Cellar Automation: Temperature Control

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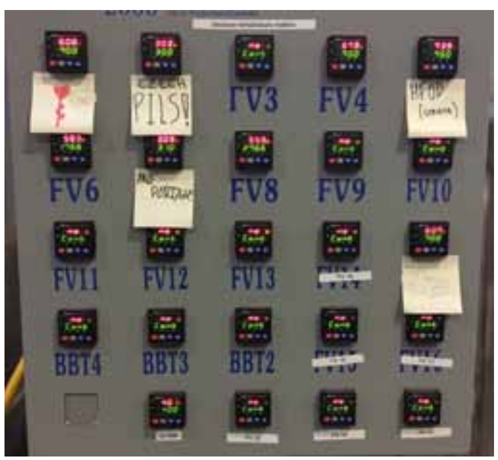
Fremont Brewing

Fremont Brewing

- Started brewing in 2009
- Operate two facilities- a production brewery (90-240bbl batches) and a small-batch brewery (10-30bbls).
- On pace to produce 42,000bbls in 2017

Small Batch Facility

- Five 15bbl FVs
- One 30bbl FV
- Isolated Temp Controllers (SOLO)



Production Facility

Large Facility:

- Five 240bbl FVs
- Seven 90bbl FVs
- Two 60bbl FVs
- PLC Controlled
- Integrated into SCADA

Overview

- Automation basics
- Components of an Automated Control System
- Basic Control Loop
- Fermentation Control System
- Fermentor Cooling Mechanics

Automation

- The technology by which a process or procedure is performed without human assistance.
- **Simple Example:** ON/OFF fermentation temperature control

Automation

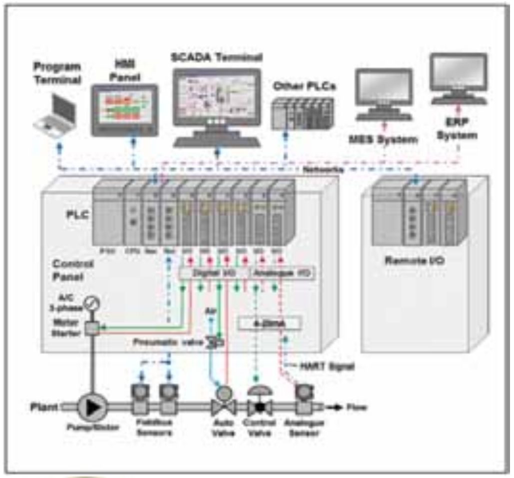
- The technology by which a process or procedure is performed without human assistance.
- **Complex:** Packaging Equipment- can filler, carton packer, robots!

Why Brewery Automation?

- Consistency (Quality!)
- Resource and Labor Efficiency
- Automated Data-logging
- Troubleshooting
- Safety

Control System Components

- Controller (CPU)
- Inputs
- Outputs
- HMI (Human Machine Interface)
- SCADA (Supervisory Control and Data Acquisition)



Control System Components

Controller

- Reads raw electric signal (i.e. temperature sensor)
- Converts inputs to human readable (degrees F)
- Stores program:
  - Set points
  - Dead Band
- Engages outputs (glycol valve)

Control System Components

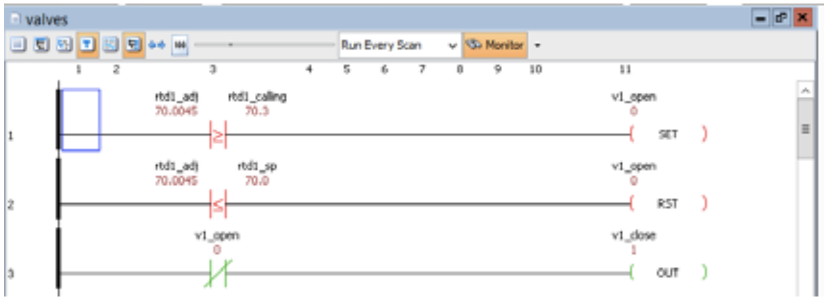
Controller

- Programmable Logic Controller (PLC)
  - More “advanced” customizable controller
  - Generally can connect to monitoring system for datalogging and/or alarming
  - User Programmable by **ladder logic.**

Control System Components

Controller

- Ladder Logic Example:



Control System Components

<u>Types of **Inputs**</u>

- **Digital** (ON/OFF)
  - Controller either receives an electric signal input or it doesn't.
  - Proximity Sensors

