

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!

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

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 · m/s per m^2

C_i Cost of supplying 1 N · m to pump fluid through the inside of the tubes, dollars/N · m

E_0 Power loss experienced on the shell side per unit outside tube area, N · m/s per m^2

C_0 Cost of supplying 1 N · m to pump fluid through the shell side, dollars/N · m

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

Engineering Units

System Profiles

Current Flowsheet Settings: Chapter14 Save As ▾

Fundamental		Fluid Flow	Fluid Properties
Time	sec		
Mole/Mass	kg		
Temperature	°C		
Pressure	kPa		
Enthalpy	J		
Work	kJ		

User Profiles

Available Components:

ID	Name	CAS ...	For...	Last Modified
1	Hydrogen	1333-74-0	H2	2016/07/01 08:36:47
2	Methane	74-82-8	CH4	2016/07/01 08:36:47
2	Methyl hydride	74-82-8	CH4	2016/07/01 08:36:47
3	Bimethyl	74-84-0	C2H6	2016/07/01 08:36:47
3	Dimethyl	74-84-0	C2H6	2016/07/01 08:36:47
3	Ethane	74-84-0	C2H6	2016/07/01 08:36:47
3	Ethyl hydride	74-84-0	C2H6	2016/07/01 08:36:47
3	Methylmethane	74-84-0	C2H6	2016/07/01 08:36:47
4	Propyl hydride	74-98-6	C3H8	2016/07/01 08:36:47
4	Dimethylmethane	74-98-6	C3H8	2016/07/01 08:36:47
4	Freon 290	74-98-6	C3H8	2016/07/01 08:36:47
4	n-Propane	74-98-6	C3H8	2016/07/01 08:36:47
4	Propane	74-98-6	C3H8	2016/07/01 08:36:47
5

