CH402 Chemical Engineering Process Design

L11 – Heat Exchanger Design III

Solution of 14-16, continued from L10

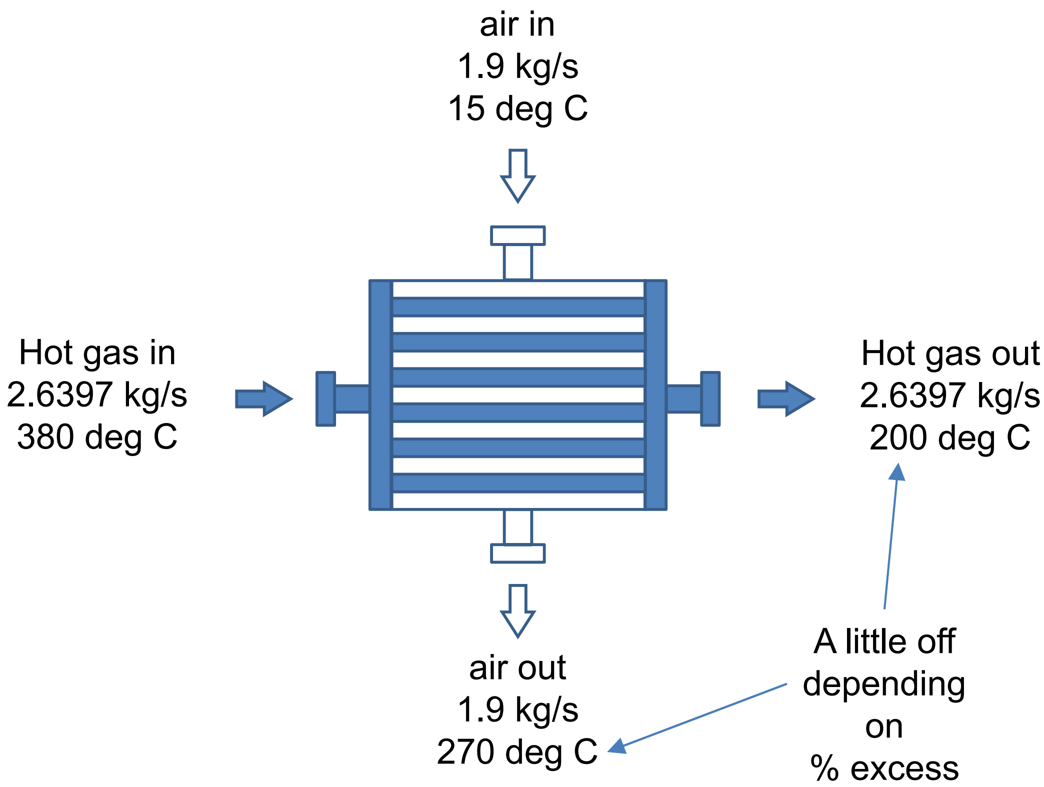
Problem 14-16

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



Tube length: 9.75 m
Number of tubes: 288
Installed cost: $77,677

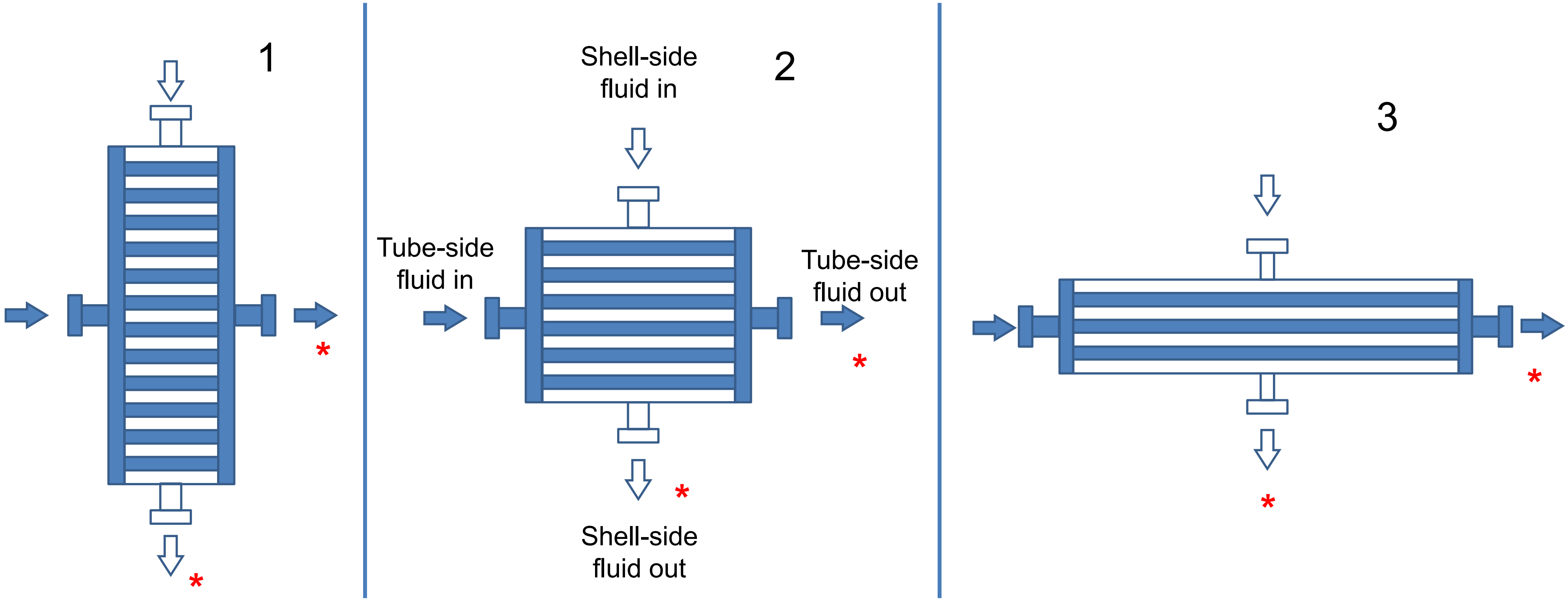
Annual op cost: $24,347

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 deg C of spec.

Use instructor-provided spreadsheet in SharePoint.

Total annual cost of heat exchanger operation

$$C_T = \underbrace{A_0 \cdot K_F \cdot C_{A_0}}_{\text{Fixed annual costs}} + \underbrace{\dot{m}_u \cdot H_y \cdot C_u}_{\text{Utility fluid costs}} + \underbrace{A_0 \cdot E_i \cdot H_y \cdot C_i}_{\text{Tube-side pumping costs}} + \underbrace{A_0 \cdot E_0 \cdot H_y \cdot C_0}_{\text{Shell-side pumping costs}}$$

