CH402 Chemical Engineering Process Design

Class Notes L10

Heat Exchanger Design II

(Solution of 14-16 with Equation 14-91)

(These slides apply to CC NXT 1.2.0 only)

WPR 1 – L12– WARNO

Date – 9 February 2026, B&D Hours.

Coverage – Lessons 1-11 (Chapters 12 and 14 and Labs 1-3).

(1) Heat Exchangers – CHEMCAD 3-step method.

- *Simple mode*, including flow rates and exchanger specs.

- *Sizing mode*, including area, number and length of tubes, resistances, Reynolds numbers, and pressure drops.

- *Simulation mode*, including outlet temperatures and exchanger costs.

- Three different exchangers, one for each step.

- Apply equation 14-91 as in problem 14-16.

(2) Pumps and Pipe flow – static and dynamic losses, pump characteristics curve, CHEMCAD pipes, pumps, nodes, and compressors. Be able to explain static and dynamic head.

(3) CHEMCAD and textbook costing tools, especially for heat exchangers, pipes, pumps, compressors.

3 problems, 200 points (80/60/60), 55 minutes

Make sure you understand Problem Sets 1-5 and Labs 1-3.

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.

Annual cost of heat exchanger operation

Important!

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

| Fixed annual costs | Utility fluid costs | Tube-side pumping costs | Shell-side pumping costs |

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/$N \cdot m$

This will be explored in detail in Lesson 11. Today – CHEMCAD base "design" case.

Format Engineering Units:
    Common SI
    Time – seconds
    Pressure – kPa
    Enthalpy – J
    Work – kJ

Thermophysical Select
Components:
    Nitrogen and
    Oxygen
    (Do not use "Air")

Thermodynamics Wizard:
    SRK for K and H

Level 1 Flowsheet

air

hot gas

1

3

2

4

Edit Streams ✕

| Flash | | Cancel | OK |
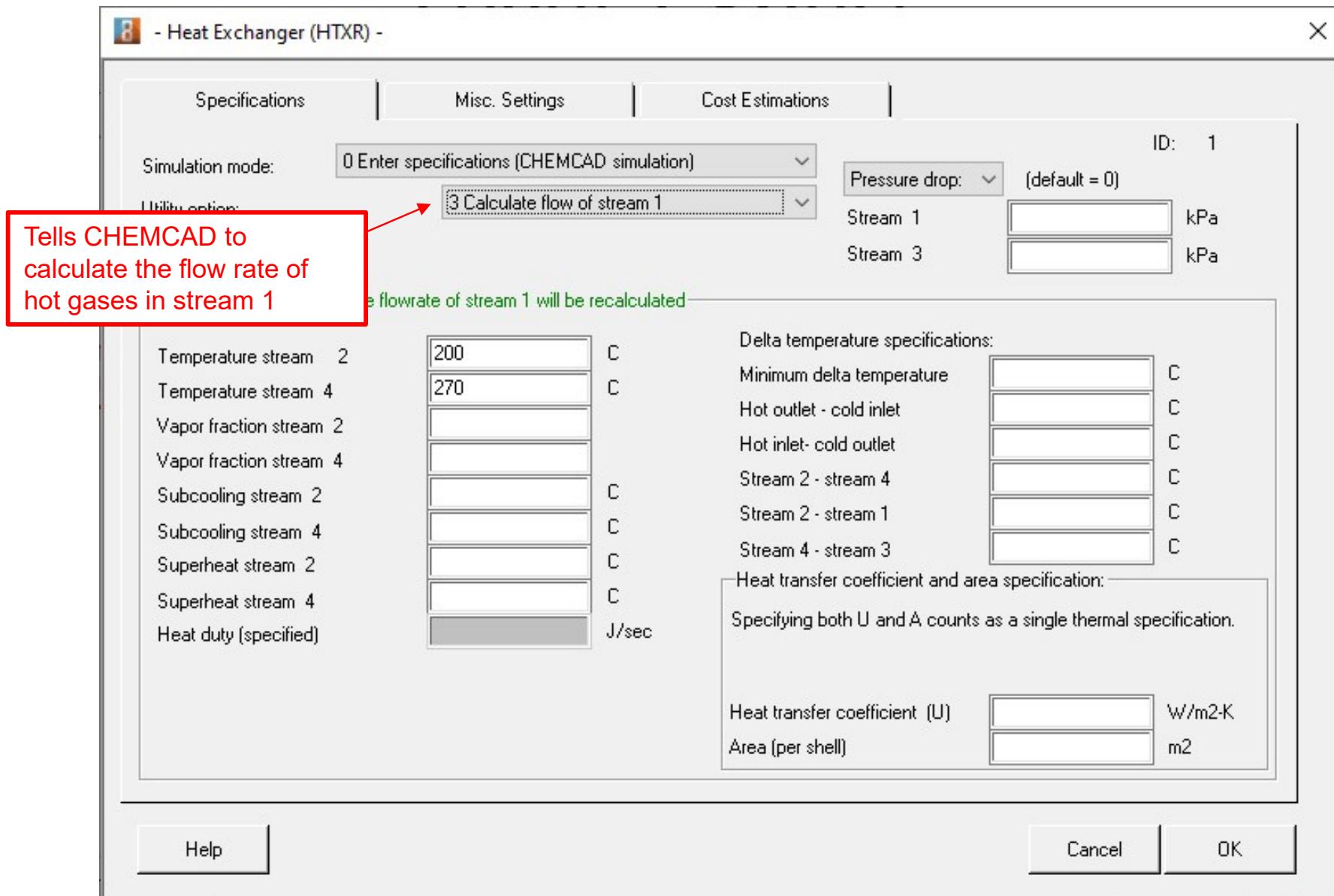
Stream No.	1	3
Stream Name		
Temp C	380	15
Pres kPa	1020	1020
Vapor Fraction	1	1
Enthalpy J/sec	367714	-23977.57
Total flow	1	1.9
Total flow unit	kg/sec	kg/sec
Comp unit	Mole fractions	Mole fractions
Nitrogen	0.79	0.79
Oxygen	0.21	0.21