Selected Components: Nitrogen, Oxygen

Top Up Down Bottom Delete Copy

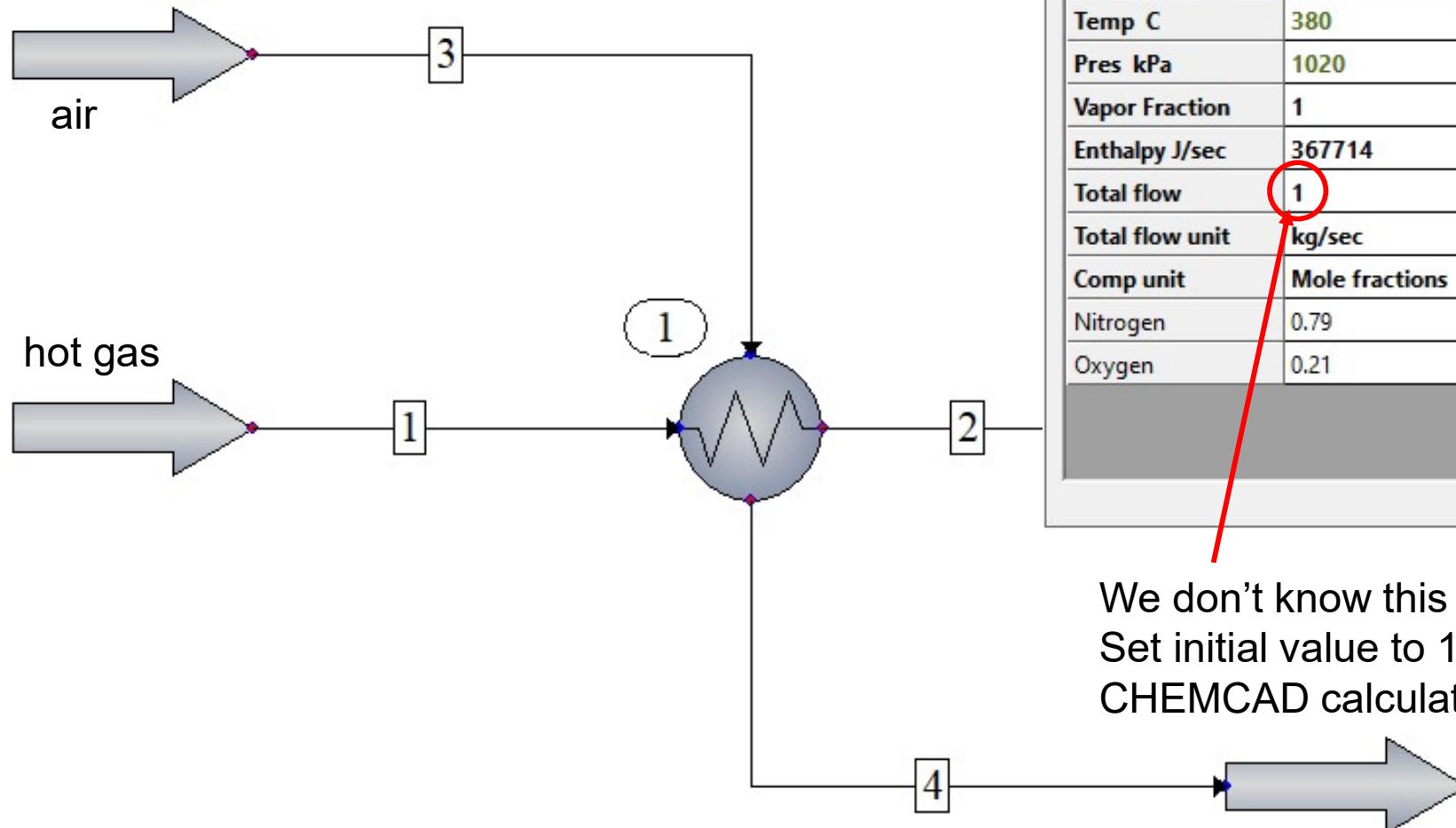
Search: Options Advanced

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

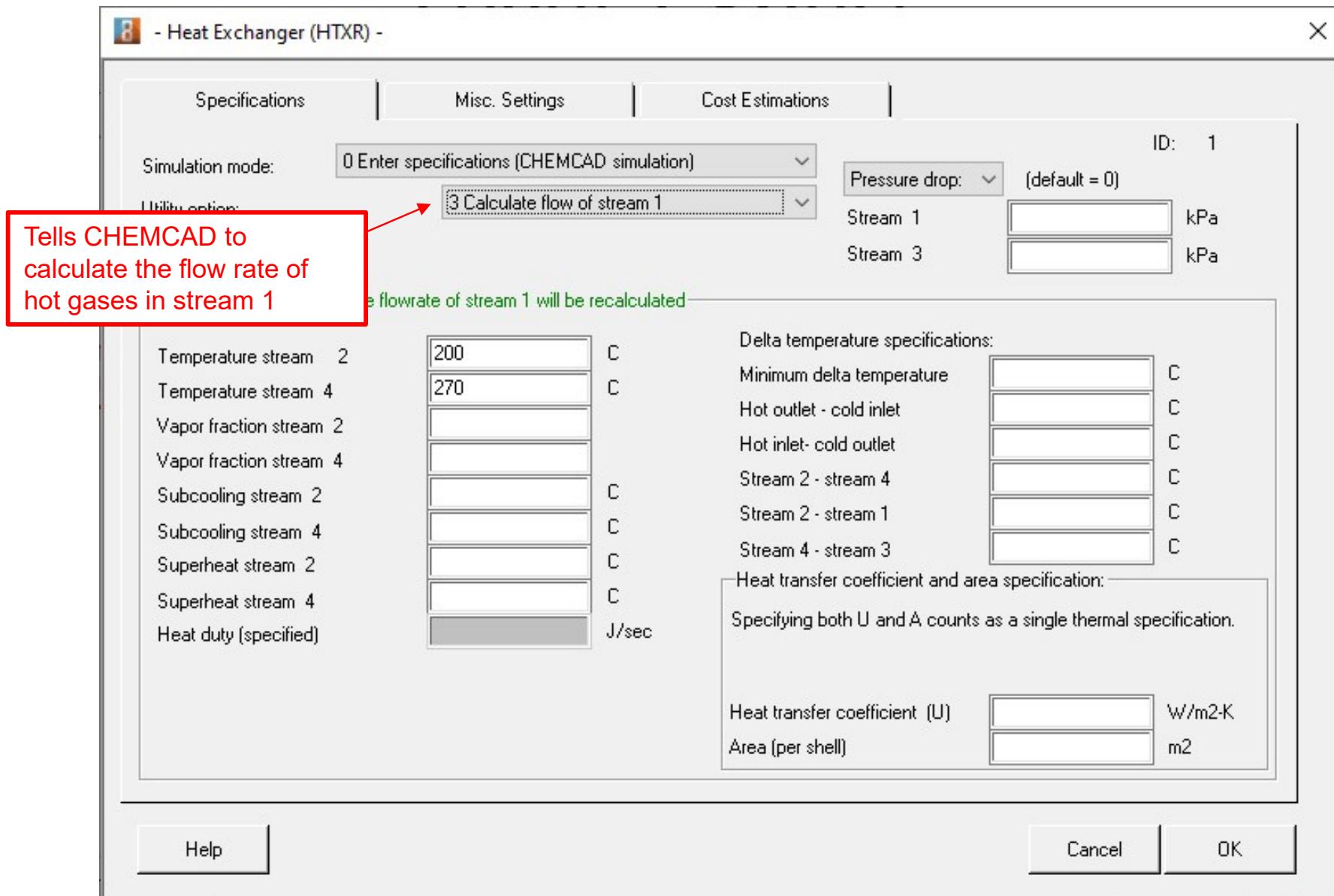


Edit Streams

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.

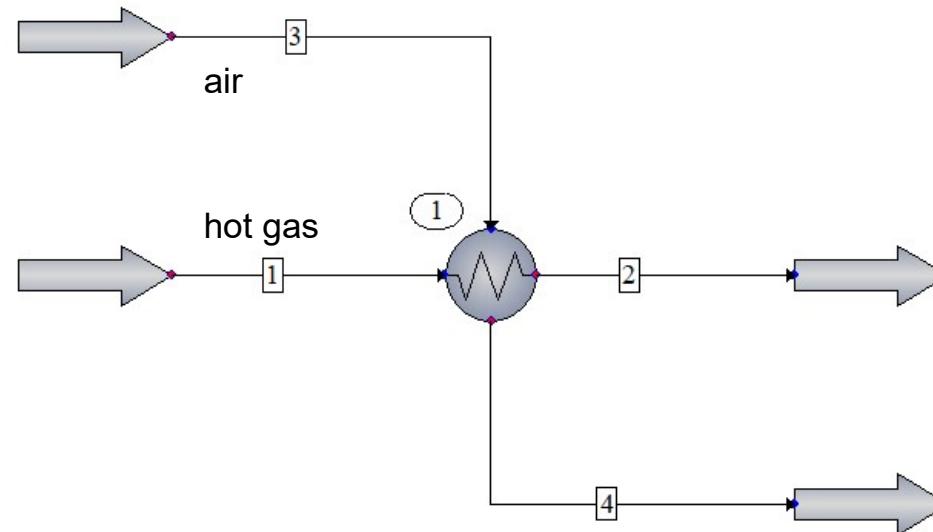
Level 1 Specs



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.

