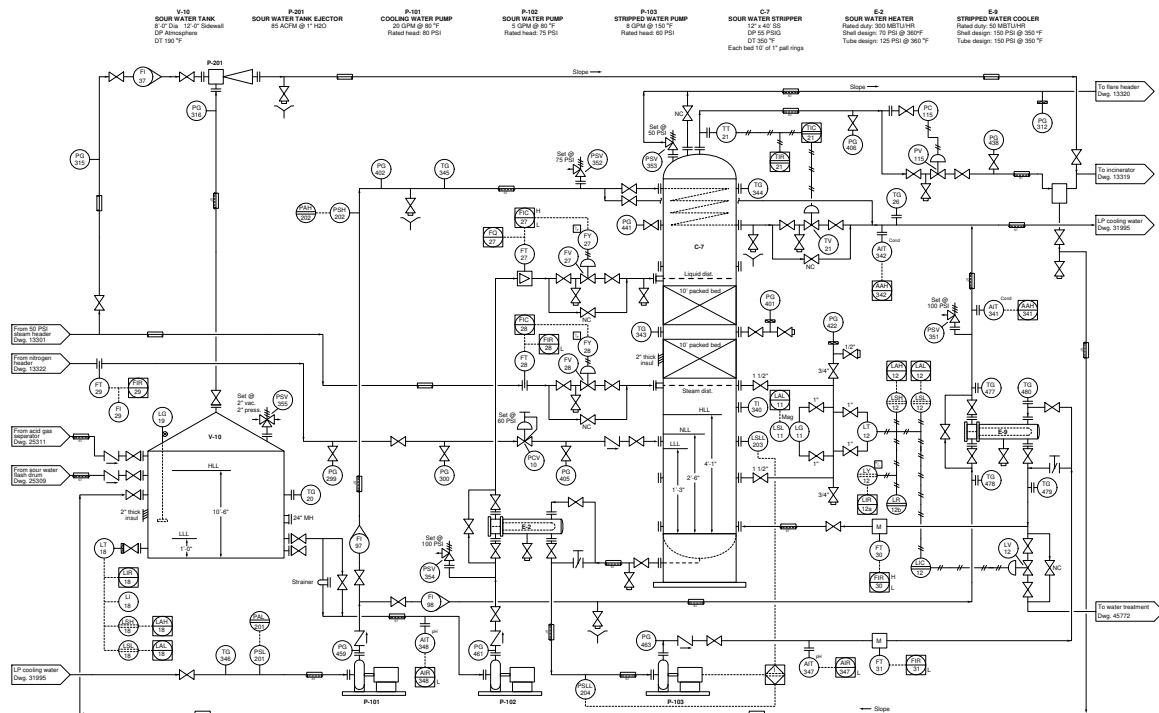
Suggestions for Socratic discussion

- Will an incorrect trim characterization in FV-25 have any deleterious effects at all?

file i01694

Oppgave 5

The stripper overhead temperature control system (loop #21) works adequately, but not as good as it could. In its present form, the temperature tends to be affected by variations in cooling water supply pressure, because this affects the differential pressure drop across control valve TV-21, and thus the flow rate through the cooling pipes in the upper section of the sour water stripping vessel:

Modify this system for better control of stripper overhead temperature, using *cascade* control.

Suggestions for Socratic discussion

- Suppose you discovered that the stripper overhead temperature was also being affected by variations in the cooling water's *temperature* as well as by the cooling water's pressure. Can you think of any control strategy that might help overcome this load variation?

file i01696

Oppgave 6

Identify what sort of control strategy this is, where two chlorine analyzers are used to measure concentration of chlorine in treated wastewater prior to final discharge, and two controllers work to position the chlorine injection valve:
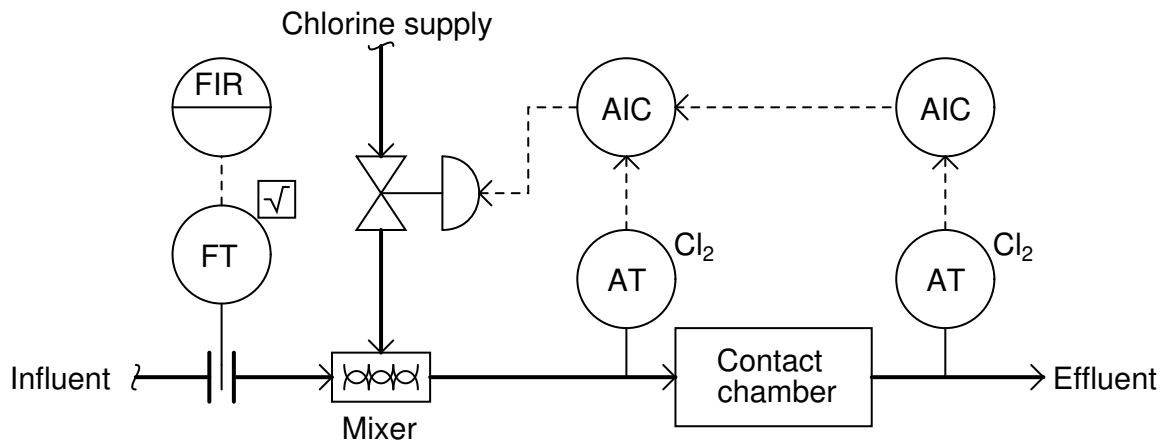
Note: a *contact chamber* is typically a vessel containing a labyrinth of baffles forcing water to reside inside it for a minimum length of time. In this case, the purpose of the contact chamber is to give chlorine gas sufficient time to disinfect biological contaminants in the water prior to discharge.

| Suggestions for Socratic discussion |

- A useful analytical technique for any complex control system is to annotate the diagram with "+" and "−" symbols at the instrument bubble inputs, designating "noninverting" and "inverting" characteristics, respectively. Show how this helps you track of all directions of action, making it easier to figure out how the control system responds to changes.

- For those who have studied control valves, determine the best opening characteristic for the valve trim (quick-opening, linear, or equal percent), assuming the chlorine pressure is regulated at a constant value, and the mixer operates at atmospheric pressure.

- Explain what will happen in this system if either of the chlorine transmitters fails with a low signal.

- Explain what will happen in this system if either of the chlorine transmitters fails with a high signal.

