Connecting Industry to Mathematics Instruction
NSF ATE Award # 1954291

Cleaning Water Analysis

How can you analyze cleaning water data to safely reduce water usage?

In partnership with
WAKE TECH
WAKE COUNTY PUBLIC SCHOOL SYSTEM
WakeEd PARTNERSHIP
Diversey

Introduction

Beverages, like milk, are processed in a closed loop circuit system that can involve among other things mixing, pasteurizing, and pressure or temperature alterations. Sanitation is very important to ensure accurate and safe consumption of finished products. Therefore, it is important that these systems are designed with a proper CIP process that is completed at a regularly scheduled interval.

“Cleaning in Place (CIP) is defined as the process of cleaning and disinfecting the internal surfaces of processing equipment without the need to dismantle or intervene manually.” [1]

Water usage and cleaning times are costly to the production process and it is common for companies to look to optimize the cleaning process for water usage and time. In this activity, you will determine the amount of rinse water going to drain (not able to be reused) during a milk processing cleaning cycle. You will use this value to determine the amount and cost of wasted resources due to the cleaning, and to check if the water consumption is meeting pre-established industry standards.

An example of a system with a CIP is a milk processing system that has the necessary cleaning cycle equipment built in that. In this system, a cleaning cycle would be run at the end of each milk processing session.

Figure 1: A CIP System

[1] Diversey. Fundamental Cleaning in Place (CIP) Concepts and Applications. https://diversey.com/en/solutions/food-and-beverage-production/knowledge-based-services/diversey-hygiene-academy/cleaning-place-cip-fundamentals

The Cleaning Cycle

There are three phases to this cleaning: an initial rinse, a cleaning with chemical solution that also contains a gradual cool down, then a final rinse. In the image shown previously in figure 1, the left and right tanks are typically designated as one to hold only clean rinsing water, and one to hold only water mixed with the detergent soaps used for cleaning. Typically the middle tank is a recovery tank and can hold clean or dirty water before it would be sent to drain.

Initial Rinse:

The cleaning water in the initial rinse is only sent around the circuit of the system one time, then it is disposed of. As long as this phase is running, the water is entering the system's circuit, circulating once, and being disposed of at the end. This process includes periodic bursts of water entering the system.

Cleaning Phase:

The cleaning phase starts with a rise in temperature of the water on the supply side. This new water has soap/caustic cleaning solutions added to it. The same cleaning water is cycled through the circuit multiple times during the duration of this phase. At the end of this phase it is returned to a holding tank for proper disposal.

Final Rinse:

The final rinse is essentially a repetition of the initial rinse, but it is important to note that it may or may not be of the same duration. After the temperature drops from the cleaning phase, the final rinse occurs, and all of this water is sent to drain.

Initial thought questions:

- What are some reasons that it would be helpful or even necessary to have cleaning equipment included in the original process system design?

- Why do you think the initial and final rinse water is continuously drained while the cleaning phase water is reused within the circuit?

Problem

In this problem, we will look at the amount of water being used in this process and compare it to an industry standard of "3X Circuit Volume". In other words, the total amount of water sent to drain should equal no more than 3 times the total circuit volume of liquid to have an efficient use of water. Any additional water used in the whole cleaning process is considered wasted due to reaching diminishing returns.

The graphs and excel spreadsheet provided in this activity contain data from a milk industry cleaning event.

Included are:

- Supply side liquid flow rates, given in gallons per minute (gpm)
  - Measured by a clamp-on ultrasonic flow meter as shown below in figure 2
  - The device pulses a noise that bounces off the back of the pipe and it's return signal is then read
- Temperatures of the supply (liquid going into the pipes from the tank) given in degrees Fahrenheit
- Temperatures of the return (liquid coming out of the pipes going to drain in the rinse phases or going to the cleaning fluid tank in the clean phases) given in degrees Fahrenheit