Control System Components

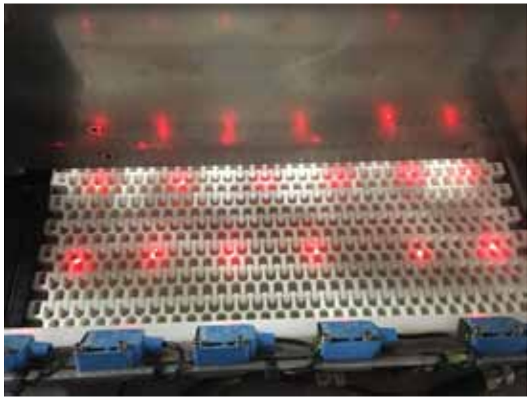
<u>Types of **Inputs**</u>

- **Digital** (ON/OFF)
- "Lidless Can" Sensor

Control System Components

<u>Types of **Inputs**</u>

- **Digital** (ON/OFF)
- Can detection "photo-eyes"



Control System Components

<u>Types of **Inputs**</u>

- **Digital** (ON/OFF)
- Butterfly valve feedback sensor (proximity switch)

Control System Components

Types of **Inputs**

- **Analog**
  - Sends a ranged input: 4-20mA, 0-10V, Voltage Pulse, RTD.
  - Translated into a precise value.
  - *Example:* A pressure transducer may be calibrated to send 4-20mA signal between 0-16psi. Therefore, 1mA = 1psi
  - 12.59mA reading = 8.59psi.

Control System Components

Types of **Inputs**

- **Analog**
- Electromagnetic Flow meter
- Outputs high frequency pulse for totalizer, ie. 10pulses per gallon. PLC translates to flow rate

Control System Components

Types of **Inputs**

- **Analog**
- RTD temperature sensor

Control System Components

Types of **Outputs**

- **Digital** (ON/OFF)
  - *Example:* Solenoid valve, Butterfly valve, Alarm light

Control System Components

Types of **Outputs**

- **Analog**
  - signal sent to VFD to control pump speed, lauter rake speed, flow control valves

Control System Components

Types of **Outputs**

- **Analog**
  - Some valves operate on **analog** output from PLC- i.e. double seat flow control valves

Control System Components

Human Machine Interface (HMI)

- Simple:

Control System Components

Human Machine Interface (HMI)

- Complex:

Control System Components

Supervisory Control and Data Acquisition (SCADA)

- Inductive Automation's Ignition

Control System Components

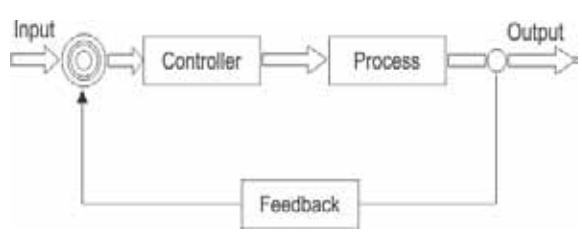
Supervisory Control and Data Acquisition (SCADA)

- Raspberry Pi?

Control Loop Basics

Process Control is done in a continuous "Loop"

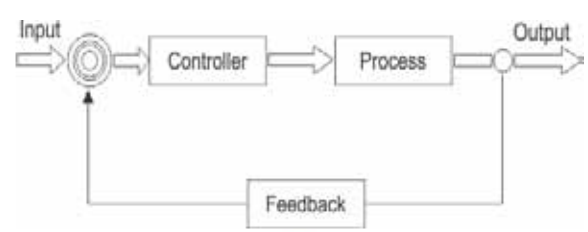
- **Goal of Loop**: control tank temperature



Control Loop Basics

Process Control is done in a continuous "Loop"

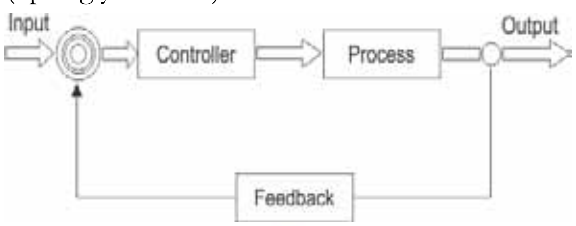
- Loop receives **Input** or **Process Value (PV)** from sensor
- i.e. Current tank temperature from **RTD**



Control Loop Basics

Process Control is done in a continuous "Loop"