- Explain what will happen in this system if the chlorine gas supply pressure suddenly decreases.

- Explain what will happen in this system if the chlorine gas supply pressure suddenly increases.

- Identify the effect of the influent flow as a *load* on chlorine control, and incorporate a suitable feedforward control strategy to compensate.

- This process is an ideal candidate for a *adaptive gain* control strategy. Research what this is, then explain why it fits this process so well. Finally, edit the control strategy to incorporate the principle of adaptive gain.

file i01806

Oppgave 7

This clearwell water level control system for a drinking water treatment facility maintains a constant level of water following filtration, for sourcing to customers:
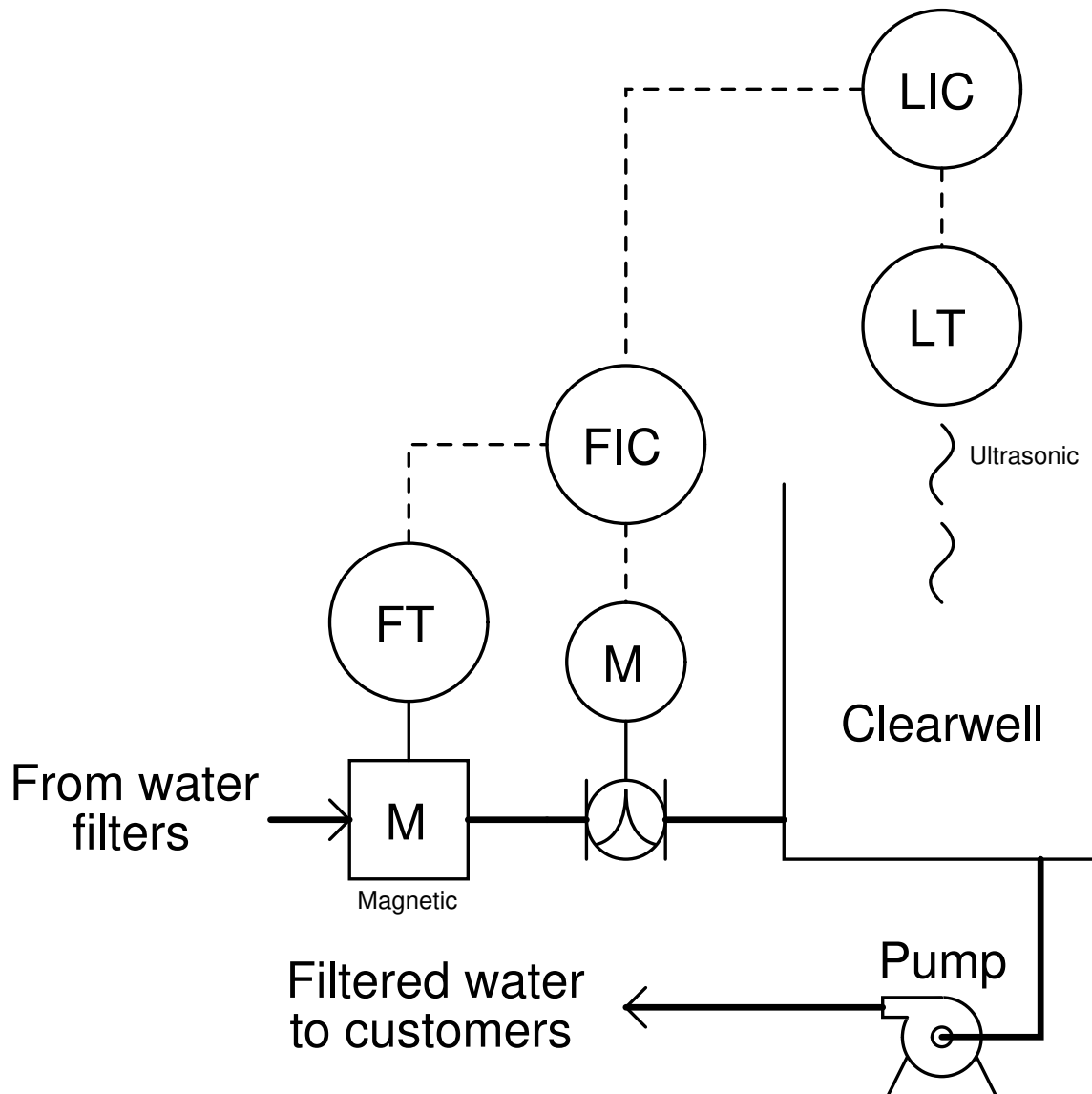

Determine what both controllers (LIC and FIC) will do over time if the control valve fails in such a way that it ignores the controller's output and opens wide. Assume both transmitters are direct-acting (i.e. greater signal with greater flow ; greater signal with greater water level) and that the control valve is signal-to-open (fail closed).

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<u>file i01998</u>

Oppgave 8

This water level control system (for a municipal water supply operation) is supposed to maintain constant water level in the filter and in the clearwell. Unfortunately, it has a problem. Operators call you urgently to determine why the clearwell is completely empty:
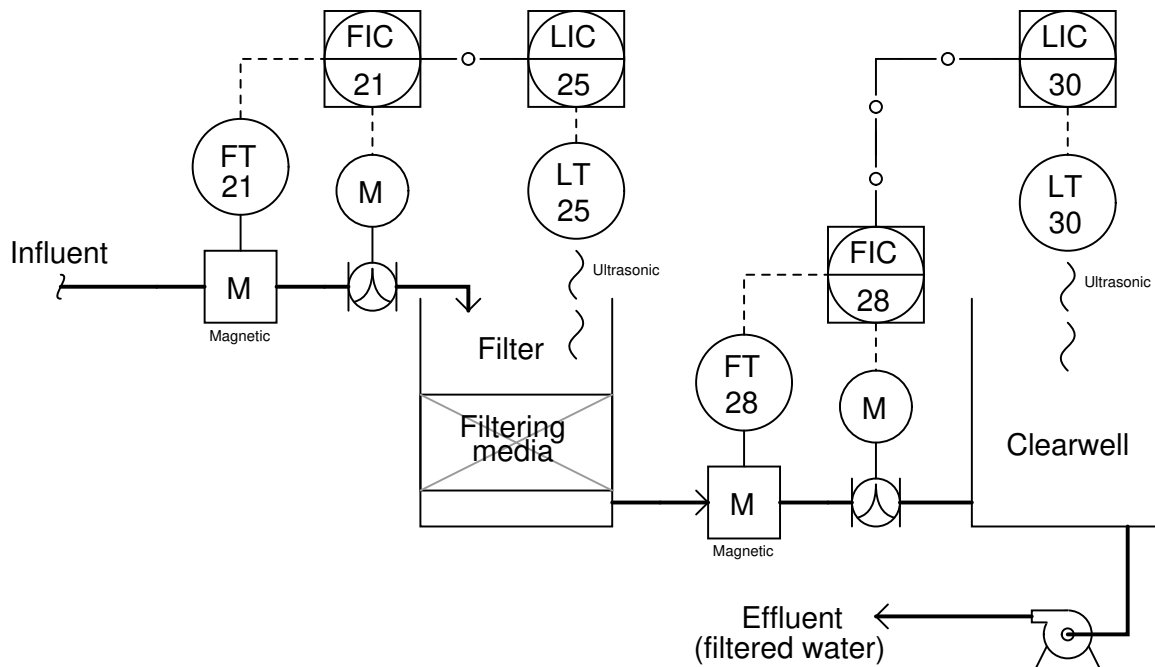
Your first step is to ask the operator if they have actually inspected the clearwell to verify that it is empty. They have, and it is. They also point to the display for level controller LIC-30 and show you that it reads 0% level.