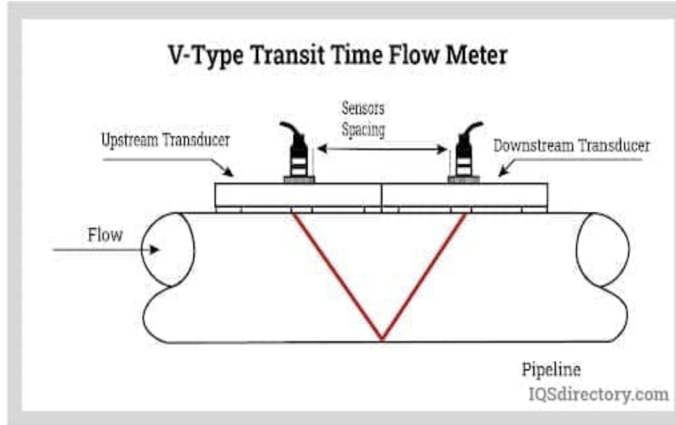
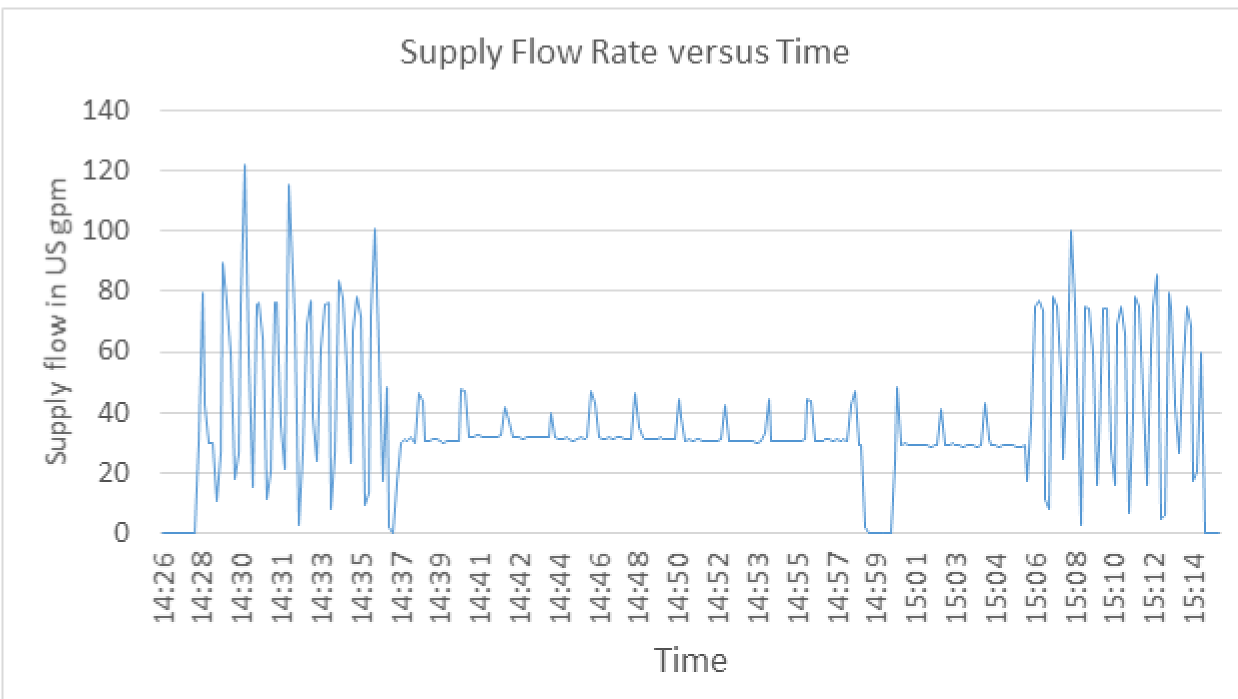


Figure 2: An Ultrasonic Flow Meter

Figure 3: The measurement of the flow rate

Part 1: Supply Flow Rate

The following graph represents the water supply flow as measured in gallons per minute (gpm).
Each data point is collected at the beginning of the circuit. Review the graph and answer the questions below.