PTW Eq. 14-91, p. 739

C_T Total annual costs, dollars/yr

A_0 Outside tube area, 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/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

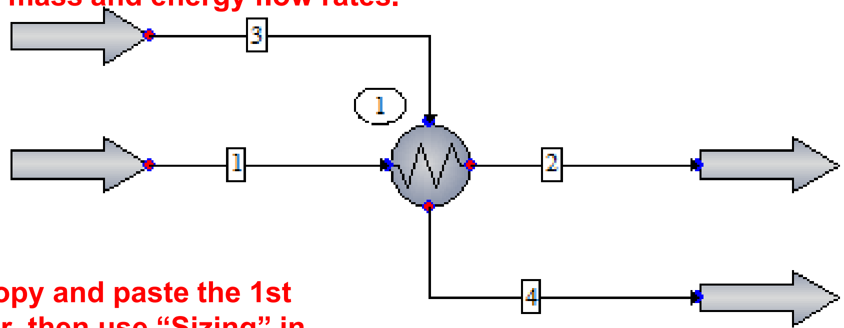
E_i Power loss due to fluid flow inside heat exchanger tubes per unit outside tube area, $N \cdot m/s$ per m^2
C_i Cost of supplying 1 $N \cdot m$ to pump fluid through the inside of the tubes, dollars/$N \cdot m$

E_0 Power loss experienced on the shell side per unit outside tube area, $N \cdot m/s$ per m^2
C_0 Cost of supplying 1 $N \cdot m$ to pump fluid through the shell side, dollars/$N \cdot m$