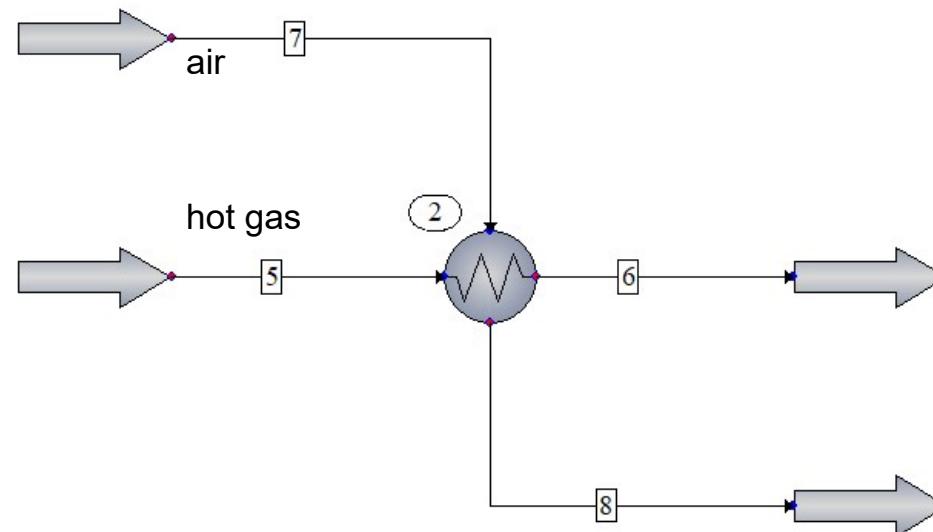
Level 2 Design

Step 1



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

Step 2 – Copy and Paste

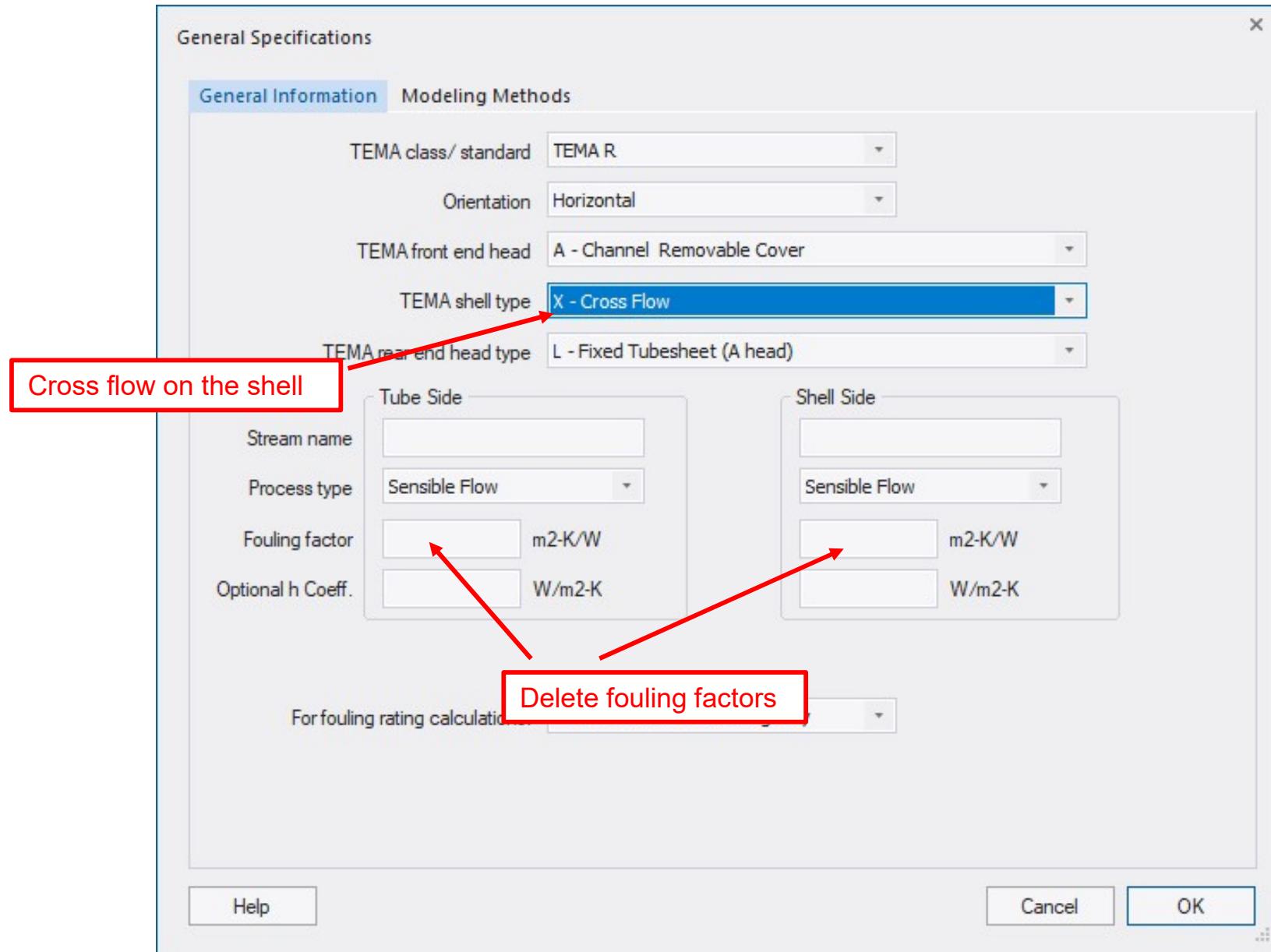


In Step 2, CHEMCAD uses mechanical details to optimize the exchanger in terms of total purchased cost.

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

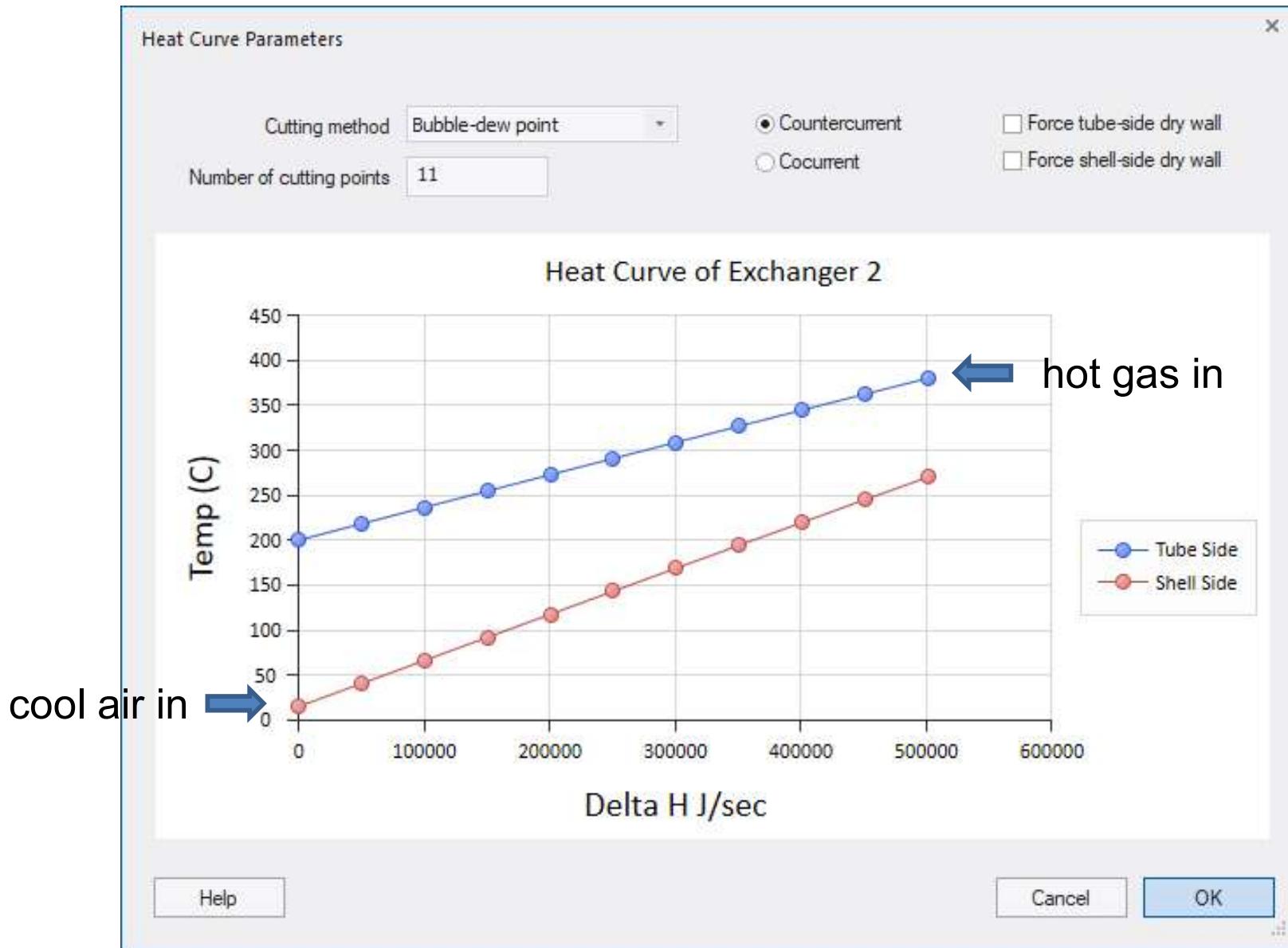
General Specs

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

Design Constraints

Design Criteria		Sizing nozzle	
Allowable tube pressure drop	34.473801 kPa	<input checked="" type="checkbox"/> Tube, inlet	
Allowable shell pressure drop	34.473801 kPa	<input checked="" type="checkbox"/> Tube, outlet	
Allowable tube velocity	76.199997 m/sec	<input checked="" type="checkbox"/> Shell, inlet	
Allowable shell velocity	76.199997 m/sec	<input checked="" type="checkbox"/> Shell, outlet	
Prefer tube length/shell diameter ratio	12		
Minimum excess %			

Limits of Design Variables			
	Lower Limits	Upper Limits	
Tube Length	0.91439998	20	m
Shell Diameter	0.1524	9	m
Baffle Cut	15	45	Percent of diameter
Baffle Spacing	0.050799999	3.175	m

Optimize number of tube passes

Help Cancel OK

Increase upper tube length

Increase shell diameter

CCTherm Configuration Group -> General Dropdown -> Design Constraints

Tube Specs

CORRECT

Tube Specifications

Number of tubes *	1396
Number of tube passes *	1
Tube outer diameter	.0254
Tube wall thickness	.00315
Tube length *	6.0960002
Roughness factor	1.5748e-06
Tube pattern	Square (90)
Tube pitch	.0381
Trufin tube code	Plain tube
Turbulator	No Turbulator
Tubesheet thickness	.0254
Number of tubesheets	2

* Field may be recalculated when design calculation is run

Help Cancel OK

Given in problem statement

Increase tubesheet thickness to 0.0254 m

This is not given. It is a TEMA spec on tubesheet thickness. Generally, it must match the tube OD.