Identify the likelihood of each specified fault for this water filtration system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this system.

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| Fault	Possible	Impossible
Transmitter FT-21 failed with low output		
Transmitter FT-21 failed with high output		
Transmitter LT-25 failed with low output		
Transmitter LT-25 failed with high output		
Transmitter FT-28 failed with low output		
Transmitter FT-28 failed with high output		
Transmitter LT-30 failed with low output		
Transmitter LT-30 failed with high output		
Effluent pump turned off		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Suggestions for Socratic discussion

- A useful problem-solving strategy for determining necessary controller actions in a cascade control system is to replace the ISA-standard "bubble" symbols for controllers with triangular opamp symbols, complete with "+" and "−" symbols at the inputs. One input of each "opamp" controller will be the PV, while the other input of each "opamp" controller will be the SP. The inverting and noninverting inputs standard to all operational amplifiers helps remind you that the PV and SP inputs of a loop controller always have opposite effects on the output signal.

- A valuable principle to apply in a diagnostic scenario such as this is *correspondence*: identifying which field variables correspond with their respective controller faceplate displays, and which do not. Apply this comparative test to the scenario described, and use it to explain why the technician's proposed test was probably not the best first step.

file i02326

Oppgave 9

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):
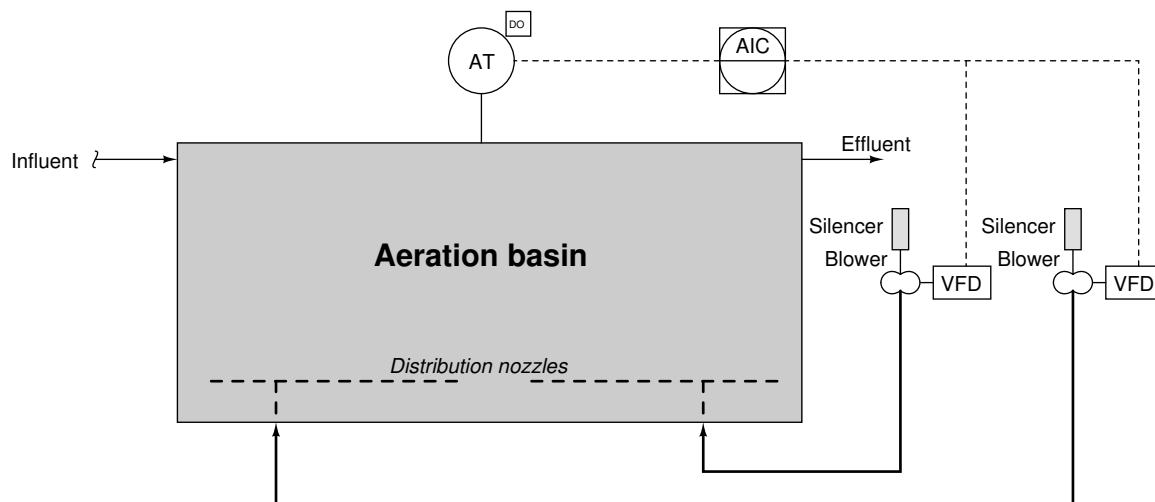

A problem with this particular system is that the nozzles at the bottom of the aeration chamber have a tendency to plug up, thus impeding air flow into the chamber. The controller (AIC) will compensate for this over time by commanding the blowers to spin faster, but the correction is not immediate which results in temporary deviations from setpoint.

Modify this control strategy so that any plugging of the nozzles will be immediately sensed and compensated for, avoiding the temporary deviations from setpoint. Feel free to add any needed field instruments to make this happen.

