

# CH402 Chemical Engineering Process Design

L11 – Heat Exchanger Design III

Solution of 14-16, continued from L10

## Problem 14-16

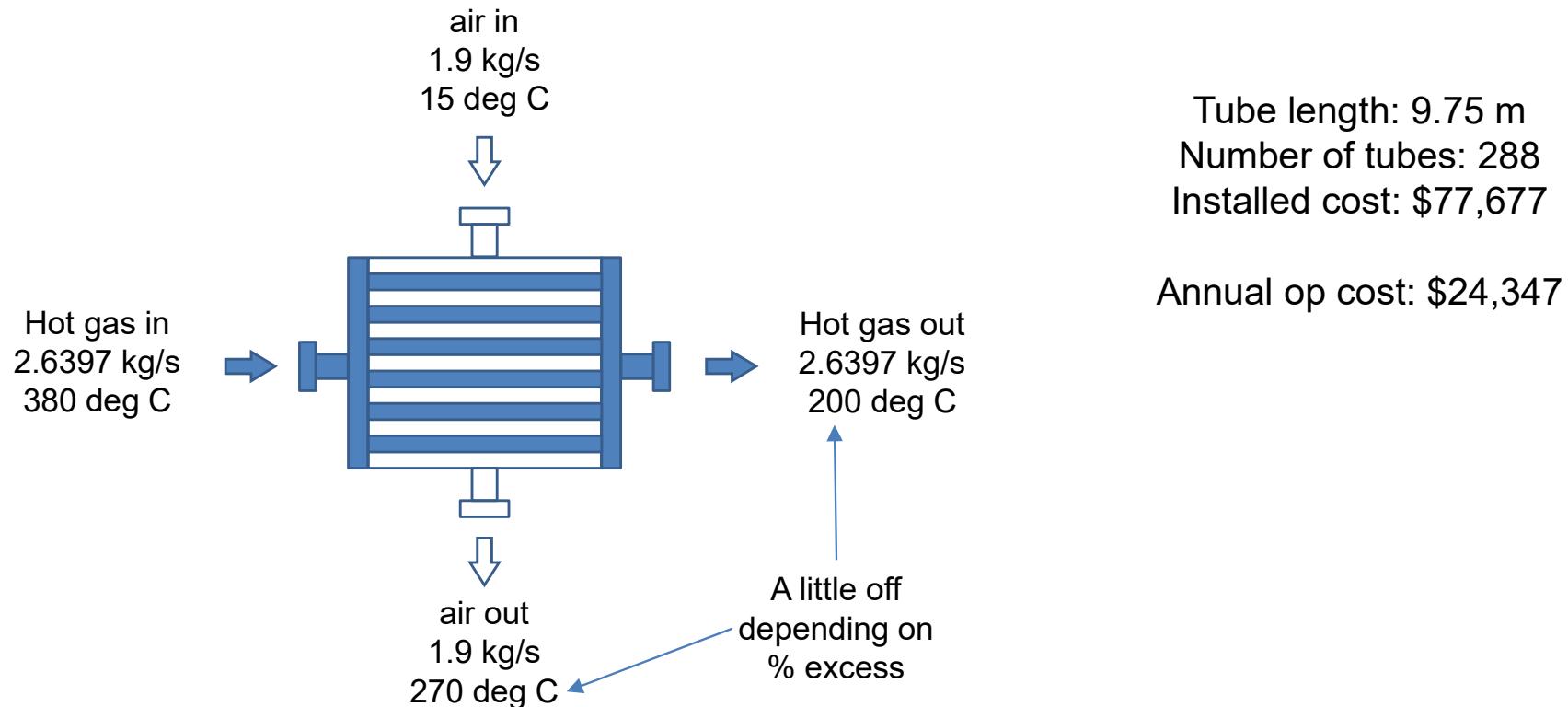
Slide 2

Air used in a catalytic oxidation process is to be heated from 15 to 270 °C before entering the oxidation chamber. The heating is accomplished with the use of product gases, which cool from 380 to 200 °C. A steel one-pass shell-and-tube exchanger with cross-flow on the shell side has been proposed. The average absolute pressure on both the tube side and the shell side is 1010 kPa, with the hot gasses being sent through the tubes. The flow rate for the air has been set at 1.9 kg/s. The inside and outside diameters for the tubes are 0.0191 and 0.0254 m, respectively. The tubes will be arranged in line with a square pitch of 0.0381 m. The exchanger operates for 8000 h/yr. The properties of the hot gases can be considered identical to those of air. The cost data for the exchanger are given in Figure 14-19 (p. 682).