INCORRECT

Tube Specifications

Number of tubes *	253
Number of tube passes *	1
Tube outer diameter	.0254
Tube wall thickness	.00315
Tube length *	
Roughness factor	1.5748e-06
Tube pattern	Square (90)
Tube pitch	.0381
Trufin tube code	Plain tube
Turbulator	No Turbulator
Tubesheet thickness	.0254
Number of tubesheets	2

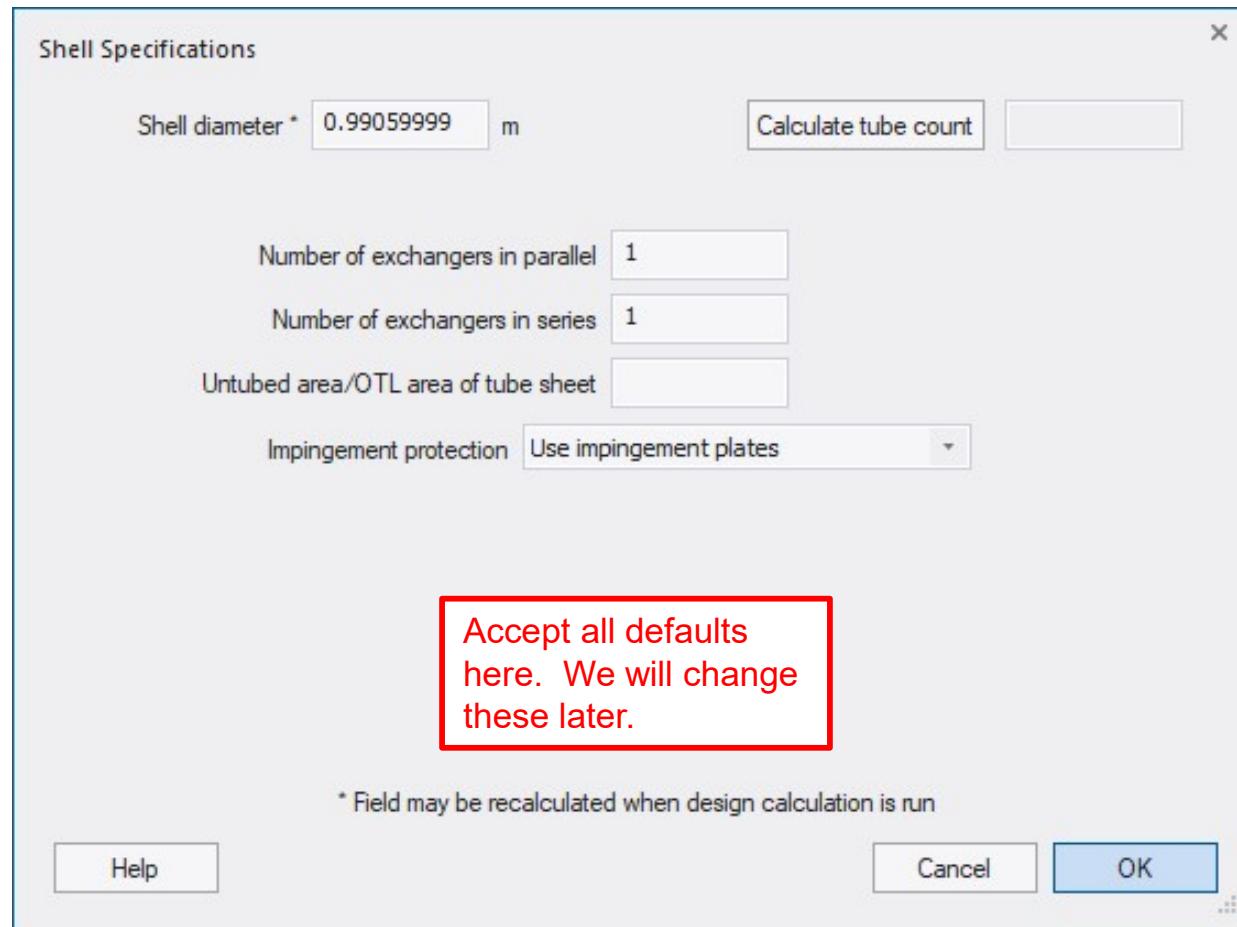
* Field may be recalculated when design calculation is run

Help Cancel OK

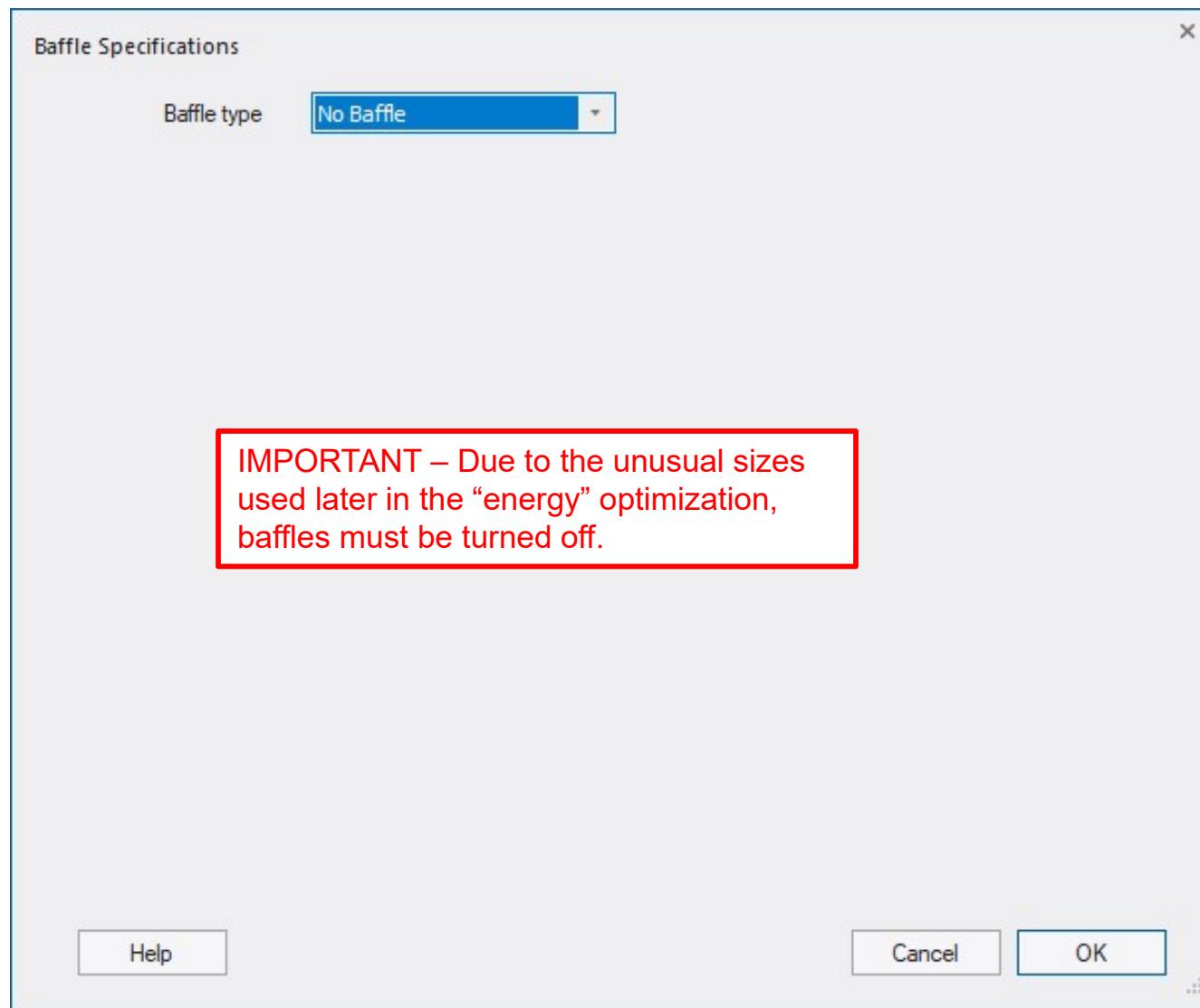
Make sure there is a value in the tube length cell.