We don't know this yet.
Set initial value to 1 kg/s
CHEMCAD calculates it.

Level 1 Specs

- Heat Exchanger (HTXR) -

| Specifications | Misc. Settings | Cost Estimations |

ID: 1

Simulation mode: 0 Enter specifications (CHEMCAD simulation)

Pressure drop: (default = 0)

3 Calculate flow of stream 1

Stream 1 _____ kPa
Stream 3 _____ kPa

Utility option:

Tells CHEMCAD to calculate the flow rate of hot gases in stream 1

...e flowrate of stream 1 will be recalculated

Temperature stream   2 | 200 | C
Temperature stream 4 | 270 | C
Vapor fraction stream 2
Vapor fraction stream 4
Subcooling stream 2 | C
Subcooling stream 4 | C
Superheat stream 2 | C
Superheat stream 4 | C
Heat duty (specified) | J/sec

Delta temperature specifications:

Minimum delta temperature   _____ C
Hot outlet - cold inlet   _____ C
Hot inlet- cold outlet   _____ C
Stream 2 - stream 4   _____ C
Stream 2 - stream 1   _____ C
Stream 4 - stream 3   _____ C

Heat transfer coefficient and area specification:

Specifying both U and A counts as a single thermal specification.

Heat transfer coefficient (U)   _____ W/m2-K
Area (per shell)   _____ m2

Help   Cancel   OK

Click "OK" then "Run." Verify that the flow rate of hot gas is 2.6397 kg/s in stream 1. This completes "Level 1" design.
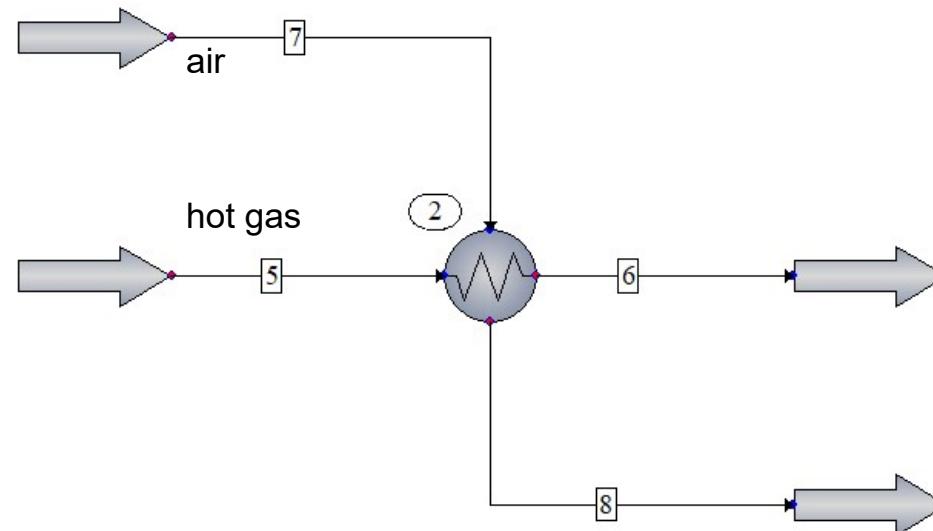
Level 2 Design