Installation costs are 15% of purchased cost, and annual fixed charges including maintenance are 20% of the installed cost. The energy cost is \$0.12/kWh. Under these conditions, determine the most appropriate tube length and purchased cost for the optimum heat exchanger.

# Lesson 10 Recap

## CHEMCAD Sizing Results

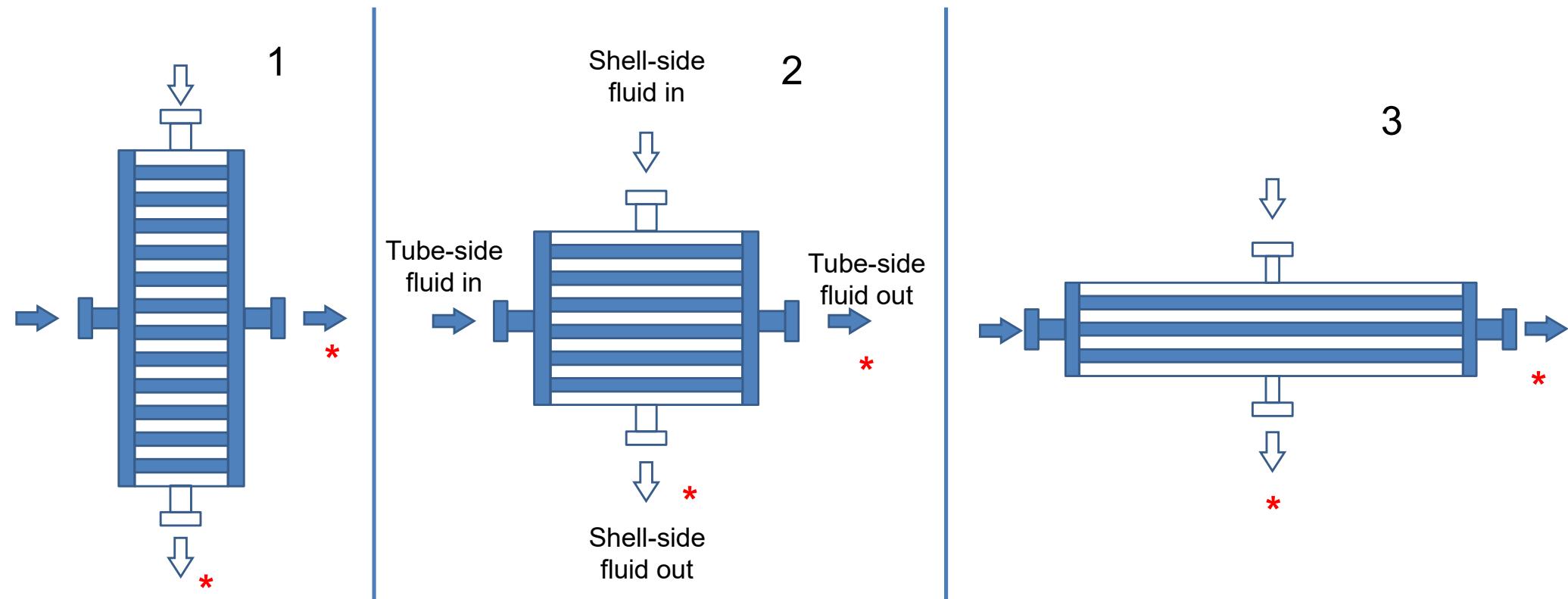


Baffles: none  
Tube OD: .0254m  
Tube ID: 0.0191  
Tube pitch: square, 0.0381m  
Material: carbon steel

Operating time: 8000 h/y  
Maintenance: 20% of installed cost  
Installed cost factor: 1.15

# Optimum tube length

Influenced by shell side DP, tube side DP, and installed cost



**Today's mission:** generate data and optimize total annual operating costs using equation 14-91.

For each iteration: Change tube length, adjust number of tubes, check outlet stream temperature specs, repeat as necessary until outlet T's (\*) are within .5 °C of spec.