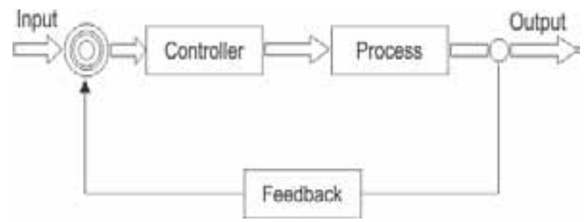
- Controller is given a **Set Point (SP)** to control this input.
- "**Process**" is some change to system- i.e. yeast heating up beer
- If **PV** is above **SP**, controller takes action to control process (open glycol valve)



Control Loop Basics

Process Control is done in a continuous "Loop"

- Once **PV** has fallen below **SP**, controller turns off valve to keep temperature at **SP**

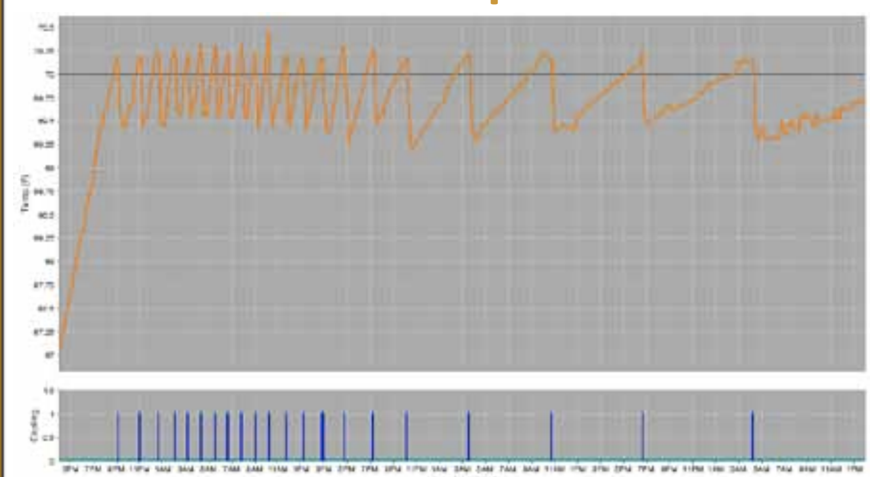


Control Loop Basics

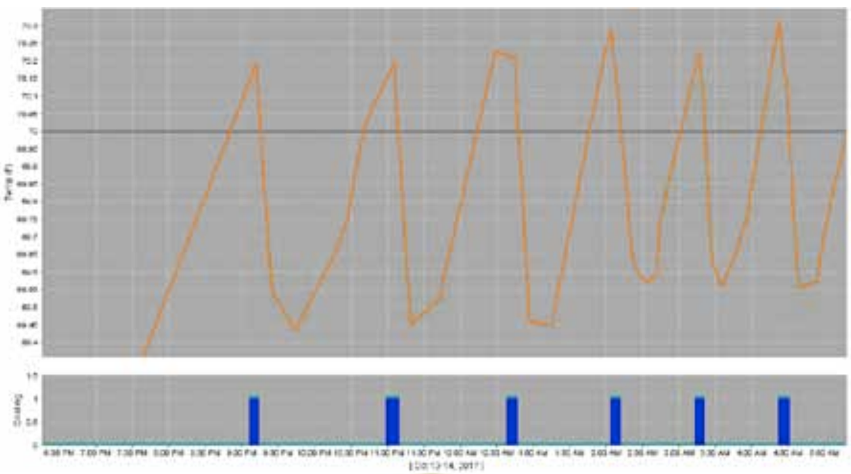
Dead Band

- Controller has parameter for how far **PV** should get above **SP** before taking action. This is called "**dead band**"
- Signal is not perfectly constant, differential avoid rapid fire valve opening and closing when **PV** is very close to **SP**

Control Loop Basics



Control Loop Basics



More Advanced Control

At Fremont, ON/OFF keeps tank temp within +/-0.5F. Can we do better? (Do we need to?)