Even though CHEMCAD calculates this number, it needs an initial guess other than "blank."

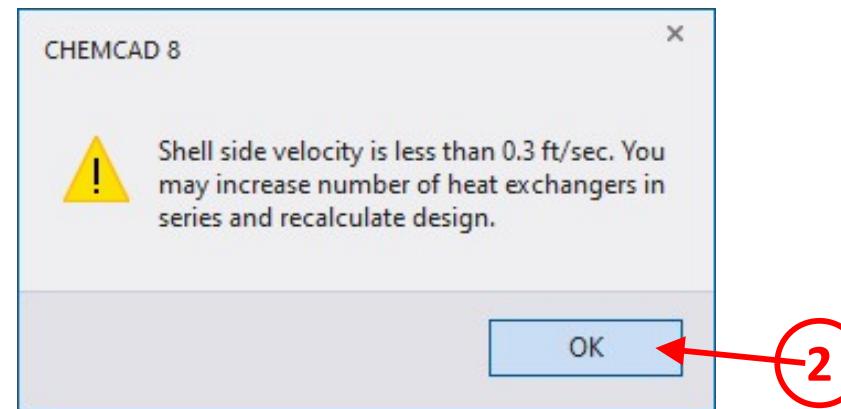
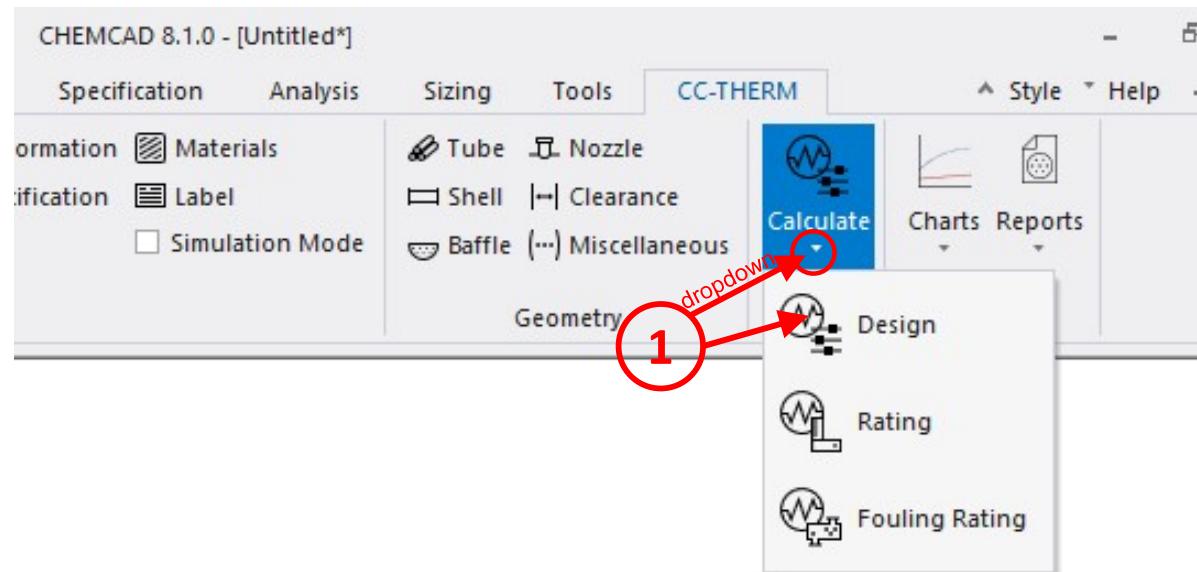
Shell Specs



Baffle Specs



Calculate: Design



TABULATED ANALYSIS

Overall Data:

Area Total	m ²	224.15	% Excess	2.72
Area Required	m ²	217.08	U Calc. W/m ² -K	19.61
Area Effective	m ²	222.98	U Service W/m ² -K	19.09
Area Per Shell	m ²	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/m ² -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
Rho V2 IN kg/m ² sec ²	1760.30	Mean Temperature C	142.50
		Press. Drop (Dirty) kPa	27.74

Low Reynolds Number.

Tube-side Data:

Film Coef. W/m ² -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	2.97
Interm. Nozzle Size m	0.00		

Resistances:

Shell-side Film	m ² -K/W	0.04073
Shell-side Fouling	m ² -K/W	0.00000
Tube Wall	m ² -K/W	0.00008
Tube-side Fouling	m ² -K/W	0.00000
Tube-side Film	m ² -K/W	0.00765
Reference Factor (Total outside area/inside area based on tube ID)		1.330

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
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Pressure Drop Distribution:

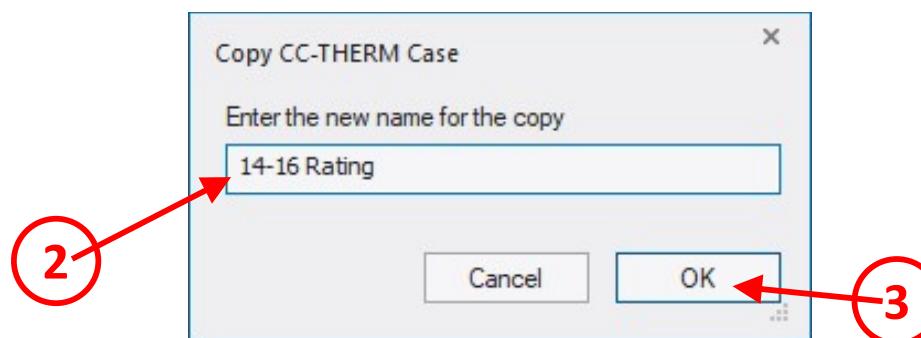
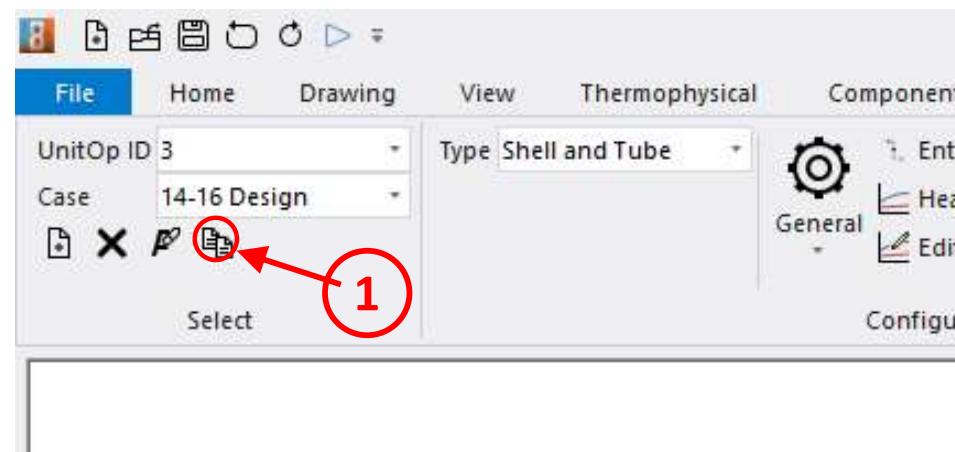
Tube Side	Shell Side		
Inlet Nozzle kPa	3.7201	Inlet Nozzle kPa	1.8239
Tube Entrance kPa	0.0389	Impingement kPa	1.1442
Tube kPa	1.0672	Bundle kPa	0.0136
Tube Exit kPa	0.0686	Outlet Nozzle kPa	2.6325
End kPa	0.0000	Total Fric. kPa	4.4700
Outlet Nozzle kPa	2.8731	Total Grav. kPa	-0.0713
Total Fric. kPa	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		