Use instructor-provided spreadsheet in SharePoint.

# Total annual cost of heat exchanger operation

$$C_T = A_0 \cdot K_F \cdot C_{A_0} + \dot{m}_u \cdot H_y \cdot C_u + A_0 \cdot E_i \cdot H_y \cdot C_i + A_0 \cdot E_0 \cdot H_y \cdot C_0$$

Fixed annual costs	Utility fluid costs	Tube-side pumping costs	Shell-side pumping costs
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PTW Eq. 14-91, p. 739

$C_T$  Total annual costs, dollars/yr

$A_0$  Outside tube area,  $\text{m}^2$

$K_F$  Annual fixed charges factor (maintenance, etc) as a fraction of installed cost, dimensionless

$C_{A_0}$  Installed cost of the heat exchanger per unit outside tube area, dollars/ $\text{m}^2$

$\dot{m}_u$  Mass flow rate of utility fluid, kg/hr

$H_y$  Hours of operation per year

$C_u$  Cost of utility fluid, dollars/kg

$E_i$  Power loss due to fluid flow inside heat exchanger tubes per unit outside tube area,  $\text{N} \cdot \text{m/s}$  per  $\text{m}^2$

$C_i$  Cost of supplying 1  $\text{N} \cdot \text{m}$  to pump fluid through the inside of the tubes, dollars/ $\text{N} \cdot \text{m}$

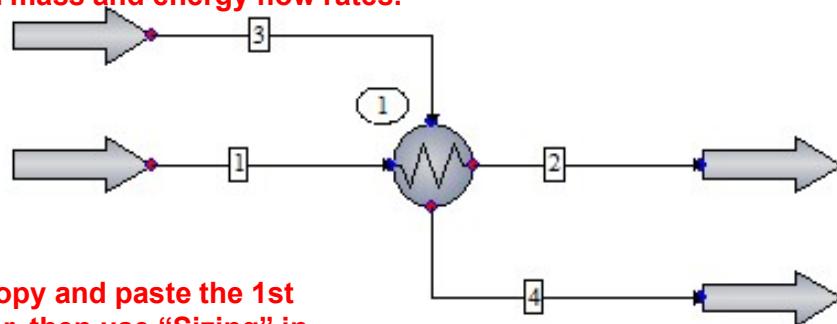
$E_0$  Power loss experienced on the shell side per unit outside tube area,  $\text{N} \cdot \text{m/s}$  per  $\text{m}^2$

$C_0$  Cost of supplying 1  $\text{N} \cdot \text{m}$  to pump fluid through the shell side, dollars/ $\text{N} \cdot \text{m}$

