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 v8.1 only)

WPR 1 – L12– WARNO

Date – 10 February 2025, 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.

(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.

Be prepared to apply equation 14-91.

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

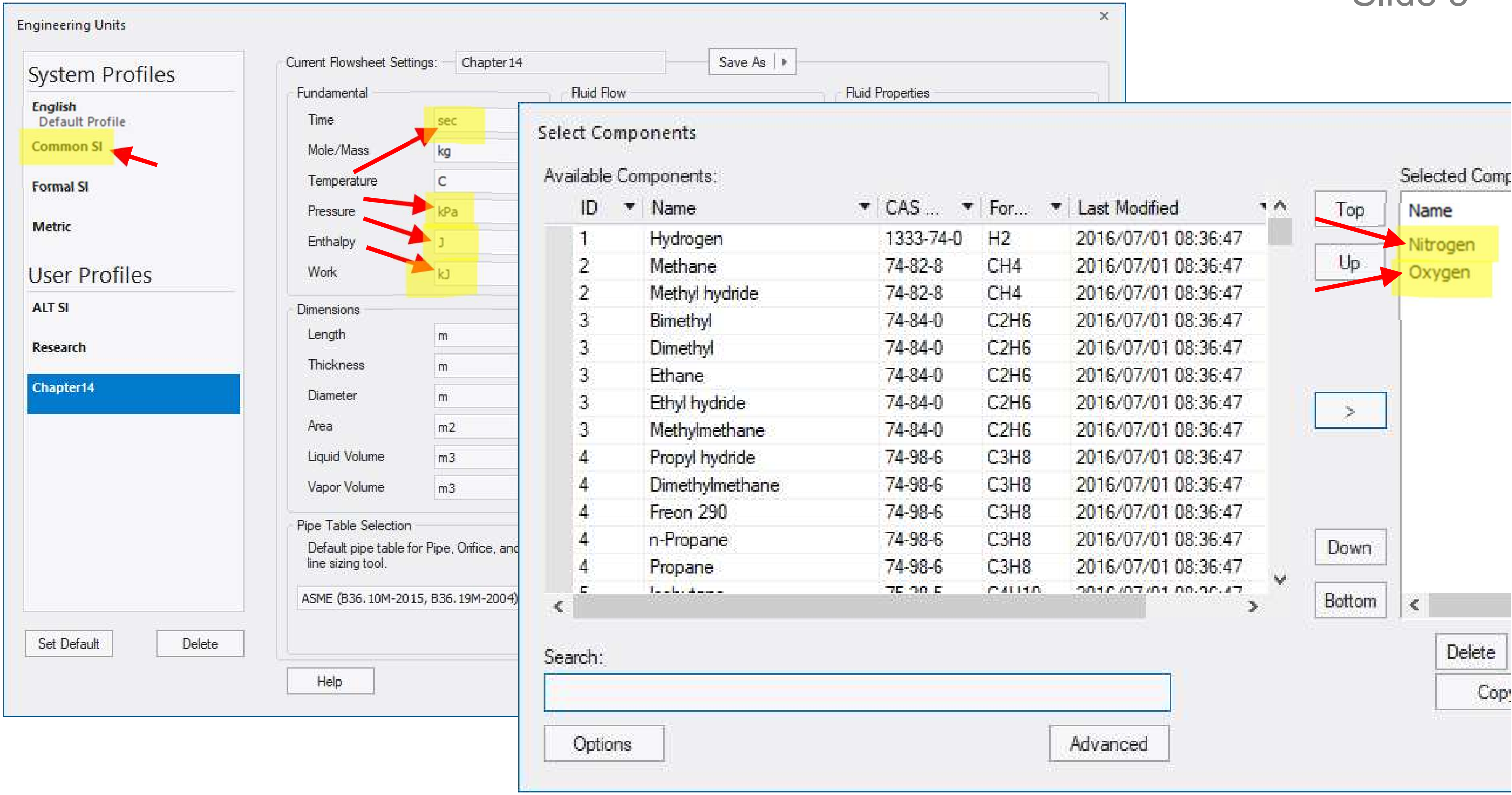
A_0 Outside tube area, m^2
K_F Annual fixed charges factor (maintenance, etc) as a fraction of installed cost, dimensionless
C_{A_0} Installed cost of the heat exchanger per unit outside tube area, dollars/m^2