Step 1

In Step 1, CHEMCAD solved mass and energy balances and determined unknown hot gas flow rate.

air

hot gas

Step 2 – Copy and Paste
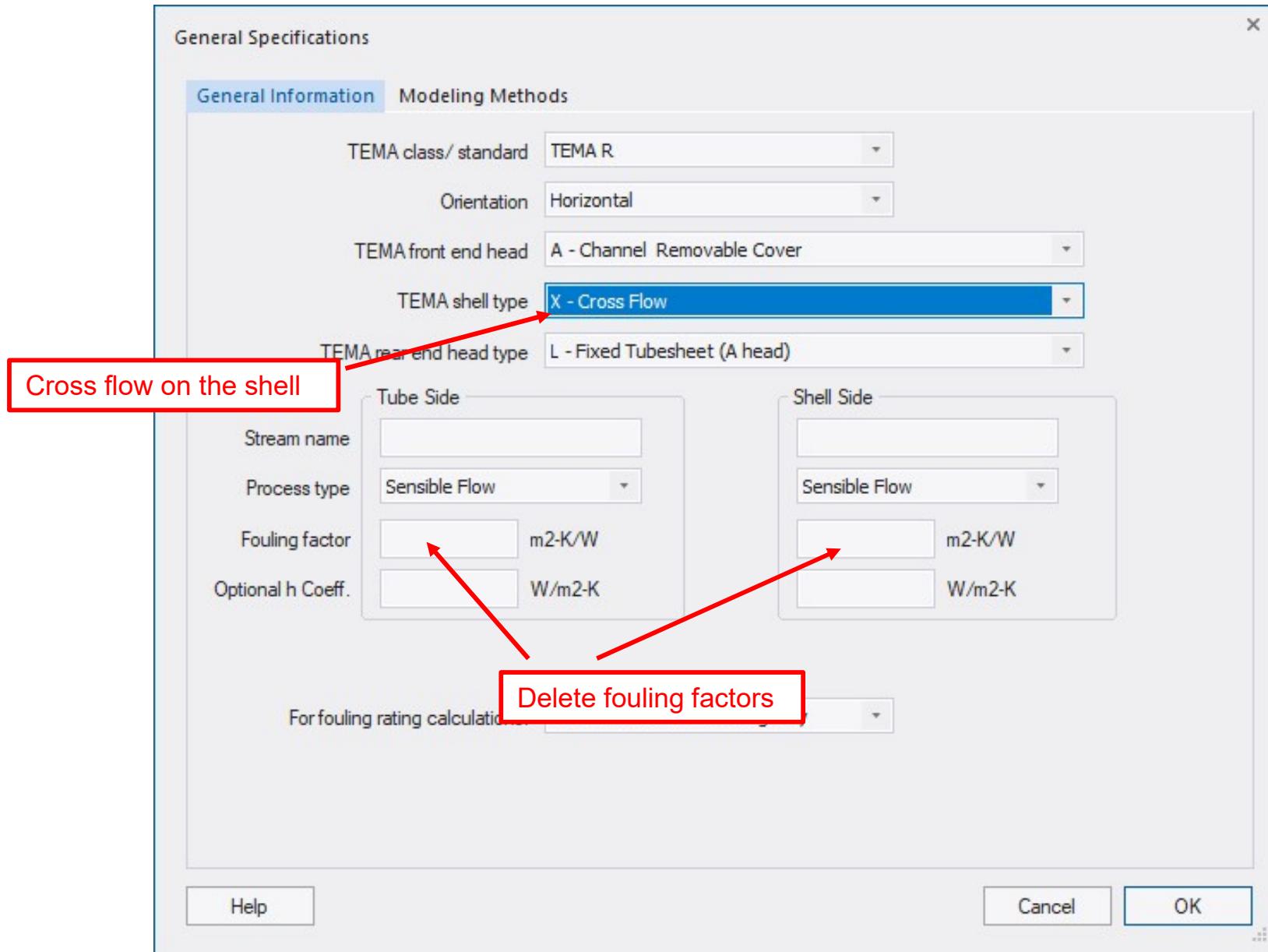
In Step 2, CHEMCAD uses mechanical details to optimize the exchanger in terms of total purchased cost.