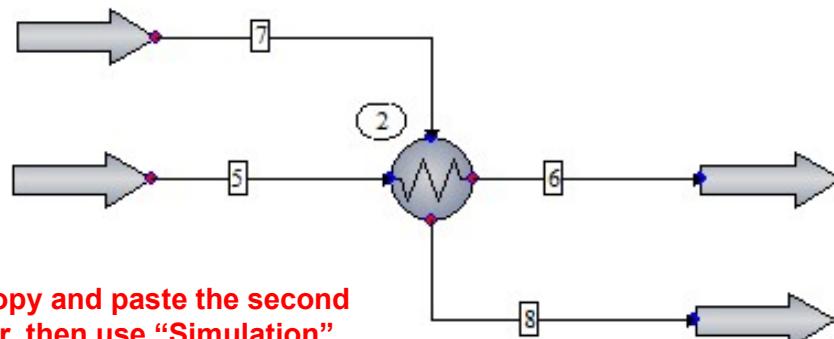
# Solution Strategy 14-16

## Use the 3-step design process

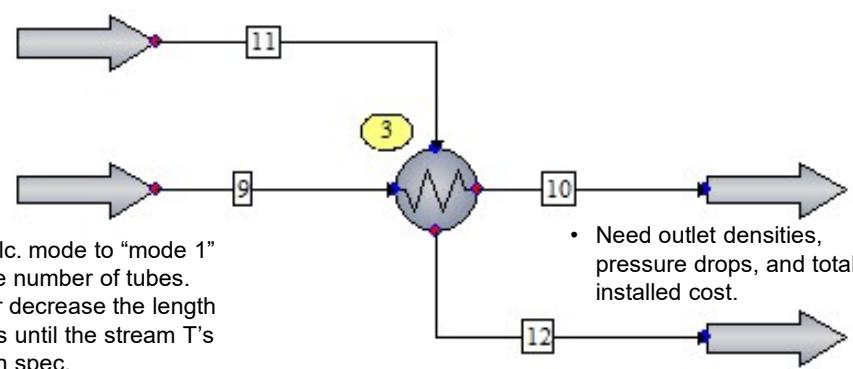
**Step 1: Use CHEMCAD to solve for all unknown mass and energy flow rates.**



**Step 2: Copy and paste the 1st exchanger, then use "Sizing" in "design" mode.**



**Step 3: Copy and paste the second exchanger, then use "Simulation" in "Shell-and-tube" mode.**



- Change calc. mode to "mode 1"
- Change the number of tubes.
- Increase or decrease the length of the tubes until the stream T's are back on spec.
- Compute installed cost.

- Information is carried forward to excel to construct a plot of total annual cost versus length.
- Cadets need to complete the checks and at least nine iterations to search for and demonstrate minimum and to practice.

A	B	C	D	E
1 Problem 14-16. Cadet Template			"sizing" checks required	
2 Optimimal Heat Exchanger Design				
3 Yellow - obtained from CHEMCAD simulations				
4 Light Blue - Values are derived from specs and do not change.				
5 White - excel calculations - verified with "checks" (results from CC design)				
6			"sizing"	
7 Spreadsheet for evaluating Equation 14-91			checks	
8 Number of tubes	N <sub>t</sub>	dimensionless	288	288
9 Length of tubes	L	m	9.750	9.750
10 Installed cost, CC	C	\$	\$82,011	\$82,011
11 Tube outer diameter	D <sub>o</sub>	m	0.0254	0.0254
12 Tube inner diameter	D <sub>i</sub>	m	0.0191	0.0191
13 Tube wall thickness	x	m	0.00315	0.00315
14 O	<b>Answers in CHEMCAD may vary slightly from these check values. Use instructor's values to complete this column to verify your calculations.</b>			
15 Ir				
16 T				
17 T				
18 T				
19 Tube-side pressure drop, CC	D <sub>p</sub> <sub>i</sub>	kPa	13.9405	
20 Tube-side average density	r <sub>i</sub>	kg/m <sup>3</sup>	6.3827	
21 Tube-side power loss per area	E <sub>i</sub>	Nm/s per m <sup>2</sup>	25.7307	
22 Shell-side (air) flow rate	m <sub>o</sub>	kg/s	1.9000	
23 Shell-side inlet fluid density, CC	r <sub>si</sub>	kg/m <sup>3</sup>	12.3104	
24 Shell-side outlet fluid density, CC	r <sub>so</sub>	kg/m <sup>3</sup>	6.3576	
25 Shell-side pressure drop, CC	D <sub>p</sub> <sub>o</sub>	kPa	16.7692	
26 Shell-side average density	r <sub>s</sub>	kg/m <sup>3</sup>	9.3340	
27 Shell-side power loss per area	E <sub>o</sub>	Nm/s per m <sup>2</sup>	15.2341	
28 Hours of operation per year	H <sub>y</sub>	h/y	8000	
29 Cost of pumping power	C <sub>i</sub>	\$/kWh	0.12	
30 Annual fixed charges factor	K <sub>F</sub>	dimensionless	0.2	
31				
32 Fixed charges		\$/y	\$16,402	
33 Tube-side pumping costs		\$/y	\$5,535	
34 Shell-side pumping costs		\$/y	\$3,277	
35 Total annual cost	C <sub>T</sub>	\$/y	\$25,214	

