6.2: Heated Surge Tank

2.1 Introduction

A surge tank is an additional safety or storage tank that provides additional product or material storage in case it becomes needed. Heat exchange can be added to surge tanks, which provides temperature control for the tank. Within a system these tanks can appear as distillation columns, reboilers, heated CSTR’s, and heated storage. They can increase production rates by allowing a batch of product to finish reacting while the initial tank is reloaded, provide constant system parameters during start up and shut down, or create additional storage space for product overflow or backup material.

Uses for Heated Surge Tanks:

- Fuel surges caused by motion of a vehicle: If fuel cannot be drawn from the primary tank, the engine resorts to a surge tank. The heat maintains the fuel’s temperature.
- Caramelization: During the formation of caramel, the mixture must be maintained at a specific temperature for a predetermined amount of time. Once the ingredients are thoroughly dissolved, the mixture is transferred to a heated surge tank and maintained until the caramel has thickened and is ready to be drawn out.
- Mixing of gases: Bulk gas lines can be connected to a heated surge tank with a pressure sensor. The pressure sensor would control the temperature. By heating the gas when it first enters the tank, there is no risk of explosion later due to expansion.
- Heated pools: Surge tanks are used to catch and store displaced water from a pool. If the pool is heated, a heated surge tank should be used to maintain the temperature of the water.
- De-aeration: Heated surge tanks are often used with de-aerators. They heat the component that will enter the de-aerator, because if the component is not preheated, the de-aerator must wait until the component reaches the correct temperature. This could waste a lot of time and energy.
• Chemical Baths: Often in industry, things need to be treated with a chemical bath. The chemicals usually need to be at a certain temperature so that it will adhere to the object. A heated surge tank is perfect for this application.

• Reboilers: Liquids coming off of a distillation column can be reheated to enter the column again at a higher temperature to drive the separation process. Many industries use this tool to obtain a more efficient separation and produce a higher net profit.

• Product or Material Backup: Heated surge tanks can also be used as simple storage in two ways. First, a surge tank can be used excess product not yet sold or otherwise moved out of the production system. Second, heated surge tanks can serve as backup for chemical or fuel supplies to a production plant, such as outdoor gasoline tanks for a backup generator in case of power failure.

2.2 Basic Design for Heated Surge Tanks

Above is a basic example of a heated surge tank. While surge tanks can have multiple inputs and outputs, for simplicity we have only included one of each here.

Connected to the tank is a temperature control, which controls the heater. Depending on the temperature of the fluid, this control will increase or decrease the heating to the tank. This will keep the fluid at the necessary temperature to meet the process requirements.

There is also a level control connected to the tank to indicate when the tank has neared maximum capacity. When this happens, the control will open the valve at the bottom of the tank, allowing the product to flow further down the process. The control can also slow or stop the flow coming through the input valve. These mechanisms will prevent the tank from overfilling. The position of the level control depends on the type of material in the process, the phase of the material, the type of level control, and the requirements of the system.

2.3 Useful Equations

The basic equations that govern heated surge tanks are shown below. First, a simple mass balance is done on the system. Second, the energy balance was simplified using the assumptions listed below. Most problems involving this type of tank can be described by these equations. Additional considerations may require additional variables and
equations.

Assumptions:

1. The substance coming into the tank is uniform.
2. No reaction is taking place.
3. The tank is well mixed, which means the temperature profile is constant throughout the tank.

2.3.1 Mass Balance

Since there is no generation from reactions inside the heated surge tank, we obtain the rate of accumulation or level inside the tank by subtracting what is coming out from what is coming in.

\[
\text{Rate of Accumulation} = (\text{Flow In}) - (\text{Flow Out})
\]

2.3.2 Energy Balance

The temperature change with respect to time is essential for the purpose of configuring a system to reach steady state. When turning a system on or off, there is a time period in which the system is in unsteady state. During this time, the system is difficult to model. In steady state, the system is easier to model because once steady state is reached the left hand term will become zero.

\[
\frac{dT}{dt} = \frac{v \rho C_{p}(T_{0}-T)+UA(T_{C}-T)}{V \rho C_{p}}
\]

2.4 Case Study - Water Purification at IBM

At IBM's manufacturing facility outside Burlington, Vermont, a heated surge tank is used in the de-ionized water system. In order to wash semi-conductor wafers in manufacturing, the water has to be about 1,000,000 times cleaner than the incoming city water. All of this purification is done on site.