$\dot{m}_u$ 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, $N \cdot m/s$ 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 case

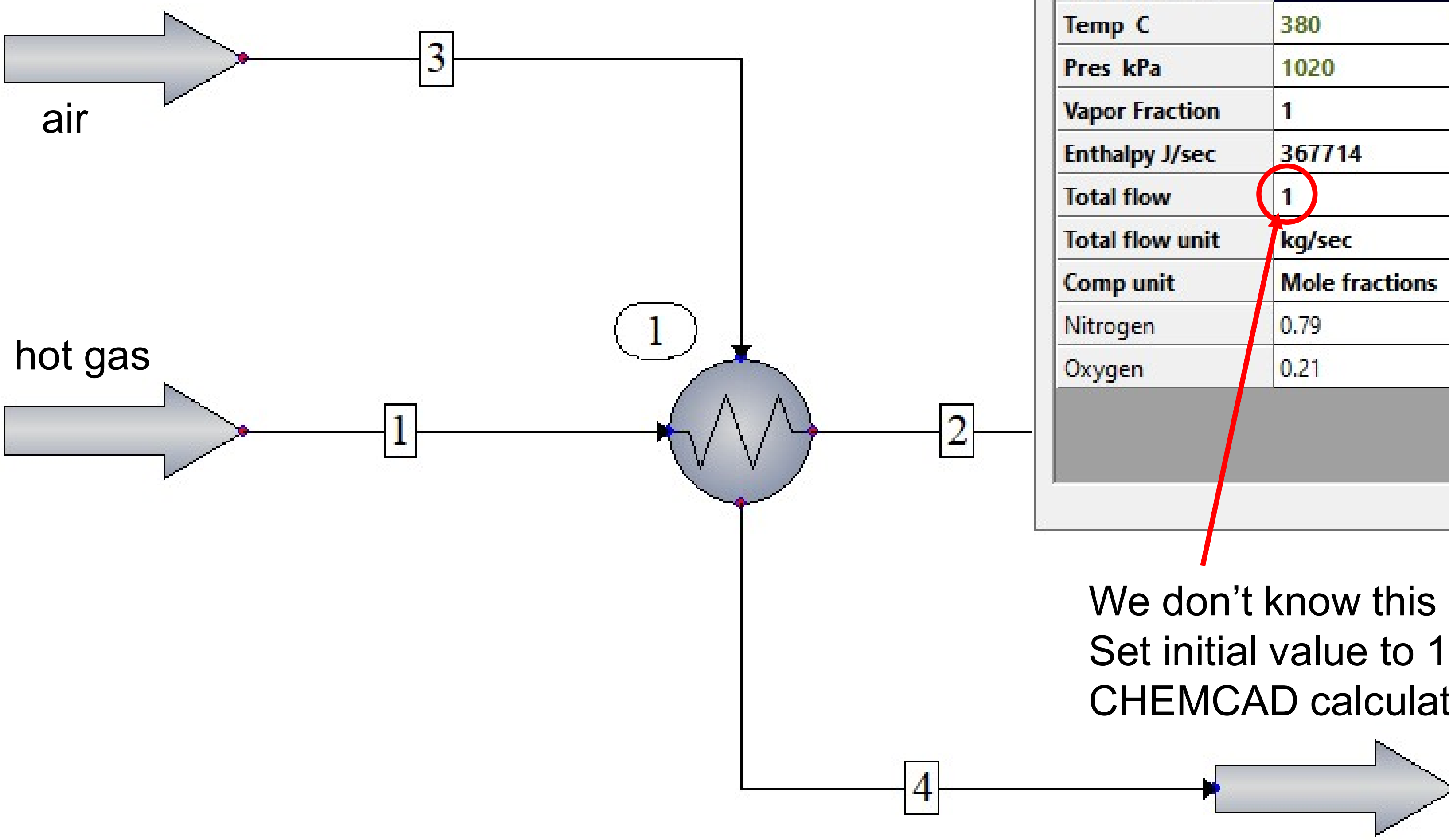


Format Engineering Units:
- Common SI
- Time – seconds
- Pressure – kPa
- Enthalpy – J
- Work – kJ