# Procedure

1. Complete the 3-step heat exchanger design as shown in Lessons 9 and 10. Set the 3<sup>rd</sup> exchanger to simulation mode.
2. In the “CCTherm” tab, make a copy of the “Case” and rename it to “14-16 Rating.” This way, you will not loose information as you conduct more iterations.
3. Change the length and number of tubes to 8 m and 620. Run the exchanger and note the output stream temperatures. If they are within 0.5 degrees, stop, and carry forward installed cost, outlet densities, and pressure drops to excel. If the outlet streams are not within 0.5 degrees, continue to add or remove tubes, while also adjusting the shell diameter, until they are.

It is important to adjust the shell diameter to match the number of tubes as closely as possible. Exchanger cost depends on shell weight, and pressure drops depend on clearance gaps between the shell and the tube bundle.

(Procedure is continued on the next slide)

# Procedure, continued

5. Change the tube length to 9.0 m. Note that this will increase the heat exchanger area. You will need to reduce the number of tubes to compensate. Decrease the number of tubes, adjust the shell diameter, and run the heat exchanger.

It is important to continue to adjust the number of tubes until the outlet temperatures match the specs within  $\pm 0.5$  °C.

6. Continue in this manner until you complete at least all required iterations, increasing the tube length in 1-m steps. Tube length is varied from 8 to 16 m in 1-m steps.
7. When you are satisfied that the plot and curve fit are acceptable, you will need to take the derivative of the resulting trendline equation, set the derivative equal to zero, and solve for the length that makes the derivative zero.

Optimum installed cost is not the same as optimum purchased cost. You will need to adjust accordingly.

# Problem 14-16 Submission Requirements

CHEMCAD and Excel files in SharePoint. CHEMCAD contains results from 3-step design method.

PDF of plot, one page, plot fits page in landscape.

PDF of spreadsheet, fonts readable, in landscape, and fit to one page  
Final answers clearly indicated.

Proper print procedure is on the next two slides.

Signed cover sheet.

One pdf bundle file (title page plus excel).

Due Friday 6 Feb by 1159

PTW\_14\_16\_AY242.xlsx No Labels Last Modified: 2h ago Brian W. Andrew BA

# Proper print setup for plot

**Print**

Copies: 1

**Printer**  
Adobe PDF Ready

**Settings**

- Print Selected Chart  
Only print the selected chart
- Collated  
1,2,3 1,2,3 1,2,3
- Landscape Orientation
- Letter  
8.5" x 11"
- Normal Margins  
Top: 0.75" Bottom: 0.75" Left:...  
[Page Setup](#)

results hidden

1 of 1

# Proper print setup for spreadsheet

**Print**

Copies: 1

**Printer**

Adobe PDF Ready

[Printer Properties](#)

**Settings**

Print Selection  
Only print the current selection

Pages:  to

Collated  
1,2,3 1,2,3 1,2,3

Landscape Orientation

Letter  
8.5" x 11"

Custom Margins

Fit Sheet on One Page  
Shrink the printout so that it fi...

[Page Setup](#)

**results hidden**

**Procedure:**

1. Repeat the "Check" calculations in column E.
2. Run ChemCAD utility mode to determine the necessary flow rate of the cold air.
3. Run using in design mode to optimize total purchase cost.
4. Complete column F for the "Sizing" results.
5. Verify the tube number while adjusting tube length to keep minimum tempos on spec.
6. Complete the "Results" in columns G through Q.
7. Add more dimensions necessary to minimize operating costs using equation 14-40.

Complete this table:	
Tube Length - Optimized, m	11.81
Installed Cost, Optimized, \$	\$45.87
urchased Cost, Optimized, \$	\$15.002 (Ans)



# Questions?