air

hot gas

Proceed to Sizing -> Shell and Tube, and enter unit 2
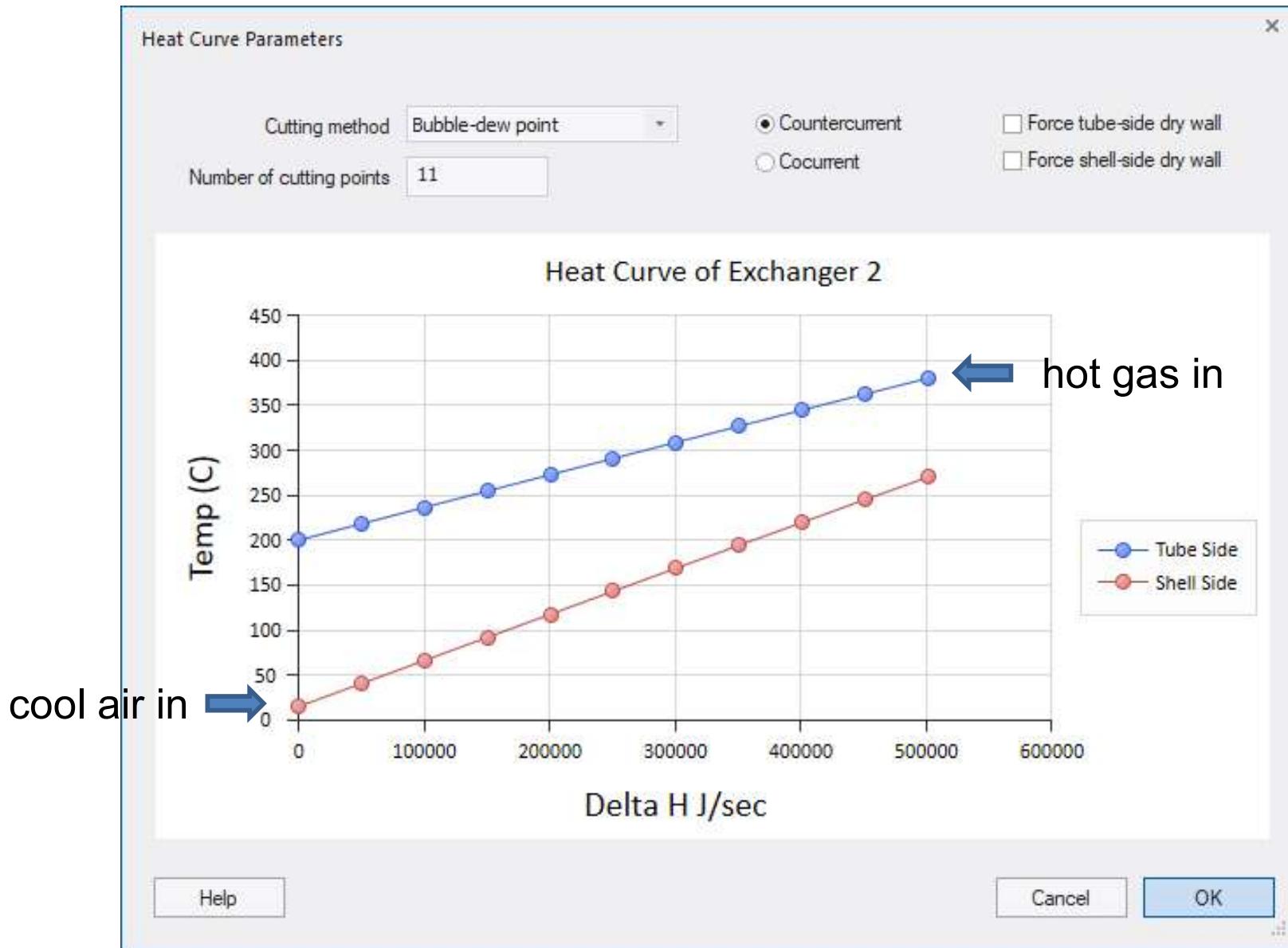
General Specs

In the CCTherm tab, in the Configuration Group, click "General," and then enter "5" for the stream entering tube side. This opens the General Specs window.