Thermophysical Select Components:
- Nitrogen and Oxygen
- (Do not use “Air”)

Thermodynamics Wizard:
- SRK for K and H

Level 1 Flowsheet



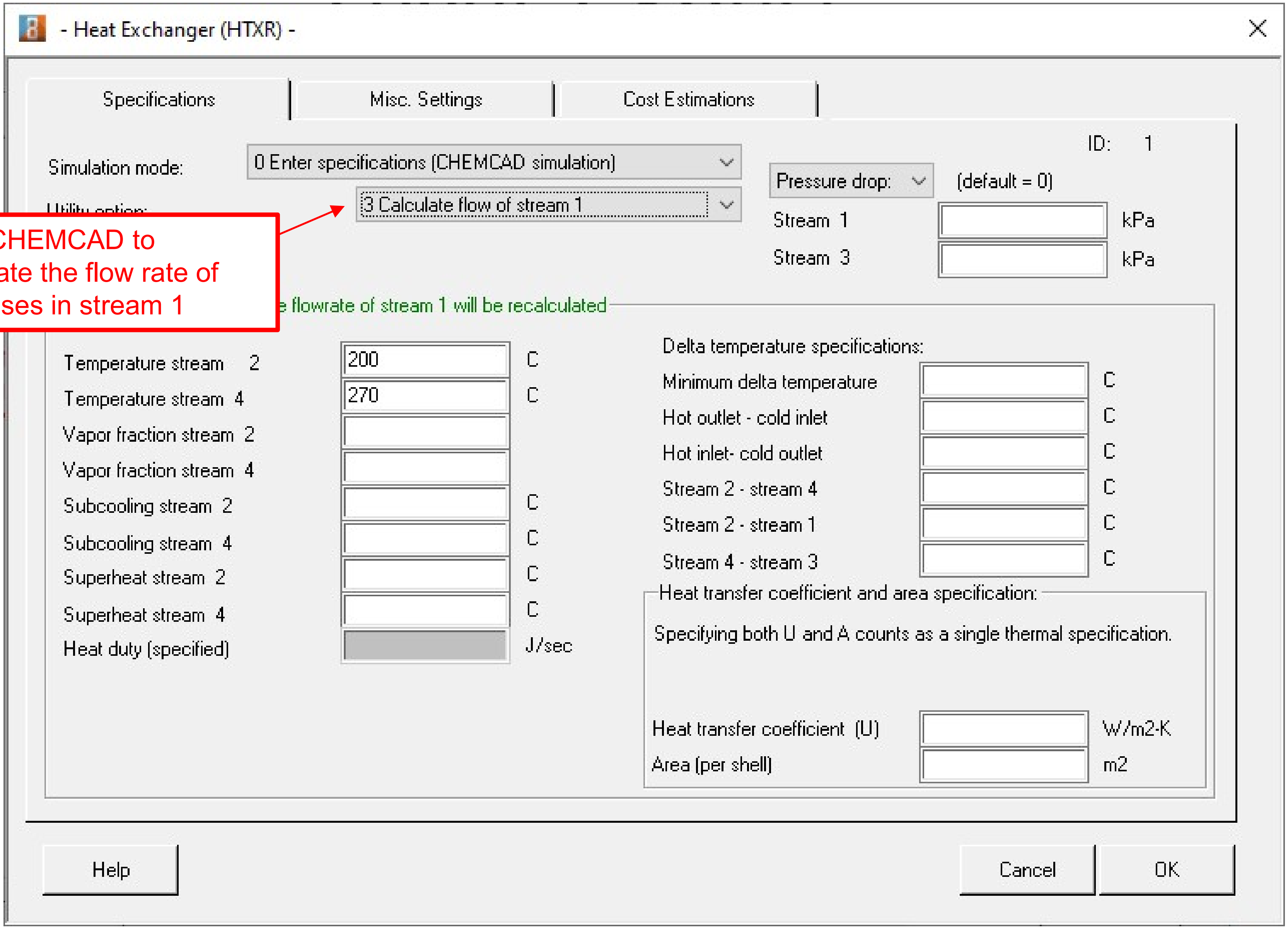
Edit Streams