The water comes in from the municipal water source at a constant flow rate, but manufacturing demand is not constant. In order to compensate for this, when the demand in manufacturing is low, a surge tank is used to store extra water for
high demand periods. Because the large tank is located outside and the winter in Vermont is very cold, the tank is heated to prevent the water inside from freezing.

During normal operation of the system, the surge tank is bypassed. When a flow controller downstream has low demand, the inlet valve opens, letting water into the surge tank. A level controller monitors the tank to make sure it doesn’t overfill and can shut off the inlet valve and let water out. A temperature controller controls the heater jacket to maintain the water around 50°C. When the demand for water increases, the flow controller near the outlet can shut off the inlet valve to the tank, and/or further open the outlet valve to access the extra water supply in the tank.

Example \(\PageIndex{1}\): Determining Temperature of Heating Fluid for Tank

A heated surge tank is being designed to hold paraffin wax coming from a distillation column at an oil refinery. High pressure steam will be used as a heating fluid in the heat exchanger to heat up and maintain the paraffin at 51°C (to maintain high viscosity and prevent solidification). The physical parameters of the tank (volume of 5 m\(^3\)) and heat exchanger within it are given. The tank is originally filled with paraffin at room temperature. At what temperature must the high pressure steam be to sufficiently heat the paraffin; will a proposed temperature of 130°C be adequate?

The paraffin comes into the tank at 37°C at a volumetric flow rate of 0.0005 m\(^3\)/s. The heat exchange coefficient is equal to 50 W/m\(^2\)/K and the area of the heat exchanger is 2.0 \(\text{m}^2\). The heat capacity of the paraffin is 2900 J/Kg/K and the density is 800 Kg/m3.

Solution

POLYMATH CODE:

\[ \frac{dT}{dt} = \left[ -v_{in} \cdot \rho \cdot C_p \cdot (T - T_{in}) + (U \cdot A \cdot (T_a - T)) \right] / (C_p \cdot V \cdot \rho) \]

- \(v_{in} = 0.0005 \text{ m}^3/\text{s}\)
- \(U = 50 \text{ W/m}^2/\text{K}\)
- \(A = 2 \text{ m}^2\)
- \(T_a = 130^\circ\text{C} = 403\text{K}\)
- \(C_p = 2900 \text{ J/Kg/K}\)
- \(\rho = 800 \text{ Kg/m3}\)
- \(T_{in} = 37^\circ\text{C} = 310\text{K}\)
- \(V = 5 \text{ m}^3\)
- \(t(0) = 0 \text{ s}\)
- \(T(0) = 298\text{K}\)
- \(t(f) = 36000 \text{ s}\)
With a heating fluid at a temperature of 130°C, the fluid only reaches a temperature of 44°C (317K). A higher capacity heating fluid must be used.

Trying a heating fluid at 277°C, we generate the plot below.

The plot shows that the tank will reach a temperature of about 55.5°C (328.5K) with a heating fluid at 277°C. This will be sufficient to maintain the paraffin in the liquid phase.

Example \(\PageIndex{2}\): Time to Reach Steady State after Heating Failure

For the same surge tank from problem 1, if the heater fails for 2 hours after 10 hours of operation and is then restarted, how long will it take after it is restarted to reach steady state?

Solution

Approximately 20 hours

The first manipulation that must be done to your Polymath code is to create an "if-then-else" statement for the \(\frac{dT}{dt}\) line for the case before hour 10, the case between hour 10 and hour 12, and the case after hour 12. For the time ranging between 10 and 12 hours, because the heating element has failed, the differential equation over this period must reflect that. Thus, the section \(U^A(Ta-T)\) from the differential equation is dropped and the equation appears as follows:

\[
\frac{dT}{dt} = \frac{-vin*rho*Cp*(T-Tin)}{Cp*V*rho}.
\]

For any other time in this simulation, the normal \(dT/dt\) equation is used. In order to determine where the surge tank reaches steady state again, the final time is increased until \(dT/dt\) approximately reaches zero. The graph generated in
Polymath will look like the following, using the code below as a parameter:

\[ \frac{d(T)}{d(t)} = \begin{cases} 
-\frac{\text{vin}\cdot\rho\cdot C_p\cdot(T-T_{in})}{C_p\cdot V\cdot \rho} & \text{if } 36000 < t < 42500 \\
-\frac{\text{vin}\cdot\rho\cdot C_p\cdot(T-T_{in})+(U\cdot A\cdot (T_{a}-T))}{C_p\cdot V\cdot \rho} & \text{else}
\end{cases} \]

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