file i03292

Oppgave 10

This clearwell water level control system for a drinking water treatment facility maintains a constant level of water following filtration, for sourcing to customers:
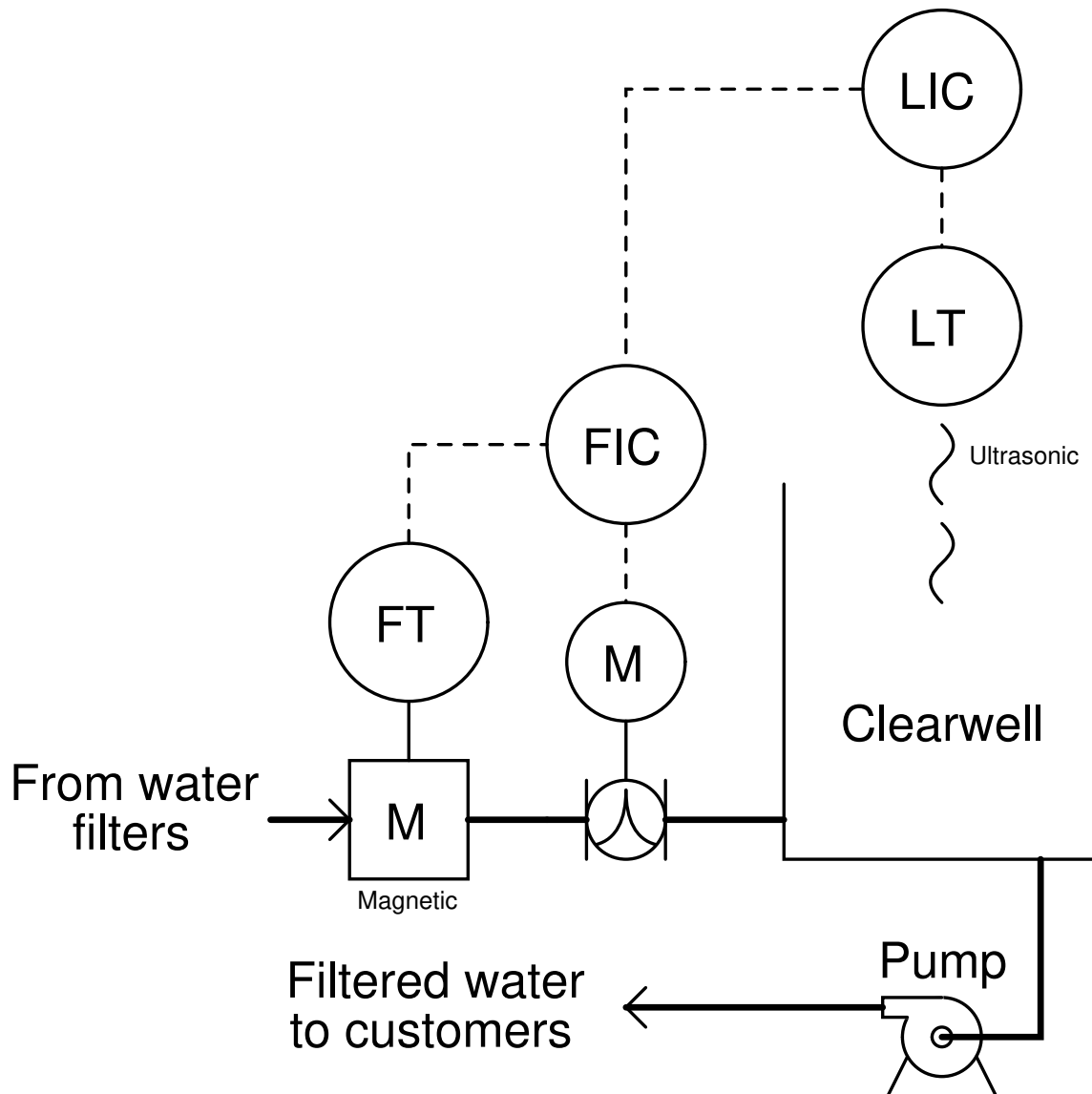
Determine what both controllers (LIC and FIC) will do over time if the flow transmitter fails in such a way that it registers zero flow regardless of the actual flow rate of water through it. Assume the level transmitter is direct-acting (i.e. greater signal with greater water level) and that the control valve is signal-to-open (fail closed).

Oppgave 11

This P&ID shows an incinerator stack used to safely burn poisonous gases. The high temperature of the gas flame reduces the poisonous compounds to relatively harmless water vapor, carbon dioxide, and oxides of sulfur and nitrogen.

The incinerator was recently out of service for three full weeks being rebuilt. Following the rebuild, operations personnel have attempted to start the incinerator's burner on plant fuel gas with no success. They can get it started with natural gas, but the burner management system keeps tripping whenever they switch to fuel gas. They call you to investigate.

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Identify the likelihood of each specified fault in this process. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this process.

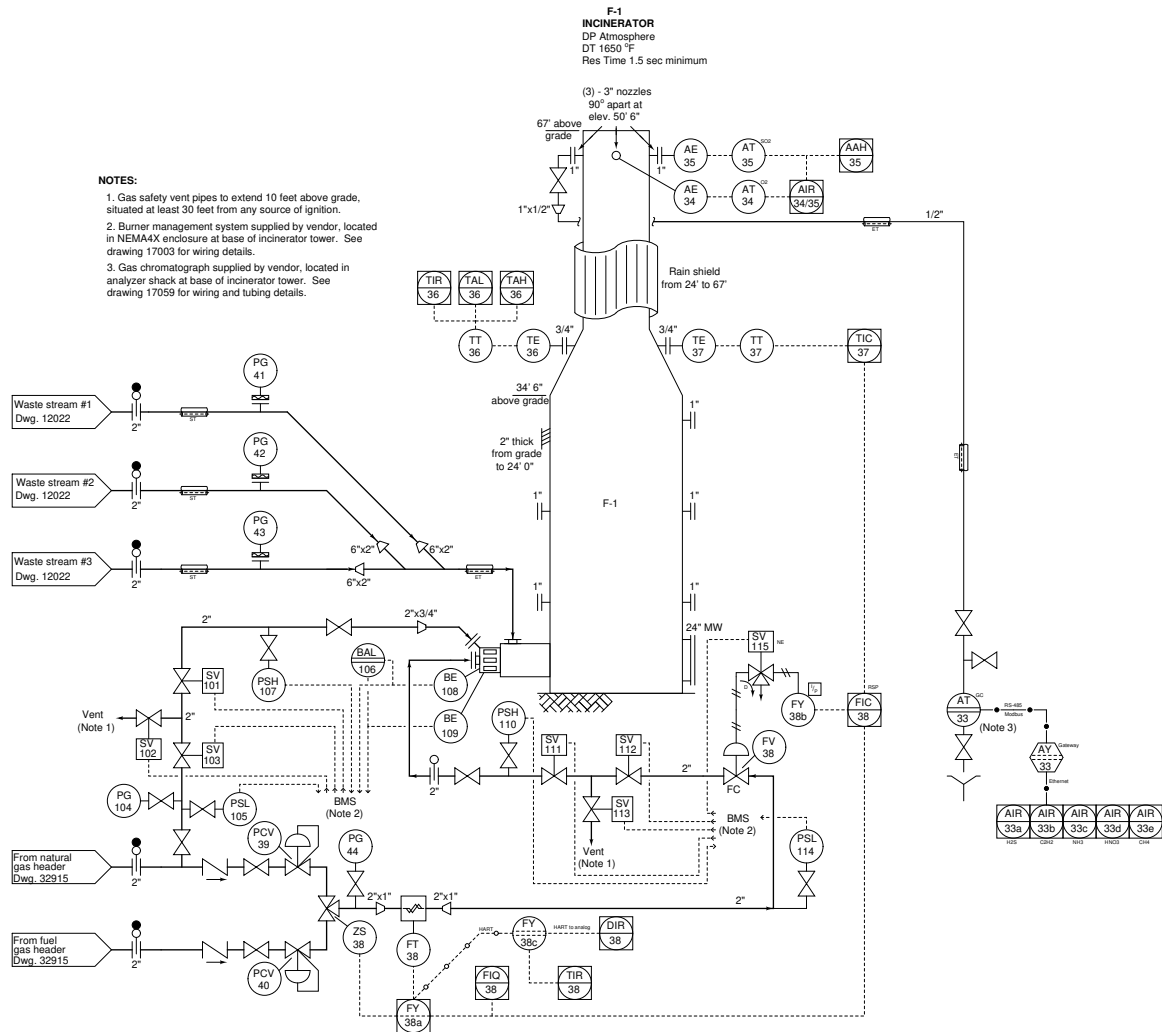| Fault	Possible	Impossible
SV-115 leaking air		
PSL-105 failed		
PSL-114 failed		
PCV-39 pressure setpoint too low		
PCV-39 pressure setpoint too high		
PCV-40 pressure setpoint too low		
PCV-40 pressure setpoint too high		
ZS-38 failed		
Blind inserted in natural gas header		
Blind inserted in fuel gas header		