Tubes:

Number	286
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

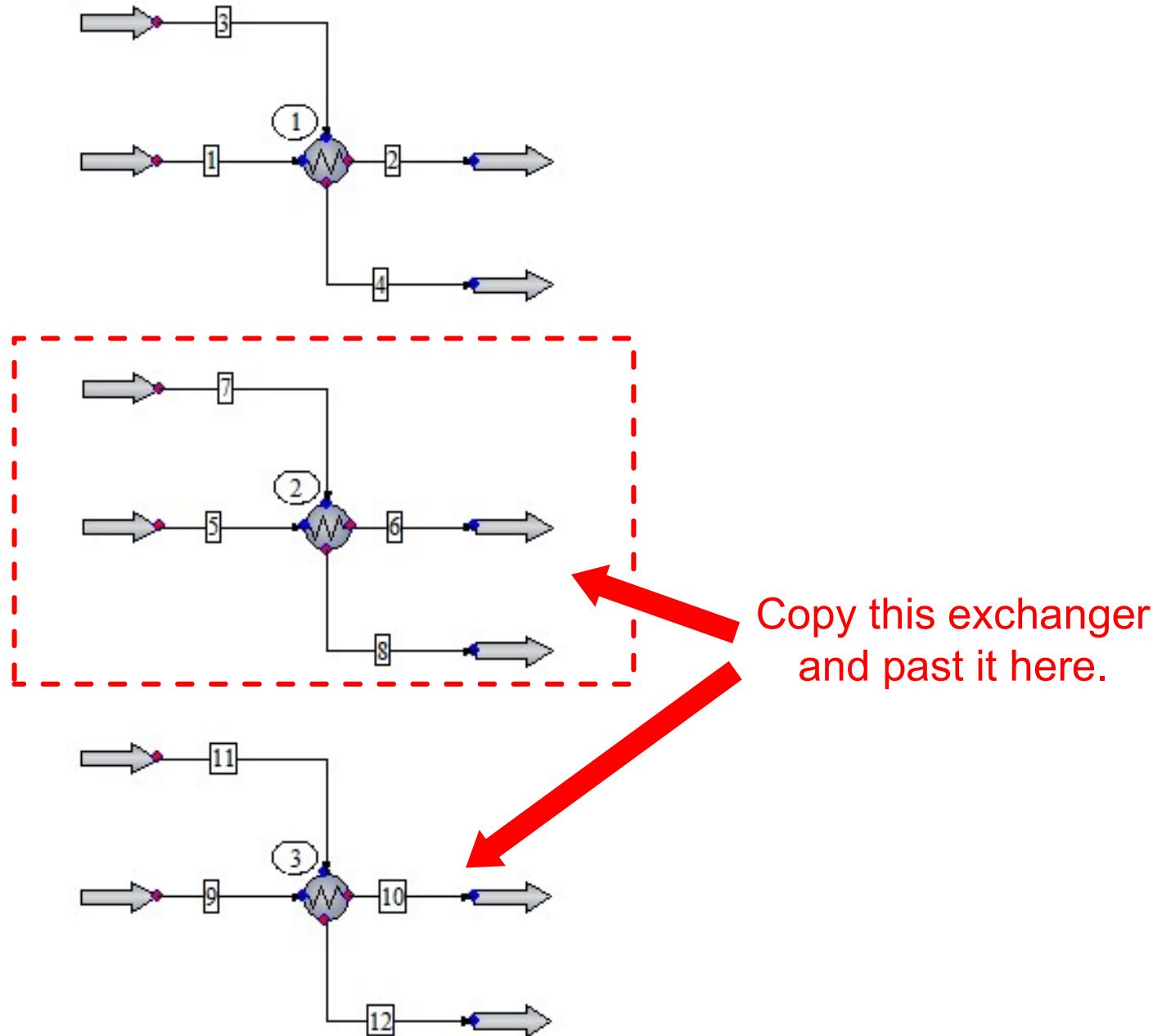
Create a Copy of Your CCTherm Design

Create a copy of your CCTherm design. This guards against loosing your work through mistakes. In the CCTherm “Select” Group -> Click “Copy CCTherm Case”



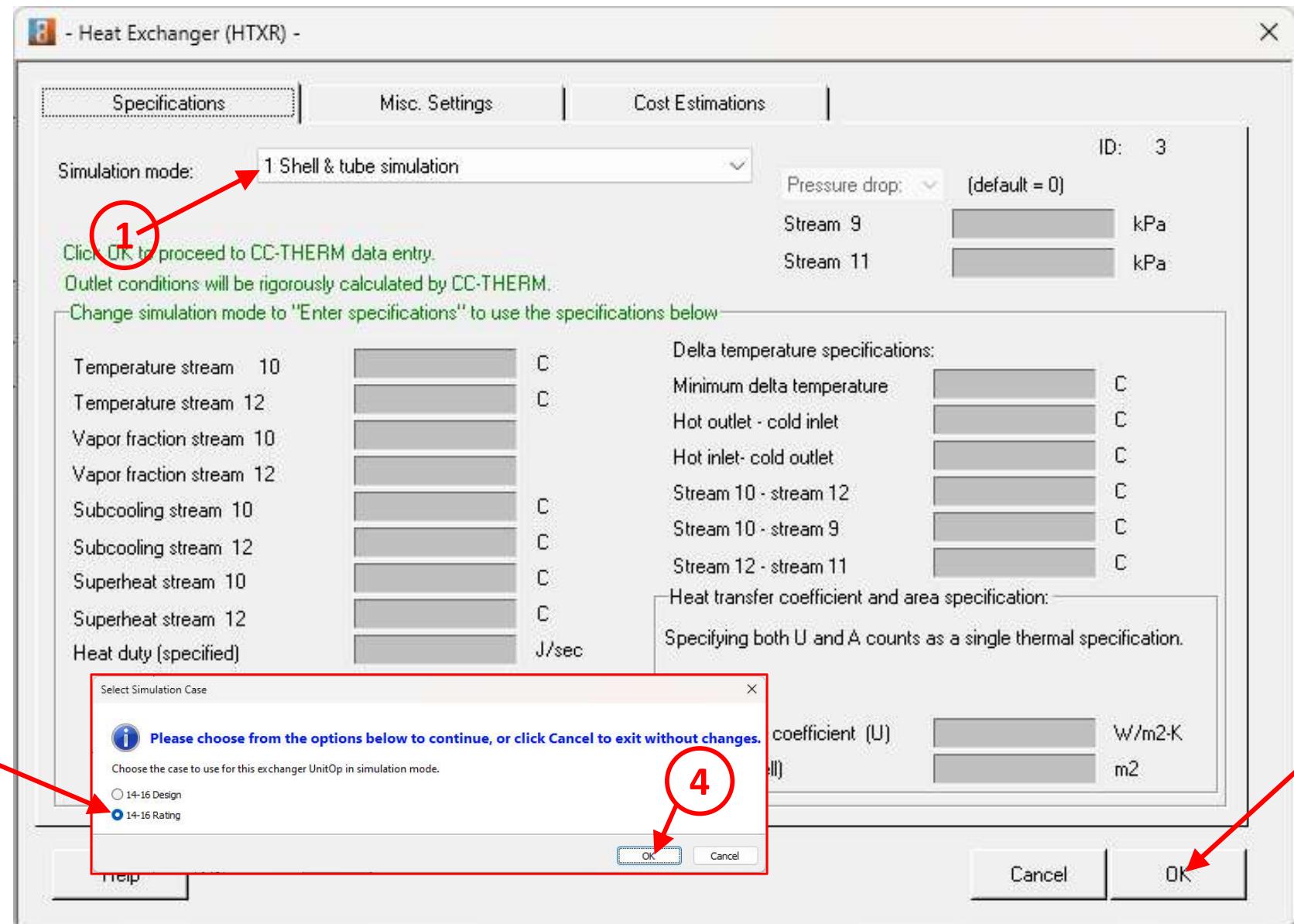
Level 3 – Shell and Tube Simulation

Copy and Paste Exchanger 2 (creating exchanger 3)