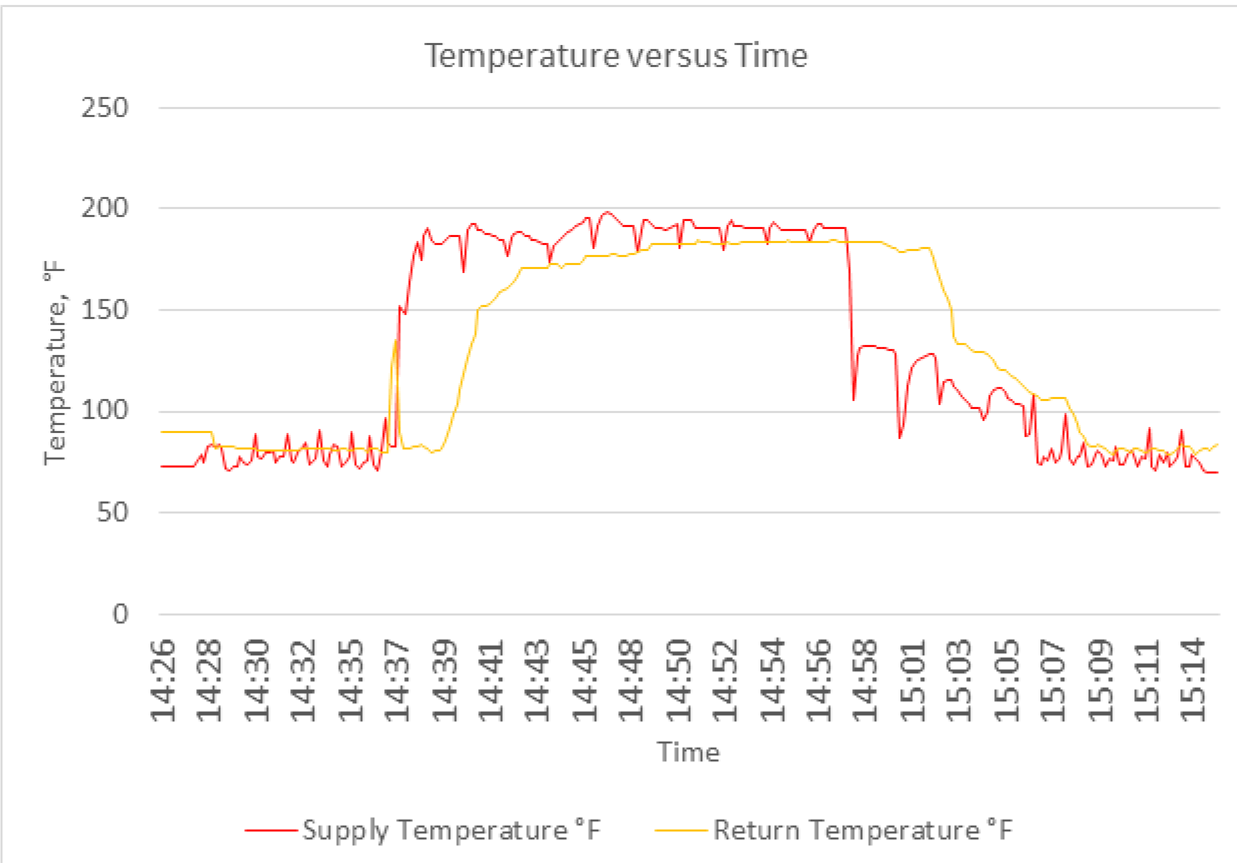
Graph 1: Supply Flow Rate versus Time

1. Using a complete sentence, describe the domain of this graph.
2. Using a complete sentence, describe the range of this graph.
3. Consider the time axis and answer the following questions:
    a. How is time formatted on this graph?
    b. How much time is represented over this graph's entirety?