file i03500

Oppgave 12

This P&ID shows an incinerator stack used to safely burn poisonous gases. The high temperature of the gas flame reduces the poisonous compounds to relatively harmless water vapor, carbon dioxide, and oxides of sulfur and nitrogen:

Identify where the measurement/control system is performing *integration* to "totalize" a quantity over time. If possible, identify realistic units of measurement for the integrated value(s).

Suppose an environmental regulatory agency required that the emissions monitoring system (loop number 33 in the P&ID) calculate the *total volume* of pollutants emitted each month, rather than just provide measurements of pollutant concentration (e.g. percent

or parts-per-million). How would it be possible to do this, and what additional field instrumentation would be required?

file i03507

Oppgave 13

An operator tells you the stack temperature of this incinerator is running high as indicated by TIC-37. The setpoint is set at 1400 degrees F, but the PV display shows a steady 1489 ^{o}F:

Identify the likelihood of each specified fault in this process. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this process.

Fault	Possible	Impossible
TT-37 miscalibrated (reading too low)		
TT-37 miscalibrated (reading too high)		
TIC-37 in manual mode		
TIC-37 in auto mode		
FIC-38 in manual mode		
FIC-38 in auto mode		
FIC-38 in cascade mode		
FT-38 miscalibrated (reading too low)		

file i03529

Oppgave 14

Denne smelteovnen har et kaskadekoblet reguleringssystem der den primære regulatoren måler temperaturen i metallet som er smeltet og sekundær regulatoren regulerer temperaturen i ovnens vegger og tak.
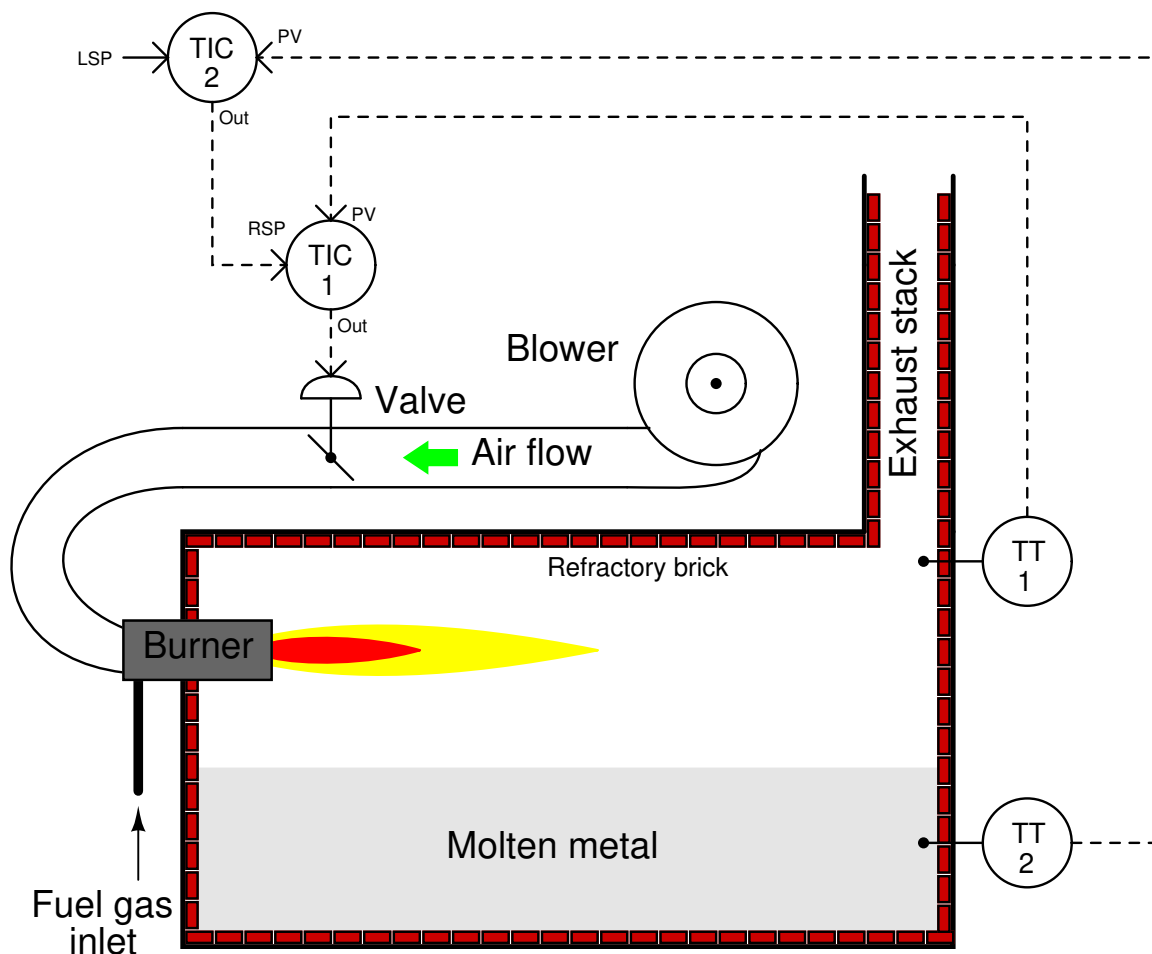
En dag blir sensorn i TT-1 defekt. Dette gjør at TT-1 sender et signal på 20.6mA. Hvilken effekt vil dette ha på reguleringssystemet?