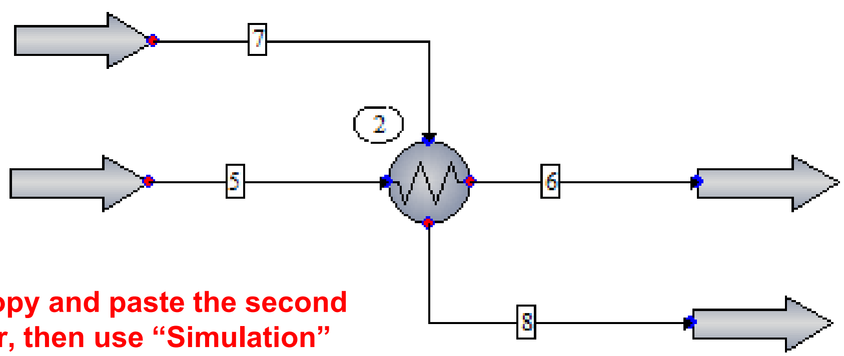
Solution Strategy 14-16

Use the 3-step design process

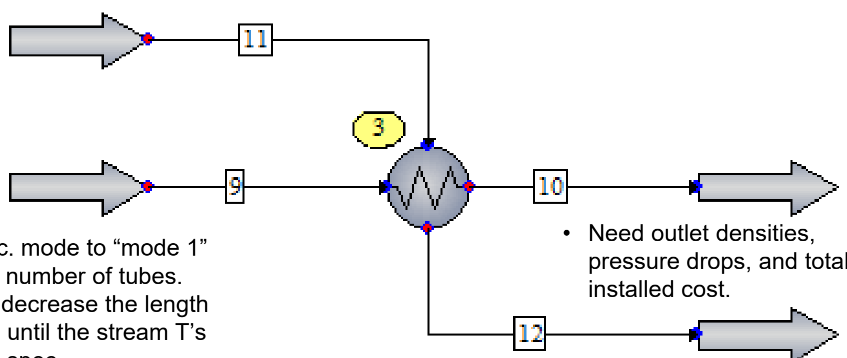
Step 1: Use CHEMCAD to solve for all unknown mass and energy flow rates.



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.

- Need outlet densities, pressure drops, and total installed cost.

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

	A	B	C	D	E
1	**Problem 14-16. Cadet Template**			"sizing" checks are re	
2	Optimimal Heat Exchanger Design				
3	Yellow - obtained from CHEMCAD simulations				
4	Light Blue - Specifications given in problem - page 753 in PTW textbook				
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_t	dimensionless	288	288
9	Length of tubes	L	m	9.750	9.750
10	Installed cost, CC	C	$	$77,677	$77,677
11	Tube outer diameter	D_o	m	0.0254	0.0254
12	Tube inner diameter	D_i	m	0.0191	0.0191
13	Tube wall thickness	x	m	0.00315	0.00315
14	Outside area of tubes	A_o	m^2	224.1	224.1
15	Installed cost per area	C_{Ao}	$\$/m^2$	$347	$347
16	Tube-side (hot gas) flow rate, CC	m_i	kg/s	2.6397	2.6397
17	Tube-side inlet fluid density, CC	r_{ti}	kg/m^3	5.3956	5.3956
18	Tube-side oulet fluid density, CC	r_{to}	kg/m^3	7.3697	7.3697
19	Tube-side pressure drop, CC	Dp_i	kPa	13.9405	13.9405
20	Tube-side average density	r_t	kg/m^3	6.3827	6.3827
21	Tube-side power loss per area	E_i	Nm/s per m^2	25.7307	25.7307
22	Shell-side (air) flow rate	m_o	kg/s	1.9000	1.9000
23	Shell-side inlet fluid density, CC	r_{si}	kg/m^3	12.3104	12.3104
24	Shell-side oulet fluid density, CC	r_{so}	kg/m^3	6.3576	6.3576
25	Shell-side pressure drop, CC	Dp_o	kPa	16.7692	16.7692
26	Shell-side average density	r_s	kg/m^3	9.3340	9.3340
27	Shell-side power loss per area	E_o	Nm/s per m^2	15.2341	15.2341
28	Hours of operation per year	H_y	h/y	8000	8000
29	Cost of pumping power	C_i	$/kWh	0.12	0.12
30	Annual fixed charges factor	K_F	dimensionless	0.2	0.2
31					
32	Fixed charges		$/y	$15,535	$15,535
33	Tube-side pumping costs		$/y	$5,535	$5,535
34	Shell-side pumping costs		$/y	$3,277	$3,277
35	**Total annual cost**	C_T	**$/y**	**$24,347**	$24,347

Procedure

1. Complete the 3-step heat exchanger design as shown in Lessons 9 and 10. Set the 3rd exchanger to simulation mode.

2. In the "CCTherm" tab, make a copy of the "Case" and rename it for each tube length iteration. 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 outlet densities, pressure drops, and total installed cost 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 tube 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 ± 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.