"Time Proportional"

- Instead of simple ON/OFF, ladder logic is slightly more complicated.
- The further away from the setpoint the longer the valve stays open. If **SP** is 70 and **PV** is 70.2, glycol might switch on for 20 seconds and then off again. If **PV** climbs to 70.5, glycol could switch on for two minutes then off again.
- Less overshooting temp because of **deadband** and undershooting past setpoint (wasted cooling energy and possibly going to a lower temp than you is desired)

Fermenter Design

- Jackets
- Thermowell placement

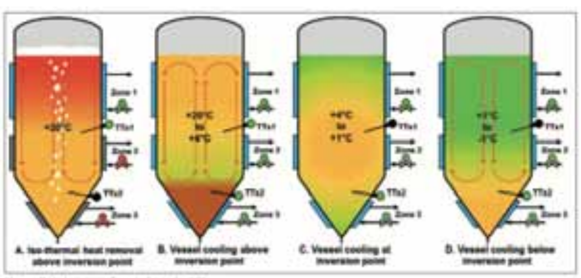


Figure 3: Attemperation regimes in CCTs.

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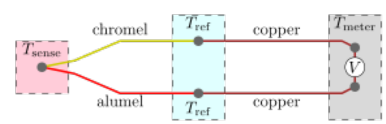
Temperature Sensor Types

Thermocouple (TC)

Principle:

- Two types of metal joined together create a tiny voltage which varies with temperature.
- Voltage is read by controller
- "Self powered"



Temperature Sensor Types

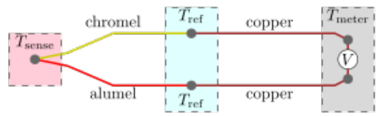
Thermocouple (TC)

Advantages:

- Cheaper
- Faster Response Time
- High range (as high as 3000 degrees)

Disadvantages:

- Less accurate (+/- 1F)

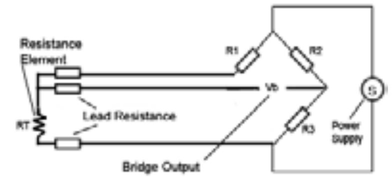


Temperature Sensor Types

Resistance Temperature Detector (RTD)

Principle:

- V (Voltage) = I (Current) * R (Resistance)
- As temperature increases, **resistance increases linearly.**
- By passing current through circuit and measuring voltage, resistance can be calculated
- Single type of metal (Platinum has best "linear" property).
- Requires power source



Temperature Sensor Types

Resistance Temperature Detector (RTD)

Advantages:

- More accurate (+/- 0.1F)
- Robust signal (less prone to electrical interference)

Disadvantages:

- More expensive
- Lower range (max 600F)
- Slower response time

Glycol Valve Types

Solenoid Valve

Advantages:

- Cheaper

Disadvantages:

- Less **flow** for same size valve than ball valve
- More prone to sticking/failure
- "Water Hammer"

Glycol Valve Types

Actuated Ball Valve

Advantages:

- Higher flow rate
- Longer cycle times (ie 10 second open)- helps with hammer
- Less prone to failure

Disadvantages:

- Cost

Fermentation

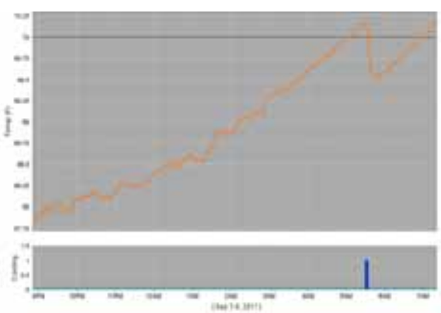
- Phases of Brewery Fermentation Cycle
  - Lag Phase
  - Active Phase
  - Final Gravity and Yeast Management
  - Cold Conditioning and Inversion Point

Fermentation

Wort Sugar =>

Ethanol + Carbon Dioxide + **HEAT**

- Temperature control is a critical fermentation parameter to control.
- If unchecked, high temperatures lead to off-flavors, yeast management issues



Fermentation Temperature Control

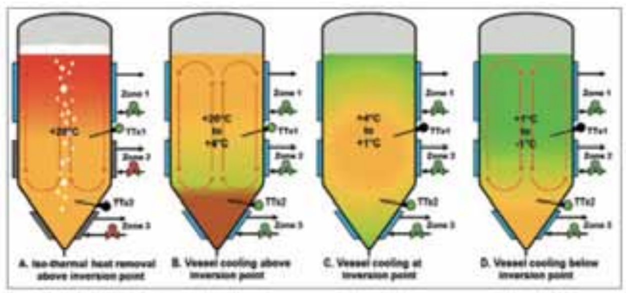


Figure 3: Attemperation regimes in CCTs.

