Overview

Friday, August 29, 2014 2:52 PM

We are replacing the heating system on one of our stirred tank storage tanks with a new apparatus. The previous one used a shell and tube heat exchanger. The new one will use a steam coil installed directly into the tank similar to a hot water heater in a house. Before we develop the control mechanism for the process, we need to know how the system behaves. Basically we need to know how fast the system can heat up and how this is affected by the quality of steam that we provide.

Day 1

Friday, August 29, 2014 2:59 PM

Ambient Lab Conditions

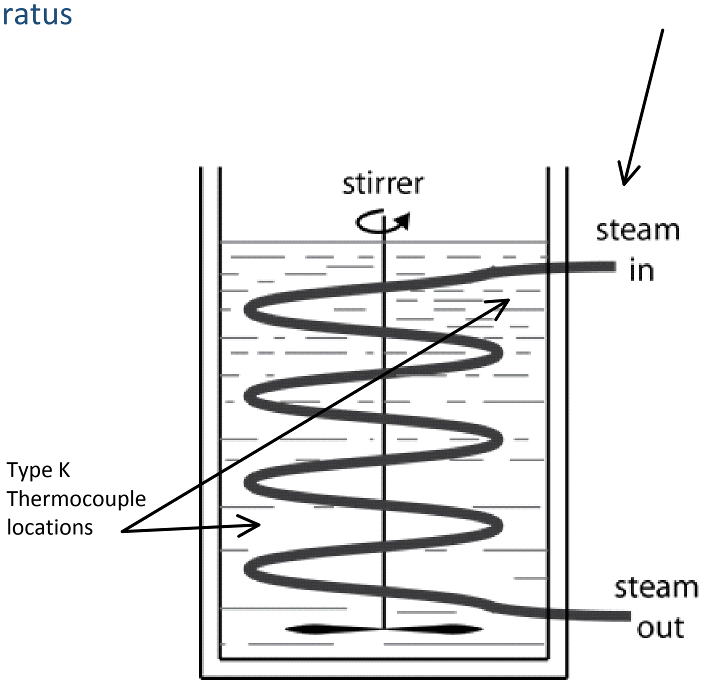
Temperature: 20.7 °C
Pressure: 85.3 kPa

Daily Objective

This is the first day we are working on the project. The objective of the day is to perform the theoretical research and analysis on the problem to figure out how to solve the problem.

Apparatus

Saturate steam flows in.
Can regulate the steam pressure in.



Tank is 66 inches tall
ID: 39 inches

Heating coil is 3/4 in Schedule 40, galvanized iron pipe
OD:1.05 in, ID: 0.825 in
33ft in length.

Tank will typically hold 300 gallons.
The coil totally covered with 300 gallons

The stem inlet is 55 inches from the bottom of the tank.

Things that can be measured with the apparatus.

- Temperature of water in the tank.
- Pressure of steam in the coil.

Things that can be changed.

- The amount of liquid in the tank.
- The pressure of the steam.

Theoretical Analysis

I remember from my chemical engineering training that whenever I have a problem involving temperatures and heat transfer, I should start with an energy balance.

Assumptions

- The system is the water in the tank.
- System is stationary, (it is stirred but the tank and water are not moving relative to the earth.)
- No mass flow across the system boundary, no inlet and outlet.

$$\Delta \mathrm{H} = Q + W$$ Energy Balance on Water

I'm a little confused here. I don't see how this will help me. It seems like time should be in here somewhere. I know that there are times in the Q's and W's, but the H term doesn't have a time.

After thinking about it with my team, we have realized that we started with a steady-state, open system energy balance. We need one with a closed system, unsteady state.

$$\frac{dU}{dt} = Q + W$$ Energy Balance on Water

The W in this equation is shaft work that comes from the stirring. I think this is negligible compared to the heat transfer.

$$\frac{dU}{dt} = Q$$

I need to now relate the U and Q to things I can measure. I think thermo class taught me how to do the U part. Heat and mass was the Q part.

$$Q = UA(T_s - T)$$

Here, T_s is the surface temperature of the coil and T is the Temperature of the water in the tank.

$$dU = \rho V C_p dT$$

I am neglecting the dV part because we have an Incompressible liquid.

$$\rho V C_p \frac{dT}{dt} = UA(T_s - T)$$

This is a differential equation. I need to make some assumptions now if I want to solve it further. If not, I will need to solve it numerically. I am going to try the easy way first and assume everything is constant except time and the temperature of the water. This allows me to separate and integrate the equation.

$$\ln\left[\frac{T_s - T}{T_s - T_1}\right] = -\frac{UA}{\rho V C_p} t$$

Experimental Approach

From the above equation, it looks like I can analyze the heat transfer by calculating the overall heat transfer coefficient UA. This will help me design how long it will take to heat up liquid as a function of steam pressure.