Heat Curves

It is a good idea to look at the heating-cooling curves. Proceed to CCTherm Configuration Group -> Heat Curve Specification

Design Constraints

CCTherm Configuration Group -> General Dropdown -> Design Constraints

Shell Specs

Baffle Specs

Baffle Specifications   ✕

Baffle type   [No Baffle   ▾]

IMPORTANT – Due to the unusual sizes used later in the "energy" optimization, baffles must be turned off.

[Help]   [Cancel]   [OK]

Calculate: Design

TABULATED ANALYSIS

Overall Data:

Area Total	m2	224.15	% Excess		2.72
Area Required	m2	217.08	U Calc.	W/m2-K	19.61
Area Effective	m2	222.98	U Service	W/m2-K	19.09
Area Per Shell	m2	222.98	Heat Duty	J/sec	5.01E+05

Weight LMTD C   144.27   LMTD CORR Factor   0.8154   CORR LMTD C   117.63

Shell-side Data:

|					
Film Coef. W/m2-K		24.55	Reynolds No.		1502
Allow Press. Drop	kPa	34.47	Calc. Press. Drop	kPa	16.32
Inlet Nozzle Size	m	0.13	Press. Drop/In Nozzle	kPa	1.82
Outlet Nozzle Size	m	0.09	Press. Drop/Out Nozzle	kPa	2.63
			Mean Temperature	C	142.50
Rho V2 IN kg/m-sec2		1760.30	Press. Drop (Dirty)	kPa	27.74

Low Reynolds Number.

Tube-side Data:

Film Coef. W/m2-K		130.72	Reynolds No.		20904
Allow Press. Drop	kPa	34.47	Calc. Press. Drop	kPa	13.94
Inlet Nozzle Size	m	0.13	Press. Drop/In Nozzle	kPa	3.72
Outlet Nozzle Size	m	0.10	Press. Drop/Out Nozzle	kPa	2.87
Interm. Nozzle Size	m	0.00			
Velocity	m/sec	5.06			

Shell:

Shell O.D.	m	0.81
Shell I.D.	m	0.79
Bonnet I.D.	m	0.79
Type		AXL
Imping. Plate		Impingement Plate

Tubes:

Number		288
Length	m	9.75
Tube O.D.	m	0.025
Tube I.D.	m	0.019
Tube Wall Thk.	m	0.003
No. Tube Pass		1
Inner Roughness	m	0.0000016
Number of tubesheets		2

Resistances:

Shell-side Film	m2-K/W	0.04073
Shell-side Fouling	m2-K/W	0.00000
Tube Wall	m2-K/W	0.00008
Tube-side Fouling	m2-K/W	0.00000
Tube-side Film	m2-K/W	0.00765