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

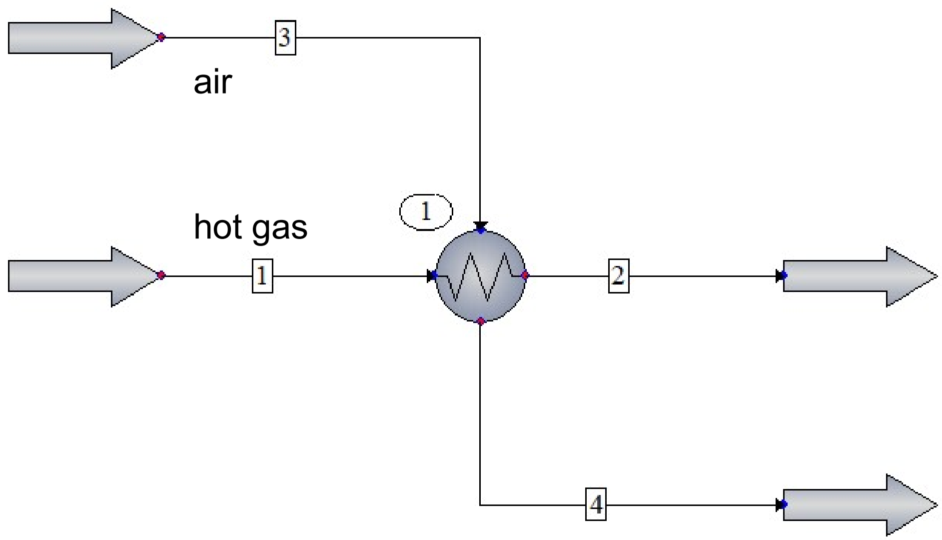


Tells CHEMCAD to calculate the flow rate of hot gases in stream 1

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.