Suppose an instrument technician replaces the bad thermocouple, but the trend of crown temperature over time begins to cycle (oscillate) more than it ever did before, refusing to settle down to setpoint. You are called to troubleshoot this problem, and you find that the replacement thermocouple was not fully inserted into the *thermowell* (the protective sheath protruding into the furnace, acting as a sort of "sock" into which the thermocouple

sensor is inserted to measure temperature without direct exposure to the environment inside the furnace).

Explain how something as simple as improper thermocouple insertion could cause the crown temperature control loop to cycle.

## Suggestions for Socratic discussion

- Determine the necessary control actions (direct vs. reverse) for each controller in this system, assuming a signal-to-open valve.

- Why do you think a cascade control strategy is used to control the burner?

- For those who have studied thermocouples, what *type* (letter code) of thermocouple would you recommend for this application, assuming a crown temperature upwards of 1800 ºF?

file i01530

Oppgave 15

This metal-melting furnace has a cascade control system, whereby a "bath" controller (sensing the temperature of the molten metal) acts as the primary, and a "crown" controller (sensing the temperature of the refractory wall and roof) acts as the secondary. The burner's heat output is a direct function of air flow through it; therefore, a wider-open air valve causes a more intense fire from the burner:
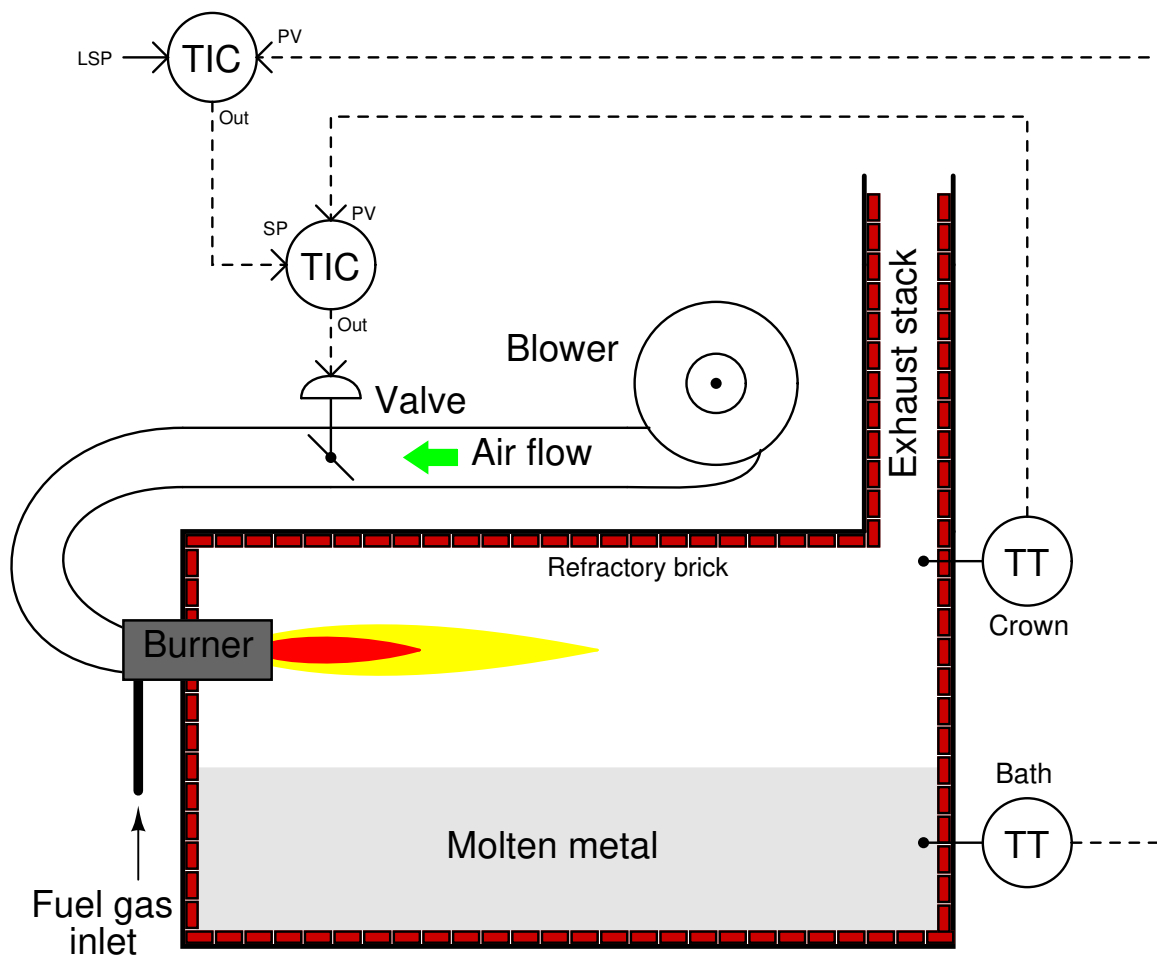
Sometimes a thick layer of "slag" covers the surface of the metal, impeding heat transfer from the burner flame to the molten metal bath. The bath controller, sensing low metal temperature, sends an ever-increasing setpoint to the crown controller, raising the air temperature inside the furnace to high levels, which then shortens the life of the refractory brick.

Can you think of a solution to this problem, whereby the secondary control loop won't be driven into saturation in the event of slag on the metal surface?

Suggestions for Socratic discussion

- Why do you suppose this furnace is equipped with a cascade control system at all? What would be wrong with just a simple single-loop PID control of metal temperature?

file i01826

Svar

Svar 1

The temperature controller (TC) provides a "remote" setpoint to the flow controller (FC), which throttles the flow control valve (FV) to achieve the desired rate of steam flow.