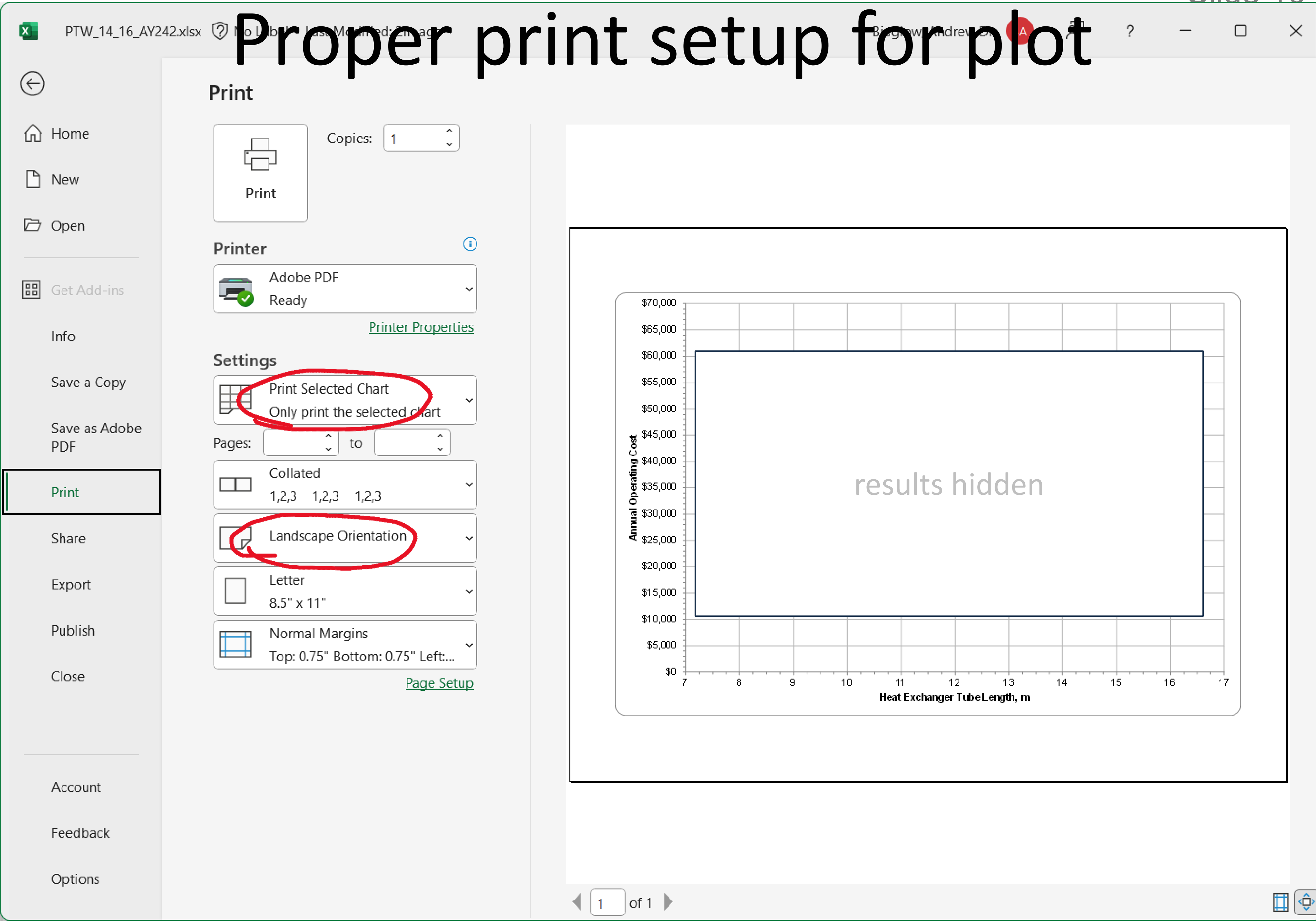
PDF of plot, one page, plot fits page, landscape.
PDF of spreadsheet, fonts readable, in landscape, and fit to one page
Final answers clearly indicated.