Reference Factor (Total outside area/inside area based on tube ID)   1.330

Pressure Drop Distribution:
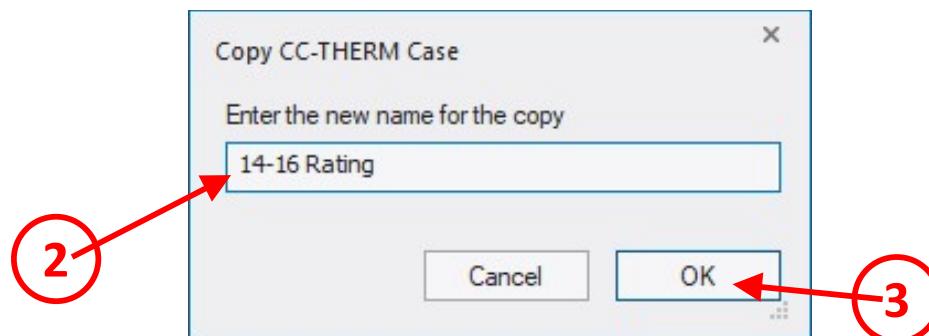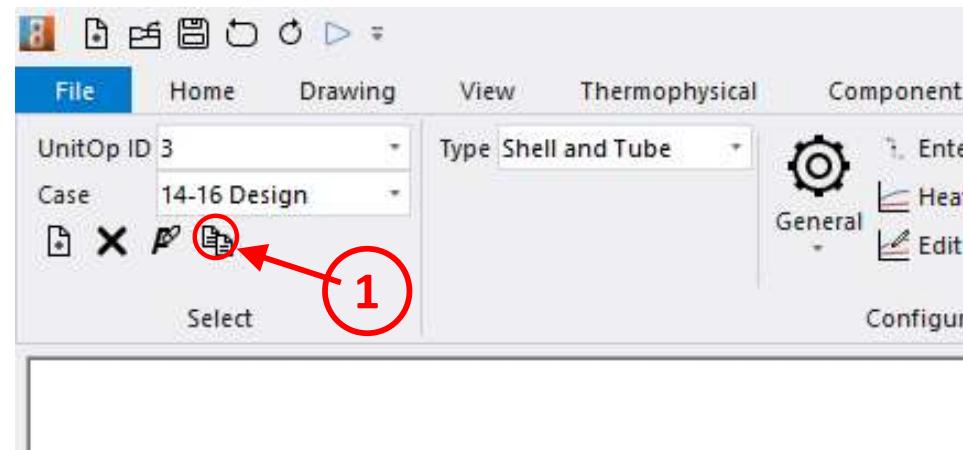
Tube Side			Shell Side		
Inlet Nozzle	kPa	3.7201	Inlet Nozzle	kPa	1.8239
Tube Entrance	kPa	0.0389	Impingement	kPa	1.1442
Tube	kPa	1.0672	Bundle	kPa	0.0136
Tube Exit	kPa	0.0686	Outlet Nozzle	kPa	2.6325
End	kPa	0.0000	Total Fric.	kPa	4.4700
Outlet Nozzle	kPa	2.8731	Total Grav.	kPa	-0.0713
Total Fric.	kPa	7.7678	Total Mome.	kPa	11.9172
Total Grav.	kPa	0.0559	Total	kPa	16.3159
Total Mome.	kPa	6.1167			
Total	kPa	13.9405			