4. How many defined sections of this graph do you see?
    a. What explanation can you give for each section?
    b. How much time does each section account for?
5. What would you say the average flow rate (in gpm) for each section is?

Part 2: Temperatures

The following graph represents the supply water temperature and the return water temperature as measured in degrees Fahrenheit (°F).
Each data point for the supply water is collected at the beginning of the circuit (with the flow data from above).
Each data point for the return water is collected at the end of the circuit. Note that the time axis is the same as the graph above. Review the graph and answer the questions below.



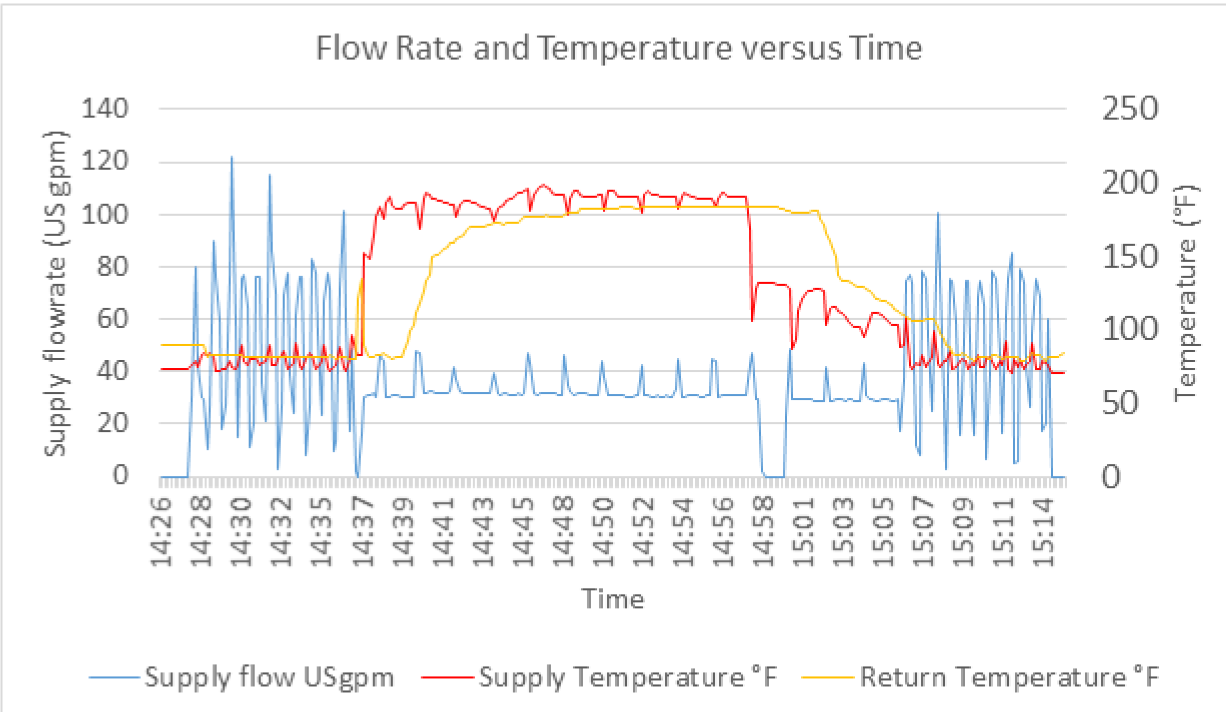
Graph 2: Temperature versus Time

1. Using a complete sentence, describe the domain of this graph.
2. Using a complete sentence, describe the range of this graph.
3. At what approximate time does the supply water temperature begin to rise?
    a. Describe what this increase means in the cleaning process.
4. At what approximate time does the return water temperature begin to rise?
    a. Describe what this increase means in the cleaning process.
5. At what approximate time does the supply water temperature begin to drop?
    a. Describe what this decrease means in the cleaning process.

6. At what approximate time does the return water temperature begin to drop?
    a. Describe what this decrease means in the cleaning process.