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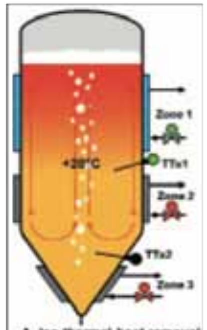
Fermentation Temperature Control

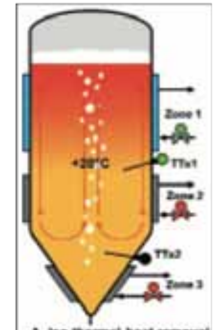
- Active Phase
  - Lots of heat generated
  - Fermenting wort is cooled by **conduction** (heat transferred from wort through jacket to glycol)
  - Tank jackets only efficiently cool wort by **convection** currents. Cooled wort is more dense which falls down the sides of tank
  - This pulls wort up the center of the tank. Currents are aided by yeast activity (CO2 evolution)
  - Because of level of wort movement, its possible to only use top jacket during active phase



A. Iso-thermal heat removal above inversion point

Fermentation Temperature Control

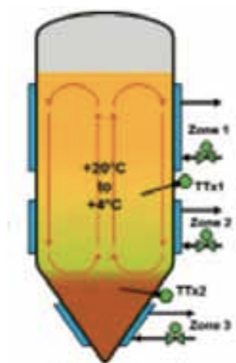
- Final Gravity / Yeast Management
  - At the end of fermentation yeast will flocculate to the bottom of the tank
  - Yeast is a good insulator. Heat can build up in the yeast pack at the bottom of the tank and be as much as **10degrees** warmer than the beer.
  - A separate cooling loop can be used to control just the yeast temperature by using cone jacket and cone RTD



A. Iso-thermal heat removal above inversion point

Fermentation Temperature Control

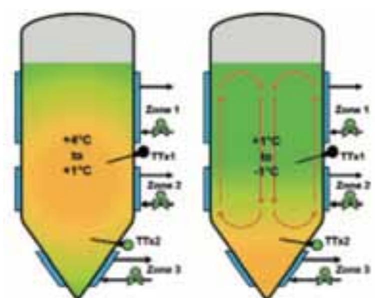
- Crash Cooling
  - All jackets are utilized to bring temperature down as quickly as possible.
  - **Convection** currents help cycle wort past jackets to cool entire tank down.
  - **Convection** continues to happen until **Inversion Point**



B. Vessel cooling above inversion point

Fermentation Temperature Control

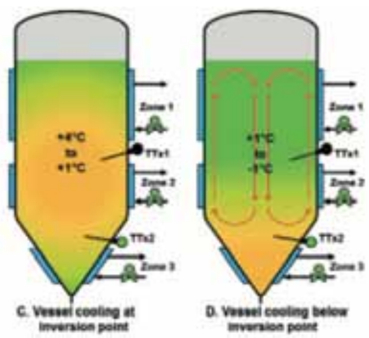
- Inversion Point
  - The temperature at which the beer will be **most dense**. Below this, beer actually becomes **less dense.**
  - Approx 34-35F for "normal" ~5%ABV beers but will be **lower** for beers with higher ABV or higher residual sugar
  - **Convection currents** stop while moving through this point
  - Pump mixing or gas rousing can help speed up cooling



C. Vessel cooling at inversion point
D. Vessel cooling below inversion point

Fermentation Temperature Control

- Inversion Point
  - Once tank is past inversion point, convection currents **reverse**. Coldest beer **rises** up the sides of the tank, pulling beer **down** the middle
  - After fully crashing to 29-30F, coldest beer will be at the **top** of the tank



Fermentation Temperature Control

- Transfer
  - Once beer has conditioned at ~30F for set amount of time, it is ready to transfer, carbonate, and enjoy!

Conclusion

- Temp Control is one of the simplest automated tasks that every brewery uses
- Accurate temperature control is critical for making consistently delicious beer. A failure of this system can lead to ruined batches
- For relatively low cost, your cellar control system can be upgraded to be able to alert you of failures or even if your fermentations are running out of spec- check out Brian's **Raspberry Pi** project!

Article Credit

- *Keeping Cool: Attemperation in fermenting and maturation vessels*- Andrew Mieleniewski and Elenor Stevens, Brewer and Distiller International August 2015
- *In Control: Automating Your Processes*- Andrew Mieleniewski and Elenor Stevens, Brewer and Distiller International April 2016

Cheers!

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UNITED WE BREW.