Create a Copy of Your CCTherm Design

Create a copy of your CCTherm design. This guards against loosing your work through mistakes. In the CCTherm "Select" Group -> Click "Copy CCTherm Case"
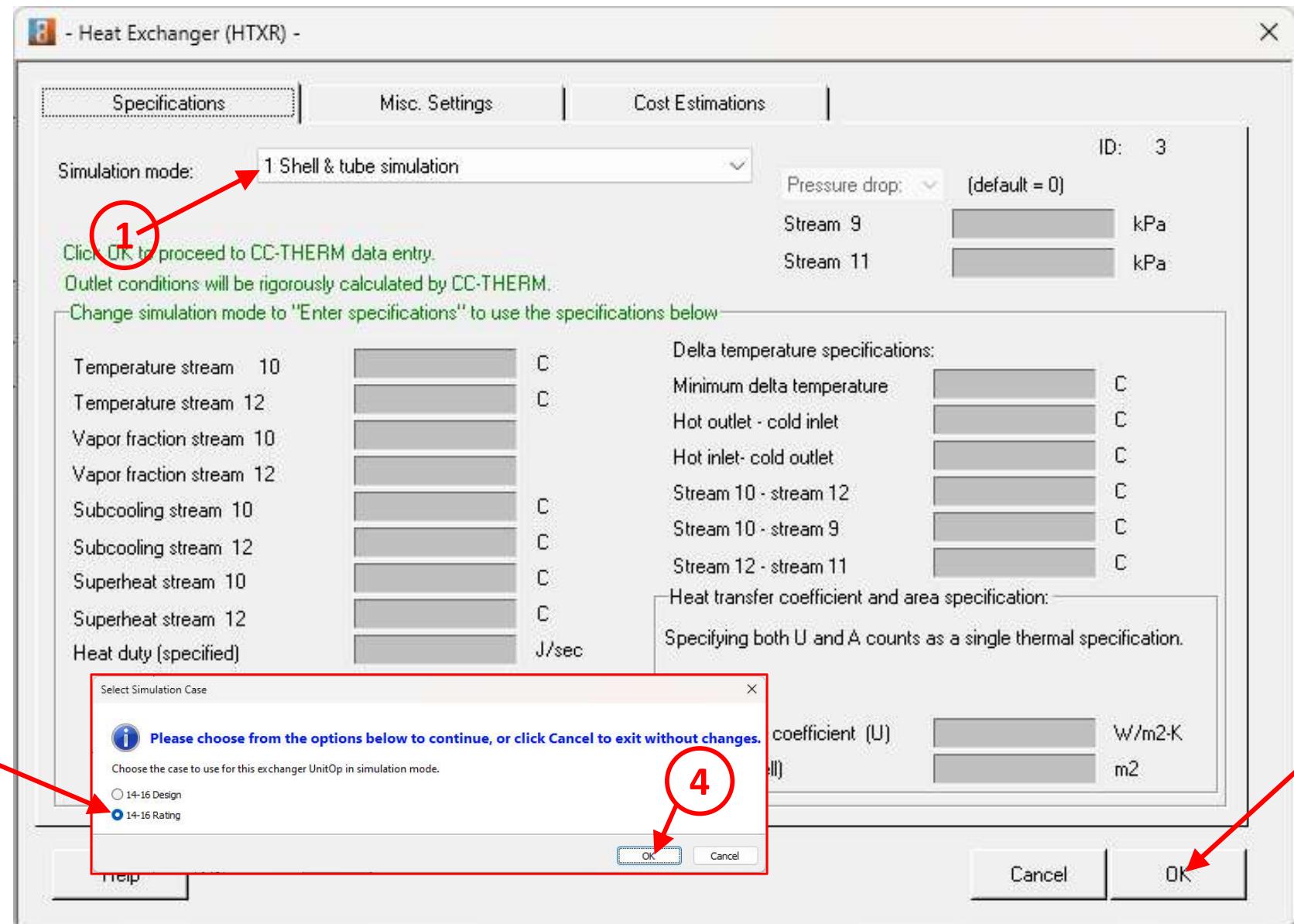
Level 3 – Shell and Tube Simulation

Copy and Paste Exchanger 2 (creating exchanger 3)

Copy this exchanger
and past it here.

Change Mode to Simulation
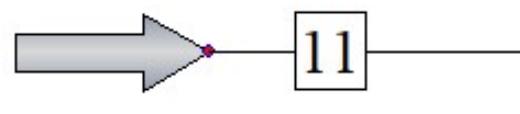
Copy and Paste Exchanger 2 (creating exchanger 3), double-click the exchanger, and change simulation mode to "1 Shell & tube simulation"

Run the Simulation
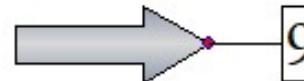
Checking results shows that outlet streams are slightly off spec based on percent excess safety factor.

What happens to P-drop when we go from 1 to 2 to 3?

1

2

3

Shell-side fluid in

Tube-side fluid in

Tube-side fluid out

Shell-side fluid out

This affects cost to push fluids.

Update Cost Index and Run Costing

In the Home tab, in the Results Group, click ⚙ (property sets)