What will be measured?

- Time
- Temperature of the water as a function of time.
- Steam pressure

What will be calculated?

- Surface temperature (from steam tables)

- Overall heat transfer coefficient UA.

Summary of Day

- The theory for analyzing the lab notebooks seems complete and reasonable.
- Next time, we need to start experiments where we measure the time vs temperature data.

Signatures

Thomas Knotts
Mike Beliveau

Day 2

Tuesday, September 2, 2014 10:21 AM

Ambient Lab Conditions

Temperature: 20.1 °C
Pressure: 86.5 kPa

Daily Objective

Perform experiments to determine the overall heat transfer coefficient of the new heating system. Today we will hold the steam pressure fixed at 2.2 psig and perform as many experimental runs as time allows to obtain good statistical data.

Experiment 1

Steam Pressure: 2.2 psig

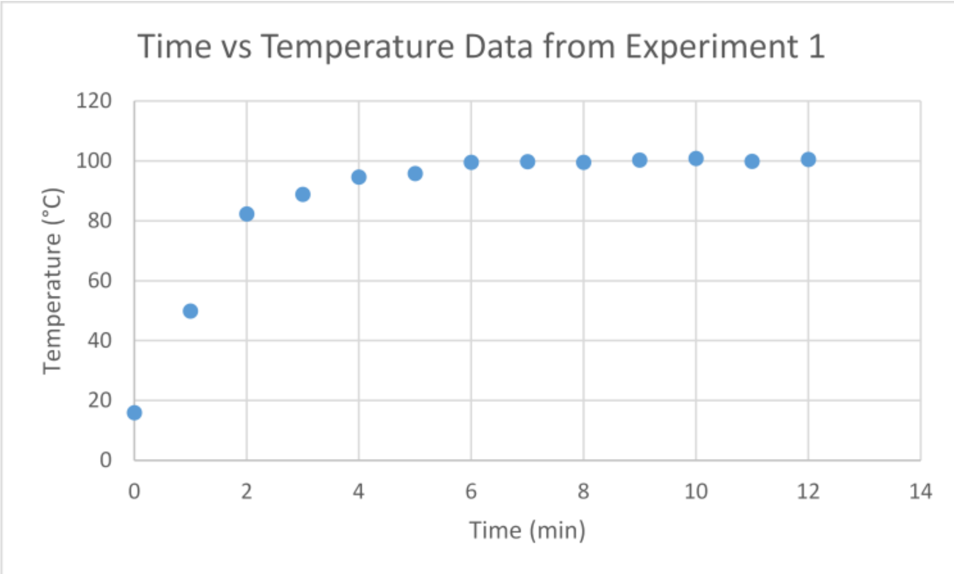
- We filled the tank with 300 gallons of water from the tap.
- The initial temperature of the water was 10 °C.
- We used a stop watch to time the data entry.
- We opened the steam valve at time t = 0.
- We recorded the temperature every 60 seconds.
- One person on the team watched the stop watch and called out when to read a data point.
- The second person read the temperature when time was marked and recorded the data.
- The data are below.

Time (min)	Temperature (°C)
0	16.0
1	49.9
2	82.3
3	88.9
4	94.6
5	95.8
6	99.6
7	99.8
8	99.6
9	100.3
10	100.9
11	99.9
12	100.5

Observations

- We stopped after 12 minutes as it seems like the system reached steady state.
- The speed at which the temperature achieved steady state surprised us. We expected it to take a longer time. It seems like our hot water heaters at home, that have a similar heating approach, take longer than this. Why?

A graph of the data is found below.



Observations

- It looks like the temperature changes a lot in the first couple of minutes. I think we should take data at shorter intervals at the beginning of the experiment.
- There is some scatter and uncertaintly in the data.
  - This is particularly seen in the first few minutes. Taking data more often should help us see the correct trend.
  - Theoretically, the steady state temperature should be constant at 100 °C, but we see it bounce around this number.
    - This is OK because it is within the error of a Type K thermocouple with an average error of ±2.2 °C. (See omega.com)
- The data look like they will fit the expression well.

Summary of Day

- The experimental apparatus works and we get reasonable data.
- The we need to take data at shorter time intervals.
- Next time, we need to take more data at a steam pressure of 2.2 psig so that we can improve the statistics of the fit. Perhaps two more runs. Then move on to a different steam pressure.

Signatures

Thomas Knotts
Mike Beliveau

Conclusions

Friday, August 29, 2014 3:00 PM

Day 2

1. The experimental apparatus works and produces reasonable data.
2. We need to sample data points more often than 1 minute intervals, particularly at the beginning of the experiment.