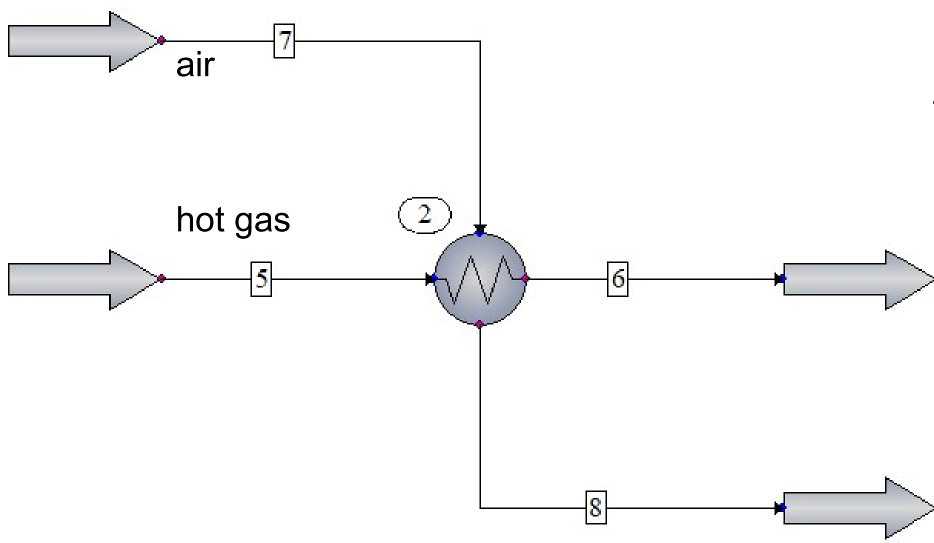
Level 2 Design

Step 1



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

Step 2 – Copy and Paste

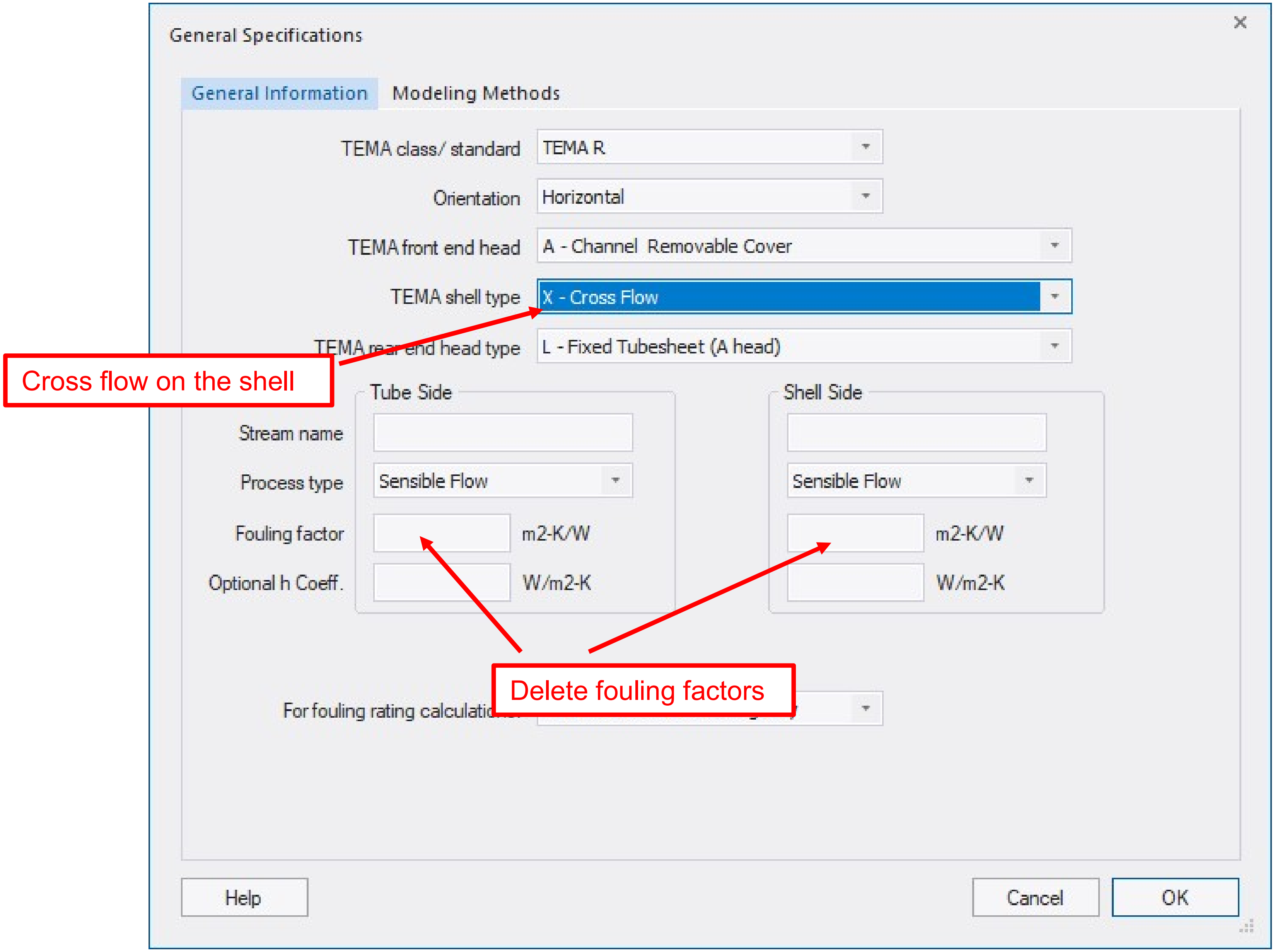


In Step 2, CHEMCAD uses mechanical details to optimize the exchanger in terms of total purchased cost.