- Master (primary) = Reactor temperature

- Slave (secondary) = Steam flow

When tuning cascaded loops, you should *always* ensure the slave loop is well-tuned before attempting to tune the master loop. I'll let you figure out why this is important!
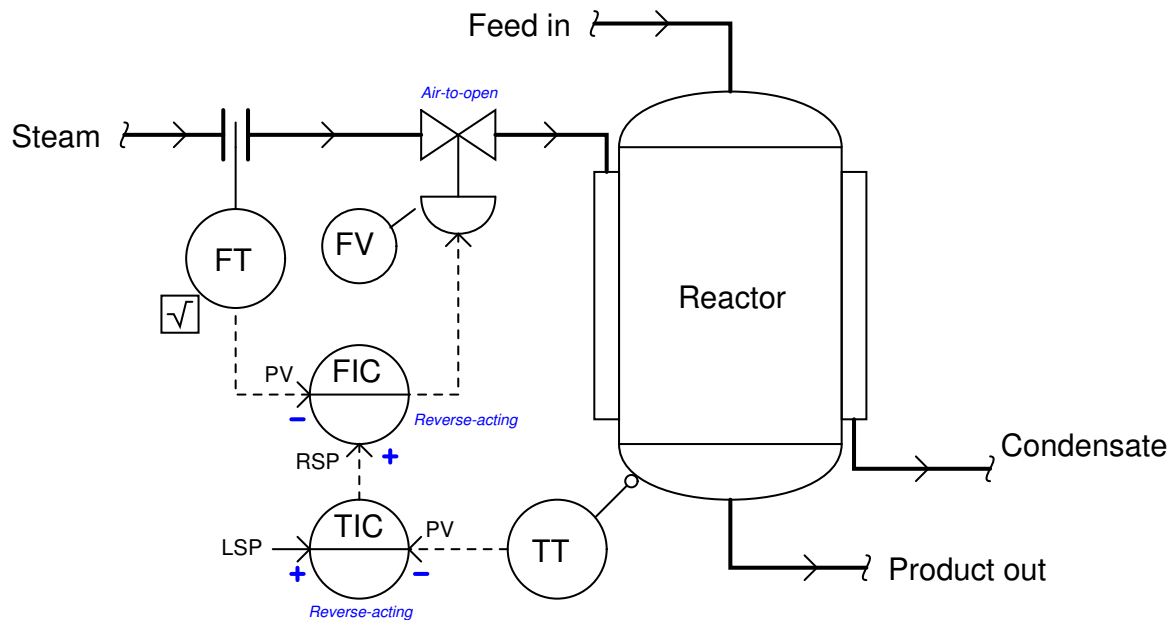
A helpful strategy for identifying necessary master and slave controller actions in a cascade control system is to re-draw the controller "bubbles" as opamp symbols instead, complete with "+" and "−" labels for noninverting and inverting inputs, respectively. Since all PID controllers have PV and SP inputs, and these inputs always have opposite effects on the output signal, the opamp conventions of "+" and "−" work very well to describe the action of any PID controller. If the PV input on the opamp controller must be noninverting ("+") in order to achieve loop stability, then that controller must be direct-acting. If the PV input on the opamp controller must be inverting ("−") in order to achieve loop stability, then that controller must be reverse-acting. The following diagram shows how to use opamp symbols to represent controller actions in the same cascaded flow/temperature control system:
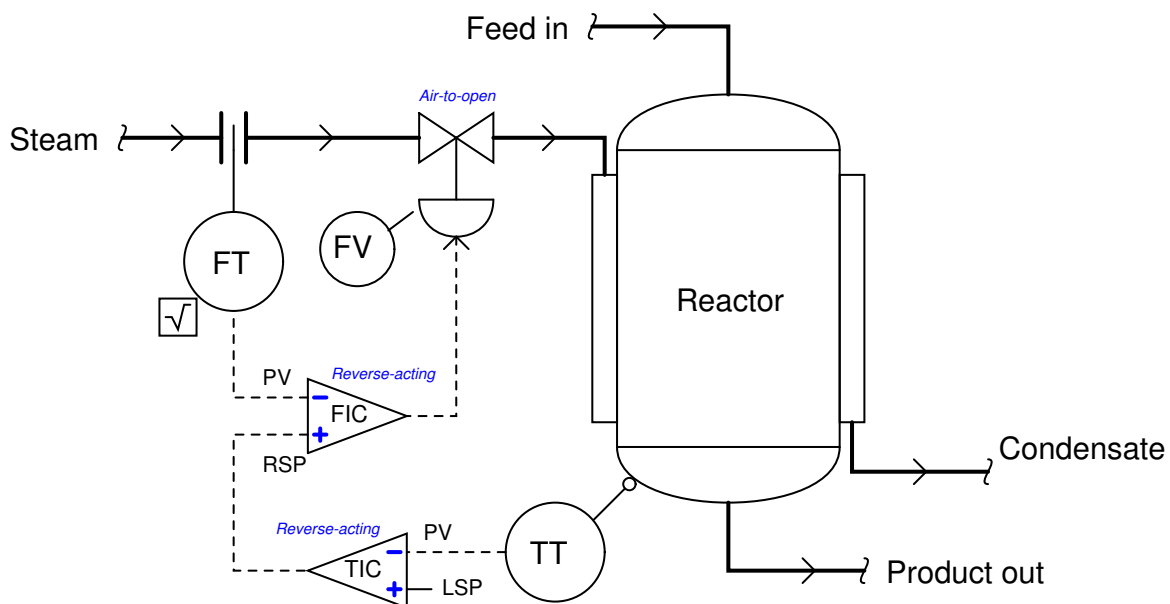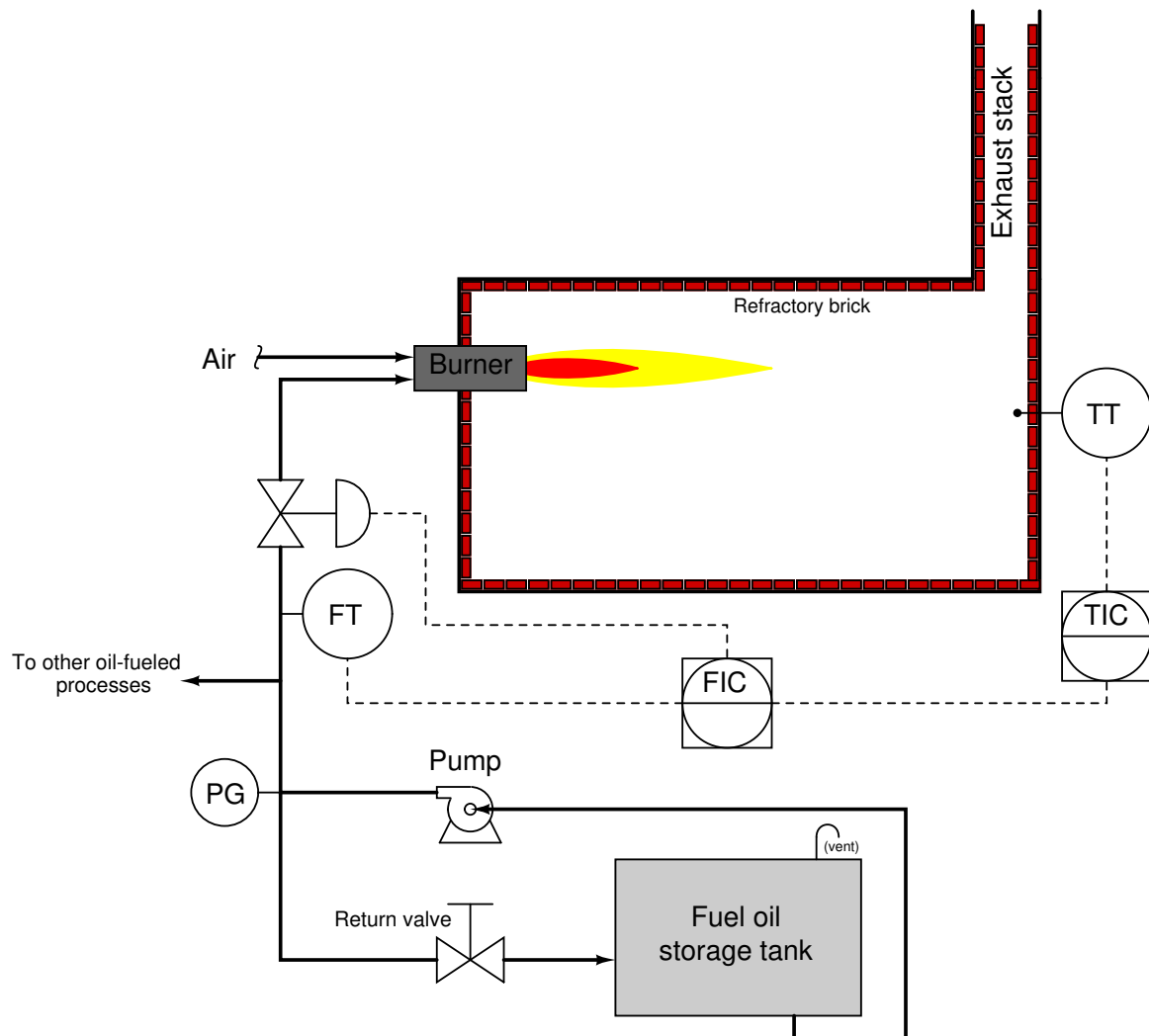