Part 3: Using the Raw Data

Below is one graph with all three data collections presented. Refer to this graph and your answers from above while you preview the questions below. Then, use the raw data provided in the given EXCEL file that is used to create these graphs and answer the following questions as accurately as possible.



Graph 3: Flow Rate and Temperature versus Time

Pause and Think:

- What change has been made to the y-axis? Why was it necessary?
- What do you notice with all three datasets presented together?

Review your answers from the flow rate graph in Part 1, then use the raw numerical data to get the most accurate answers to the questions below.

1. What is the time increment used in the data sampling?
2. At what time stamp and flow rate would you say the end of the initial rinse occurs at?
    a. What is the total time of the initial rinse? (Highlight this section of data in a color)
3. At what time stamp and flow rate would you say the end of the cleaning phase occurs at?
    a. What is the total time of the cleaning phase? (Highlight this section of data in a new color)
4. At what time stamp and flow rate would you say the end of the final rinse occurs at?
    a. What is the total time of the final rinse? (Highlight this section of data in a new color)
5. The first non-zero flow rate measured is 30.55 gpm (gallons per minute). Find this data point in the data provided. Using this data point and your answer to number one, find how many gallons of water

entered the circuit at this time. Hint, can you look at the units and use dimensional analysis to help you answer this question?

    a. Discuss your reasoning with your partner before moving on. Record a short discussion synopsis here. (Did you both start with the same answer? How did you agree on one answer?)

6. Using the process from number 5, determine the total volume of water used in the initial rinse phase of the cleaning process.
7. Using the process from number 5, determine the total volume of water used in the final rinse phase of the cleaning process.
8. What is the total amount of rinse water (initial and final) used in one full cleaning cycle?
9. What is the total rinse time (initial and final) used in one full cleaning cycle?

Review your answers from the temperature graph in Part 2, then use the raw numerical data to get the most accurate answers to the questions below.

10. When does the heated cleaning water begin to enter the circuit on the supply side?
11. When does the heated cleaning water initially reach the end of the circuit? (Look at the return water data)
12. How much time did it take for the heated cleaning fluid to travel once through the entire circuit?
13. Using the above information, find the volume of the water used in one circuit cleaning. This is called the circuit volume.

Part 4: Water Usage Analysis

Pause and Think:

- What are some reasons for a company to strive to reduce the volume of rinse water used?

1. The industry standard for the amount of rinse water that goes to drain for one whole cleaning cycle is 3X circuit volume. Anything above this amount of water is considered over rinsing and wasteful. What is the amount for 3X circuit volume in this system?
2. Compare the number above to the total rinse water calculated in Part 3 number 8. Is the system over rinsing?
    a. If so, by how much?
3. If this system is cleaned 2X/week, how much water could be saved each week?
    a. How much water could be saved each year?
4. Plan how to reduce the initial and final rinse water to stay within the industry 3X circuit volume standard. Review the initial and final rinse phases and find how long each one should take to use 3X circuit volume of water (total, not each).
    a. How long would it take for this system to use 3X circuit volume of water during its rinse phases?
5. Refer to part 3 number 9 when you calculated the total rinse time. How much time do you save by reducing the rinse flow water time for one cleaning cycle?

6. If production time costs $10,000/hour and that time is recovered through CIP optimization of rinse water, how much money did you save the plant with this project? (Assume this system is cleaned 2X/week)