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

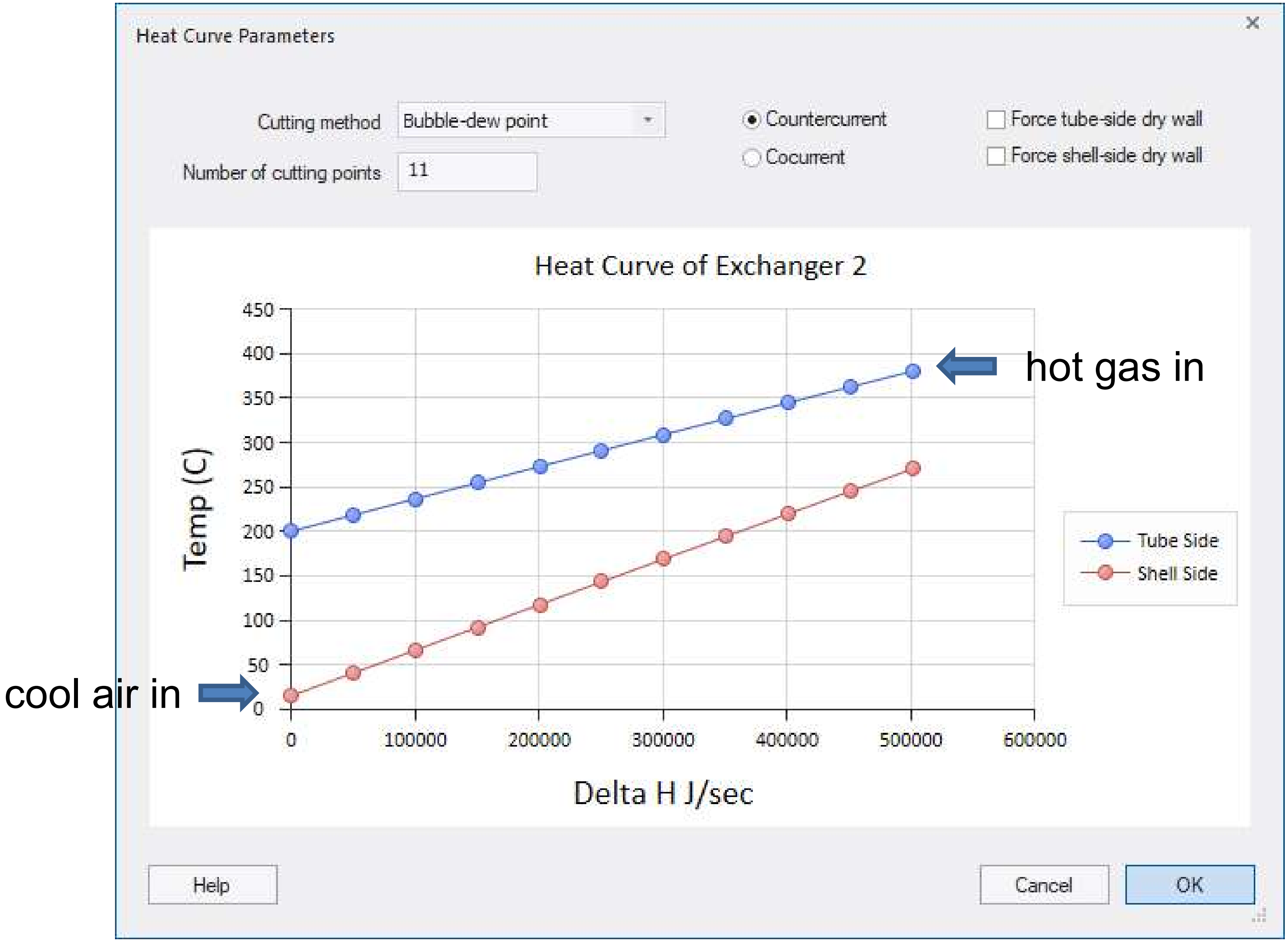
General Specs

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.

