Worksheet: Kettle Boiler

Name(s) _____

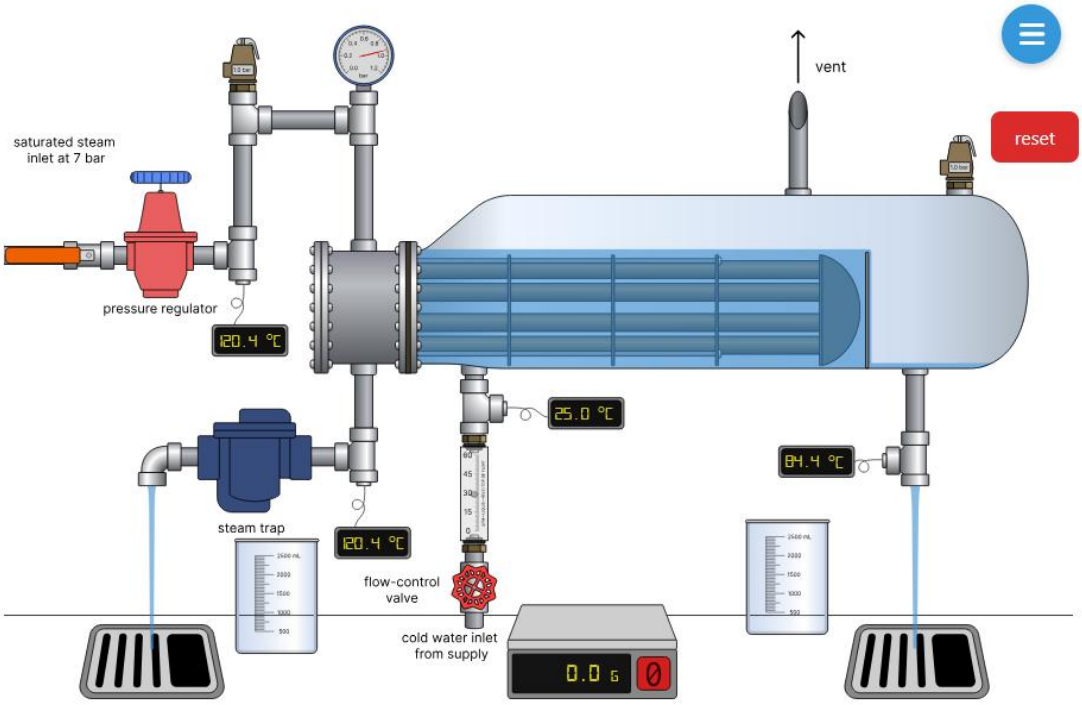
A kettle boiler is a type of heat exchanger used to vaporize a liquid. They are commonly used as reboilers at the bottom of industrial distillation columns. In a distillation application, liquid enters the shell side of the boiler from the stripping section. Part of this liquid is vaporized and sent back up the column; the remainder flows out as the bottom product. This experiment uses a small-scale kettle boiler where steam is a heat source to boil water. As in distillation, part of the liquid fed to the boiler is vaporized, and the remainder flows out as a liquid. The important principles for this type of heat exchanger include boiling and condensing heat transfer. This experiment measures the heat transfer rate, which is compared to predictions based on typical boiling and condensing heat transfer coefficients.

Student learning objectives

After completing this activity, you will be able to:

1. control the liquid-to-vapor ratio leaving the boiler by adjusting process parameters.
2. measure the heat duty of a boiler using both tube-side and shell-side energy balances.
3. measure the overall heat transfer coefficient for a heat exchanger that involves phase change on both sides.
4. predict the overall heat transfer coefficient for this type of heat exchanger from industrial correlations.

Equipment



Kettle Boiler Specifications

Tube outside diameter = 5/8 inch

Tube inside diameter = ½ inch

Tube length = 21.6 inches

Tube material: copper

Geometry: 4 tubes per pass, 2 tube passes, 8 tubes total

Questions to answer before starting experiment

1. x
2. y

Experimental Procedure

1. For the first trial, use a steam pressure of 0.2 bar and a cold-water rate of 0.40 L/min.
2. Record all measurements in Table 1.
3. Open the red valve on the cold-water supply and adjust the valve with the mouse until the rotameter is set to the desired cold-water flow rate in L/min. Record the water inlet temperature from the thermocouple in the inlet line. Note that the boiler shell will begin to fill with water.
4. Open the steam shutoff valve (move red handle from vertical to horizontal).
5. Slowly turn the blue valve handle on the steam pressure regulator and watch the pressure gauge downstream of the regulator. Adjust to the desired pressure, but do not exceed 1 bar because the pressure relief valve opens at this pressure.
6. Visually monitor the liquid level in the boiler shell and wait for this level to become steady.
7. Measure the flow rate of the hot water that overflows the weir and drains from the shell of the boiler through the lower exit pipe. Measure the time required to collect 1000 mL of water. Also, record the temperature of this stream from the outlet pipe thermocouple.
8. Measure the temperature and flow rate of the condensed steam leaving the steam trap following the same procedure used for the shell-side exit stream.
9. For trial 2, keep the cold-water flow rate the same (0.4 L/min) and increase the steam pressure significantly, but below the maximum of 1 bar and follow steps 3 – 8 and record the measurements in Table 2.
10. For trial 3, adjust the steam pressure to 0.2 bar and increase the cold-water flow rate to a significantly larger value within the rotameter range (up to 60 L/min) and follow steps 3 – 8 and record the measurements in Table 3.

Table 1

Tube side		Shell side	
Steam inlet pressure (bar)	0.20	Water inlet flow rate (L/min)	0.40
Temperature of inlet steam (°C)		Water inlet temperature (°C)	
Mass of steam condensate collected (g)		Mass of outlet stream collected (g)	
Time of collection (s)		Time of collection (s)	
Mass flow rate of steam (g/s)		Mass flow rate for liquid water outlet (g/s)	
Temperature of steam condensate(°C)		Temperature of liquid water outlet (°C)	

Table 2

Tube side		Shell side	
Steam inlet pressure (bar)		Water inlet flow rate (L/min)	0.4
Temperature of inlet steam (°C)		Water inlet temperature (°C)	
Mass of steam condensate collected (g)		Mass of outlet stream collected (g)	
Time of collection (s)		Time of collection (s)	
Mass flow rate of steam (g/s)		Mass flow rate for liquid water outlet (g/s)	
Temperature of steam condensate(°C)		Temperature of liquid water outlet (°C)	

Table 3

Tube side		Shell side	
Steam inlet pressure (bar)	0.20	Water inlet flow rate (L/min)	
Temperature of inlet steam (°C)		Water inlet temperature (°C)	
Mass of steam condensate collected (g)		Mass of outlet stream collected (g)	
Time of collection (s)		Time of collection (s)	
Mass flow rate of steam (g/s)		Mass flow rate for liquid water outlet (g/s)	
Temperature of steam condensate(°C)		Temperature of liquid water outlet (°C)	

Analysis

What do students do with the data?

Questions to answer