Proper print procedure is on the next two slides.

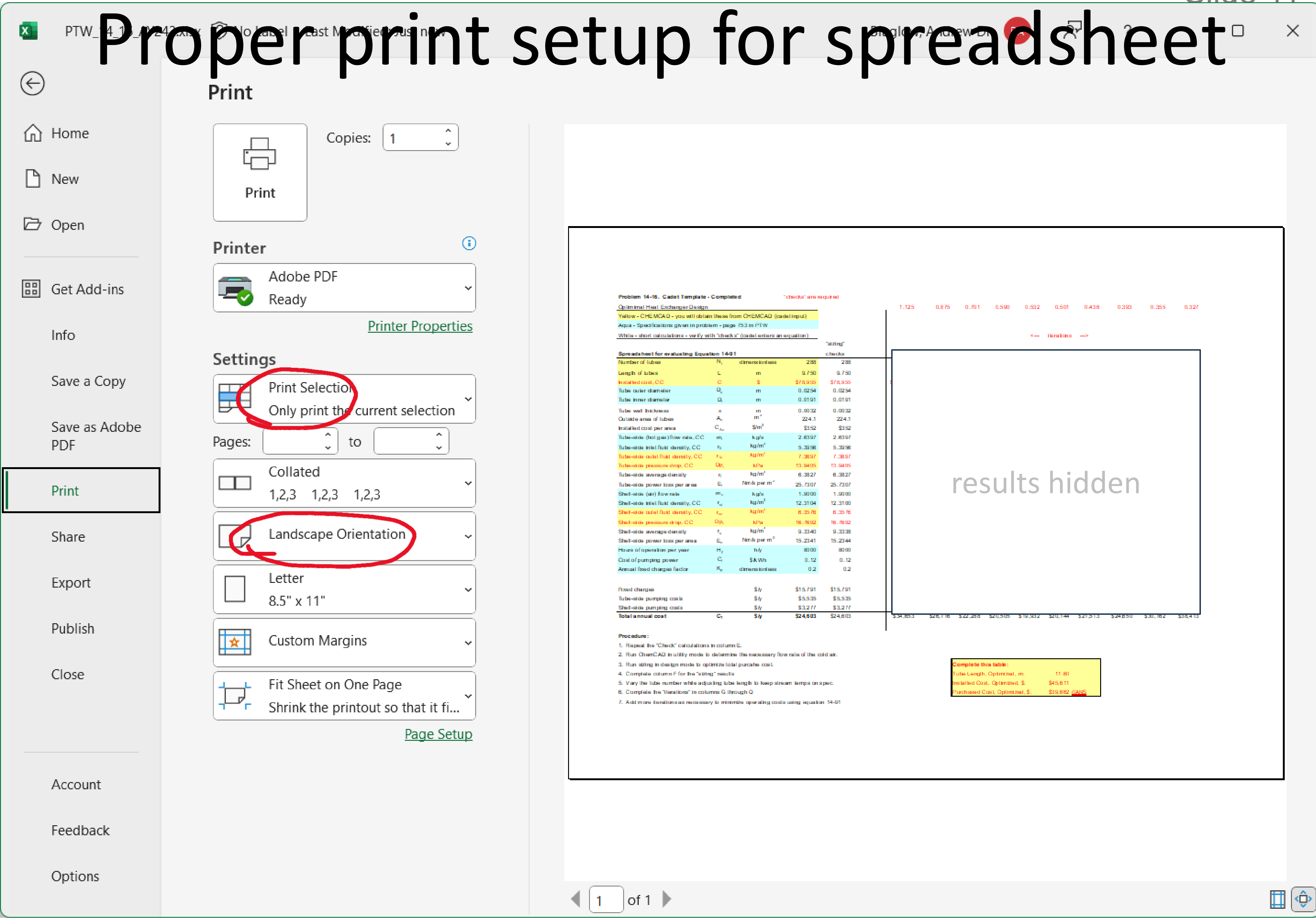
Signed cover sheet.
One pdf bundle file (title page plus excel).

Due Thursday 6 Feb by 1159

Proper print setup for plot



Proper print setup for spreadsheet



Questions?