Change Mode to Simulation

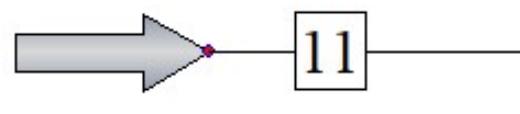
Copy and Paste Exchanger 2 (creating exchanger 3), double-click the exchanger, and change simulation mode to “1 Shell & tube simulation”



Run the Simulation

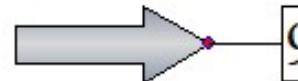
Checking results shows that outlet streams are slightly off spec based on percent excess safety factor.

ID	11
T	15.00 C
P	1020.00 kPa
W	1.90 kg/sec



Note Temperatures are close to spec but for more precise optimization, we will need to tighten these up.

ID	9
T	380.00 C
P	1020.00 kPa
W	2.64 kg/sec



3



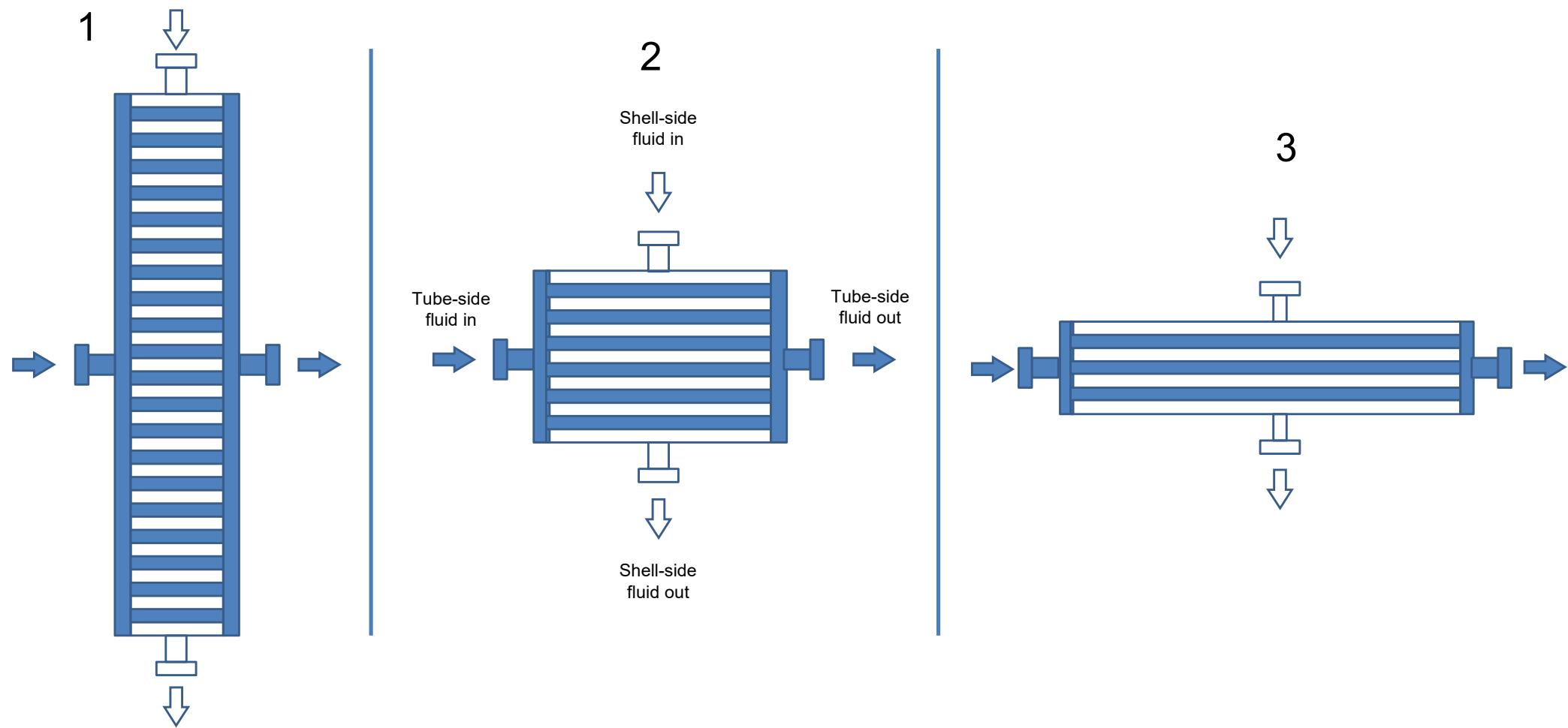
ID	10
T	198.54 C
P	1006.06 kPa
W	2.64 kg/sec



ID	12
T	272.00 C
P	1003.23 kPa
W	1.90 kg/sec

Note Outlet pressures give average pressure close to spec. Recall from problem statement that the average absolute pressure on both the tube side and the shell side is 1010 kPa.

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



This affects cost to push fluids.

Update Cost Index and Run Costing

Heat Exchanger (HTXR) -

Specifications | Misc. Settings | Cost Estimations

Activate the costing tool.

ID: 3

Run the costing report after running the unit

Cost model: Shell and tube
Exchanger type: Fixed head
Evaporator type: Forced circulation
Design pressure: kPa
Install factor: **1.15**
Material factor: **1**
Pressure factor: **1.15813**
Type factor: **0.655386**

Material selection for this model:
Shell and tube
Carbon steel

Chemical Engineering Plant Cost Index

Year/Month Selection for the Cost Index
Year: 2026
Month: February

Calculated Results

Type	Cost Index
CE Index	830.50
Equipment	1045.80
Heat exchangers and tanks	815.70
Process machinery	1057.50
Pumps and compressors	1677.10
Electrical equipment	917.90
Structural supports and misc.	1142.00
Construction labor	390.30
Buildings	835.10
Engineering and supervision	313.20