Problem 14-16. Cadet Template			"sizing" checks are required		
Optimimal Heat Exchanger Design					
Yellow - obtained from CHEMCAD simulations					
Light Blue - Values are derived from specs and do not change.					
White - excel calculations - verified with "checks" (results from CC design)					
			"sizing"		
Spreadsheet for evaluating Equation 14-91			checks		
Number of tubes	N_t	dimensionless	288		
Length of tubes	L	m	9.750		
Installed cost, CC	C	$	$82,011		
Tube outer diameter	D_o	m	0.0254		
Tube inner diameter	D_i	m	0.0191		
Tube wall thickness	x	m	0.00315		
Outside area of tubes	A_o	m^2	224.1		
Installed cost per area	C_{Ao}	$/m^2$	$366		
Tube-side (hot gas) flow rate, CC	m_i	kg/s	2.6397		
Tube-side inlet fluid density, CC	r_{ti}	kg/m^3	5.3956		
Tube-side oulet fluid density, CC	r_{to}	kg/m^3	7.3697		
Tube-side pressure drop, CC	Dp_i	kPa	13.9405		
Tube-side average density	r_t	kg/m^3	6.3827		
Tube-side power loss per area	E_i	Nm/s per m^2	25.7307		
Shell-side (air) flow rate	m_o	kg/s	1.9000		
Shell-side inlet fluid density, CC	r_{si}	kg/m^3	12.3104		
Shell-side oulet fluid density, CC	r_{so}	kg/m^3	6.3576		
Shell-side pressure drop, CC	Dp_o	kPa	16.7692		
Shell-side average density	r_s	kg/m^3	9.3340		
Shell-side power loss per area	E_o	Nm/s per m^2	15.2341		
Hours of operation per year	H_y	h/y	8000		
Cost of pumping power	C_i	$/kWh	0.12		
Annual fixed charges factor	K_F	dimensionless	0.2		
Fixed charges		$/y	$16,402		
Tube-side pumping costs		$/y	$5,535		
Shell-side pumping costs		$/y	$3,277		
Total annual cost	C_T	$/y	$25,214		

Complete this portion of the template.

Values in column D are checks to confirm your work.

Blue rows are specs or calculated from the specs from the problem and are typed in as is. These numbers do not change.

Yellow rows (red font) come from CHEMCAD exchanger 3. These numbers will change in the optimization, but not yet.

White rows are formula entries. Calculation of cells E21 and E21 (power losses) are calculated from the methods in slide 24.

Formulas are shown in slide 26.

Problem 14-16. Cadet Template				"sizing" checks are required	
Optimimal Heat Exchanger Design					
Yellow - obtained from CHEMCAD simulations					
Light Blue - Values are derived from specs and do not change.					
White - excel calculations - verified with "checks" (results from CC design)					
				"sizing"	
Spreadsheet for evaluating Equation 14-91				checks	
Number of tubes	N_t	dimensionless	288	288	
Length of tubes	L	m	9.750	9.750	
Installed cost, CC	C	$	$82,011	$82,011	
Tube outer diameter	D_o	m	0.0254	0.0254	
Tube inner diameter	D_i	m	0.0191	0.0191	
Tube wall thickness	x	m	0.00315	=(E11-E12)/2	
Outside area of tubes	A_o	m^2	224.1	=PI()*E11*E9*E8	
Installed cost per area	C_{Ao}	$/m^2	$366	=E10/E14	
Tube-side (hot gas) flow rate, CC	m_i	kg/s	2.6397	2.6397	
Tube-side inlet fluid density, CC	r_{ti}	kg/m^3	5.3956	5.3956	
Tube-side oulet fluid density, CC	r_{to}	kg/m^3	7.3697	7.3697	
Tube-side pressure drop, CC	Dp_i	kPa	13.9405	13.9405	
Tube-side average density	r_t	kg/m^3	6.3827	=AVERAGE(E17:E18)	
Tube-side power loss per area	E_i	Nm/s per m^2	25.7307	=1000*E19*E16/E20/E14	
Shell-side (air) flow rate	m_o	kg/s	1.9000	1.9000	
Shell-side inlet fluid density, CC	r_{si}	kg/m^3	12.3104	12.3104	
Shell-side oulet fluid density, CC	r_{so}	kg/m^3	6.3576	6.3576	
Shell-side pressure drop, CC	Dp_o	kPa	16.7692	16.7692	
Shell-side average density	r_s	kg/m^3	9.3340	=AVERAGE(E23:E24)	
Shell-side power loss per area	E_o	Nm/s per m^2	15.2341	=1000*E25*E22/E26/E14	
Hours of operation per year	H_y	h/y	8000	8000	
Cost of pumping power	C_i	$/kWh	0.12	0.12	
Annual fixed charges factor	K_F	dimensionless	0.2	0.2	
Fixed charges		$/y	$16,402	=E30*E15*E14	
Tube-side pumping costs		$/y	$5,535	=E21*E14*E28*E29/1000	
Shell-side pumping costs		$/y	$3,277	=E27*E14*E28*E29/1000	
Total annual cost	C_T	$/y	$25,214	=SUM(E32:E34)	

Good Luck!