Part 5: Degree of Cleaning Analysis

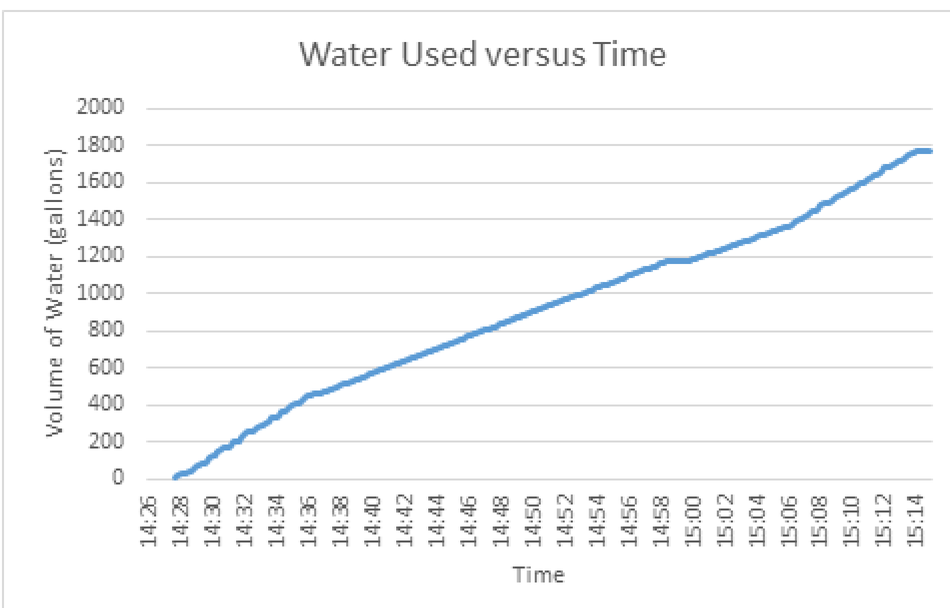
Pause and Think:

- What are some factors that you think would affect the degree of cleaning (how clean the system gets)?

1. Do you think the velocity of the fluid entering the circuit will affect the degree of cleaning?
   a. Why or why not?
2. Return to your answer from Part 1, number 5. Use your estimate to find an average of how fast the water flows into the pipe in ft/sec in the initial rinse phase if the circuit is built using a 3 inch diameter pipe. (Hint, use dimensional analysis.)
3. If the industry standard is a minimum of 5 ft/sec, does the initial rinse average flow rate meet the standard?
   a. If not, what average gallons per minute are needed to meet the industry standard of 5 ft/sec minimum?

Part 6: Total Volume Analysis

In part 3, you were asked to calculate the amounts of water used during the initial and final rinse. While there are a few different ways to get this answer, you may have created a new excel column that shows the accumulated total of the gallons of water used. If not, create that column now, then graph the accumulated volume of water in gallons on the time domain given. Your first attempt at this graph should look like the one below.



Graph 4: Accumulated Water Volume

Pause and Think:

- Look at the total volume of water in gallons used according to the graph given.
    - Does it seem accurate?
    - What do you know about this process that is not reflected in this graph?

1. Find the data point from part 3, number 2 where you determined when the initial rinse phase ended. Replace the cumulative volume value in Excel with a 0 at this point. Why would we do this?
    a. What change is reflected in the graph?
    b. What value can we now see on the graph?
2. After the initial rinse is the cleaning phase. What happens to the water in the circuit during the cleaning phase?
    a. Repeat the process in part 2, by adding a new 0 to the beginning data point of the final rinse phase, and splitting the graph into 3 sections.
3. At the beginning of the cleaning cycle, the soapy water enters the circuit and then is re-circulated during the whole cleaning process. But a 0 in the cumulative volume column where the return temperature begins to rise. (Reference Part 3, number 11). Look at the new section created on the graph. What does this section represent?
4. At the end of the cleaning cycle, there is some new cold water that is pulsed into the circuit to begin the cooling process. Because new water is being added to the system, add a 0 to the volume column where you see the supply water temperature begin to decrease.
5. Add a title and axis labels to your graph, then copy and paste it below.

6. Reading the graph from left to right there are now 5 sections. Which section of the graph does not accurately represent what is happening in the cycle?
    a. Why?
7. From the data, pick 2 data points in the leftmost section. Calculate the average rate of change (ARC) and write a sentence explaining it in context.
    a. Where previously in this activity has this value been mentioned?
8. Which section of the graph is the steepest?
    a. What does this represent?