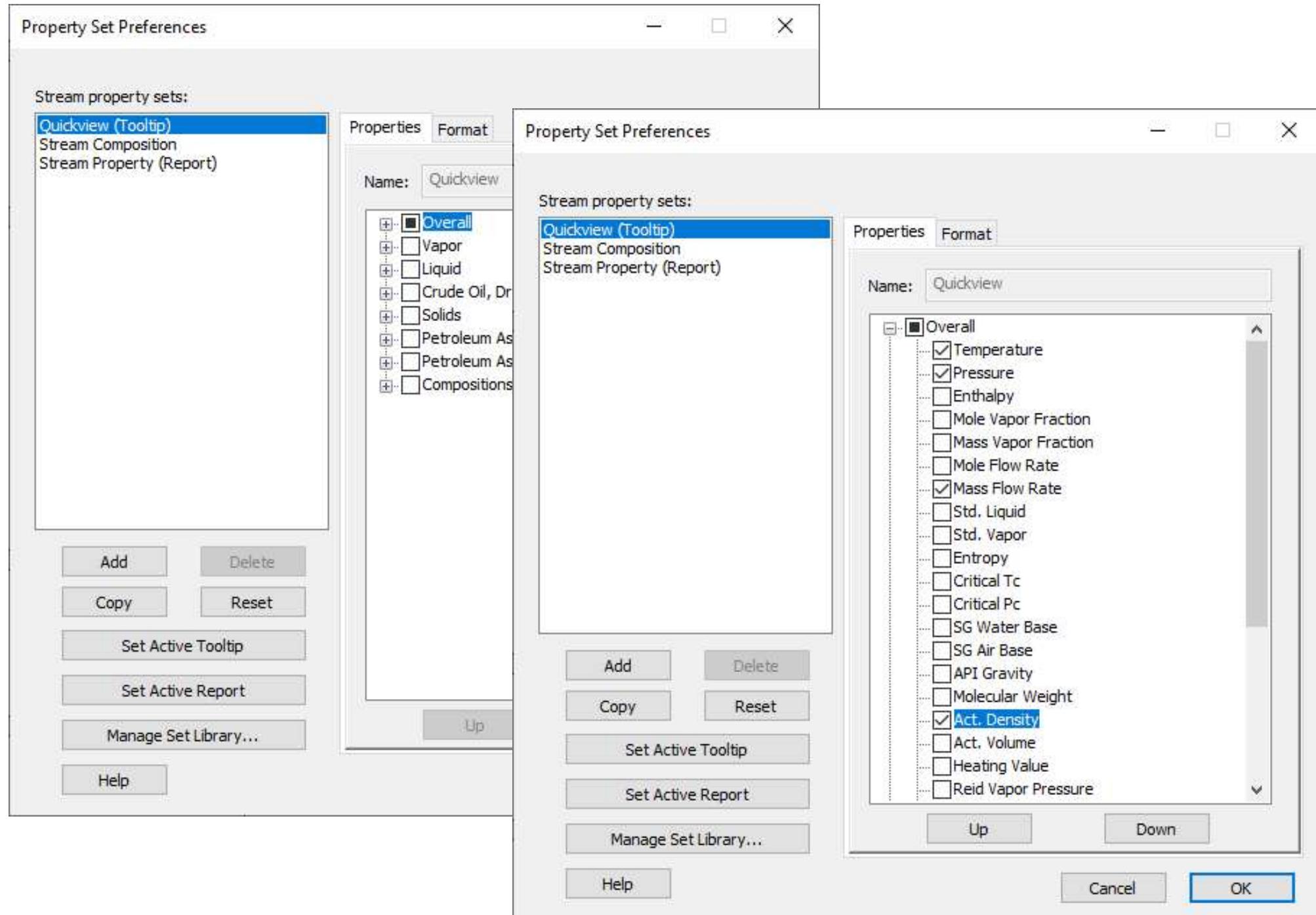
Make sure month and year are correct..

Heat exchanger index from course web site.

Add "costing_data" to CHEMCAD directory.

Cancel OK

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



mass flow rate has units of kg/s
and is volumetric flow rate
multiplied by density
 $\frac{\text{m}^3}{\text{s}} \cdot \frac{\text{kg}}{\text{m}^3} = \frac{\text{kg}}{\text{s}}$

power in watts

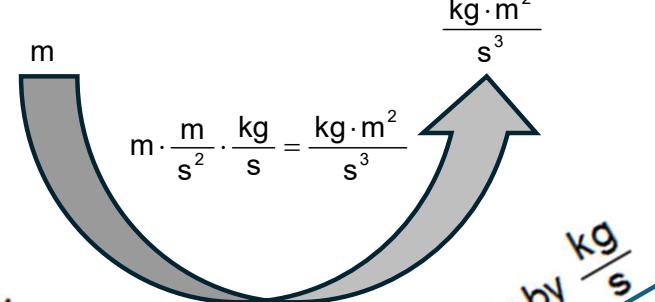
$$\frac{\text{kg} \cdot \text{m}^2}{\text{s}^3}$$

meters of head

gravitational acceleration
 $g = 9.8 \text{ m/s}^2$

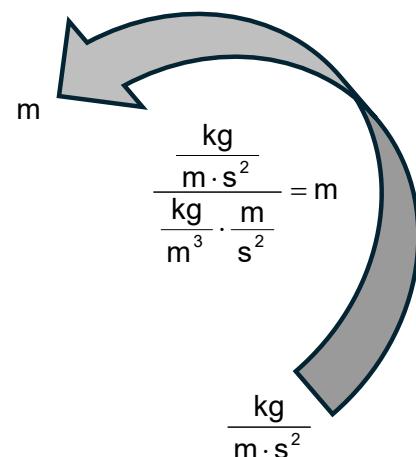
m

multiply by $\frac{\text{m}}{\text{s}^2}$
divide by $\frac{\text{m}}{\text{s}^2}$



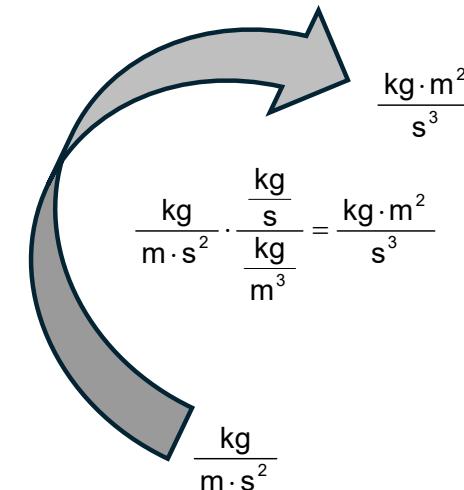
$$\frac{\text{m}^2}{\text{s}^2}$$

multiply by $\frac{\text{kg}}{\text{s}}$
divide by $\frac{\text{kg}}{\text{s}}$



divide by $\frac{\text{kg}}{\text{m}^3}$
multiply by $\frac{\text{kg}}{\text{m}^3}$

$$\frac{\text{kg}}{\text{m} \cdot \text{s}^2}$$



density ρ has
units of kg/m^3

pressure in pascals

Problem 14-16. Cadet Template**"sizing" checks are required**

Optimal 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)

Spreadsheet for evaluating Equation 14-91				"sizing" 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 outlet fluid density, CC	r _{to}	kg/m ³	7.3697	
Tube-side pressure drop, CC	D _{p<i>i</i>}	kPa	13.9405	
Tube-side average density	r _t	kg/m ³	6.3803	
Tube-side power loss per area	E _i	Nm/s per m ²	25.7402	
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 outlet fluid density, CC	r _{so}	kg/m ³	6.3576	
Shell-side pressure drop, CC	D _{p<i>o</i>}	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	\$5,537	
Shell-side pumping costs		\$/y	\$3,277	
Total annual cost	C _T	\$/y	\$25,216	

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		
Optimal 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)				
Spreadsheet for evaluating Equation 14-91		"sizing" 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 * E8 * E9	
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 outlet fluid density, CC	r _{to}	kg/m ³	7.3697	7.3697
Tube-side pressure drop, CC	D _p _i	kPa	13.9405	13.9405
Tube-side average density	r _t	kg/m ³	6.3803 = AVERAGE(E17:E18)	
Tube-side power loss per area	E _i	Nm/s per m ²	25.7402 = 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 outlet fluid density, CC	r _{so}	kg/m ³	6.3576	6.3576
Shell-side pressure drop, CC	D _p _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	\$5,537 = E21 * E14 * E28 * E29 / 1000	
Shell-side pumping costs		\$/y	\$3,277 = E27 * E14 * E28 * E29 / 1000	
Total annual cost	C _T	\$/y	\$25,216 = SUM(E32:E34)	

Good Luck!