Note that it is always the *inputs* of a controller we label with "+" or "−" symbols, never the *output* of a controller.

Svar 2

Svar 3

There are multiple solutions one could implement to fix this problem. Here is one:

Svar 4

Hint: the rundown tank's level control system is *cascaded* to a flow controller (FIC-25).

Svar 5

Svar 6

Svar 7

The flow controller (FIC) will send a "close" signal to the valve, because its transmitter indicates the flow rate is excessive.

The level controller's output will saturate low, telling the flow controller to stop the flow as the clearwell level rises well above setpoint due to the uncontrolled flow coming in.

Svar 8

Partial answer:

Fault	Possible	Impossible
Transmitter FT-21 failed with low output		
Transmitter FT-21 failed with high output		
Transmitter LT-25 failed with low output		$\checkmark$
Transmitter LT-25 failed with high output		
Transmitter FT-28 failed with low output		
Transmitter FT-28 failed with high output	$\checkmark$	
Transmitter LT-30 failed with low output		
Transmitter LT-30 failed with high output		
Effluent pump turned off		

Svar 9

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

Svar 10

The flow controller (FIC) will send a "full-open" signal to the valve, because its transmitter indicates the flow rate is less than it should be.

The level controller's output will saturate low, telling the flow controller to stop the flow as the clearwell level rises well above setpoint due to the uncontrolled flow coming in.

Svar 11

Fault	Possible	Impossible
SV-115 leaking air		√
PSL-105 failed		√
PSL-114 failed		√
PCV-39 pressure setpoint too low		√
PCV-39 pressure setpoint too high		√
PCV-40 pressure setpoint too low	√	
PCV-40 pressure setpoint too high	√	
ZS-38 failed		√
Blind inserted in natural gas header		√
Blind inserted in fuel gas header	√	

Svar 12

FIQ-38 is a mass flow totalizer, integrating the mass *flow rate* signal coming from flow transmitter FT-38 to arrive at a total mass of fuel gas burned over time. Realistic units of measurement would be kilograms or pounds (mass).

In order to do the same for stack emissions, we would need to measure the flow rate of exhaust through the incinerator stack, then multiply that flow rate signal by each pollutant's measured concentration (to arrive at flow rate for each pollutant), then integrate each of those pollutant gas flow rates over time to calculate pollutant volumes.

Svar 13

Fault	Possible	Impossible
TT-37 miscalibrated (reading too low)		√
TT-37 miscalibrated (reading too high)		√
TIC-37 in manual mode	√	
TIC-37 in auto mode		√
FIC-38 in manual mode	√	
FIC-38 in auto mode	√	
FIC-38 in cascade mode		√
FT-38 miscalibrated (reading too low)		√

Svar 14

Not having the thermocouple fully inserted into the thermowell leads to additional *lag time*, as the air gap between the thermocouple tip and the thermowell bottom generates a time lag between the thermowell temperature and the thermocouple tip temperature.

Svar 15