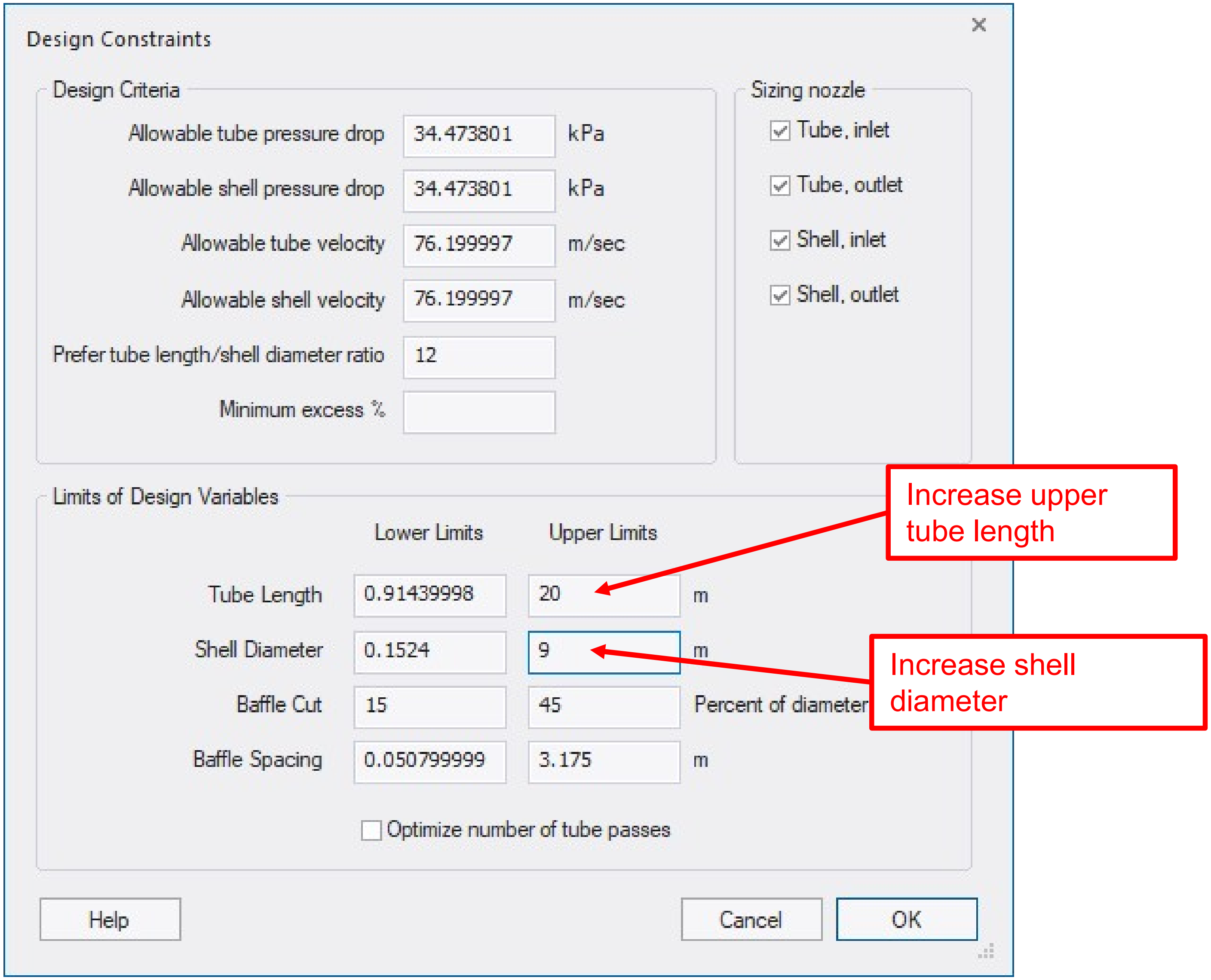


Heat Curves

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

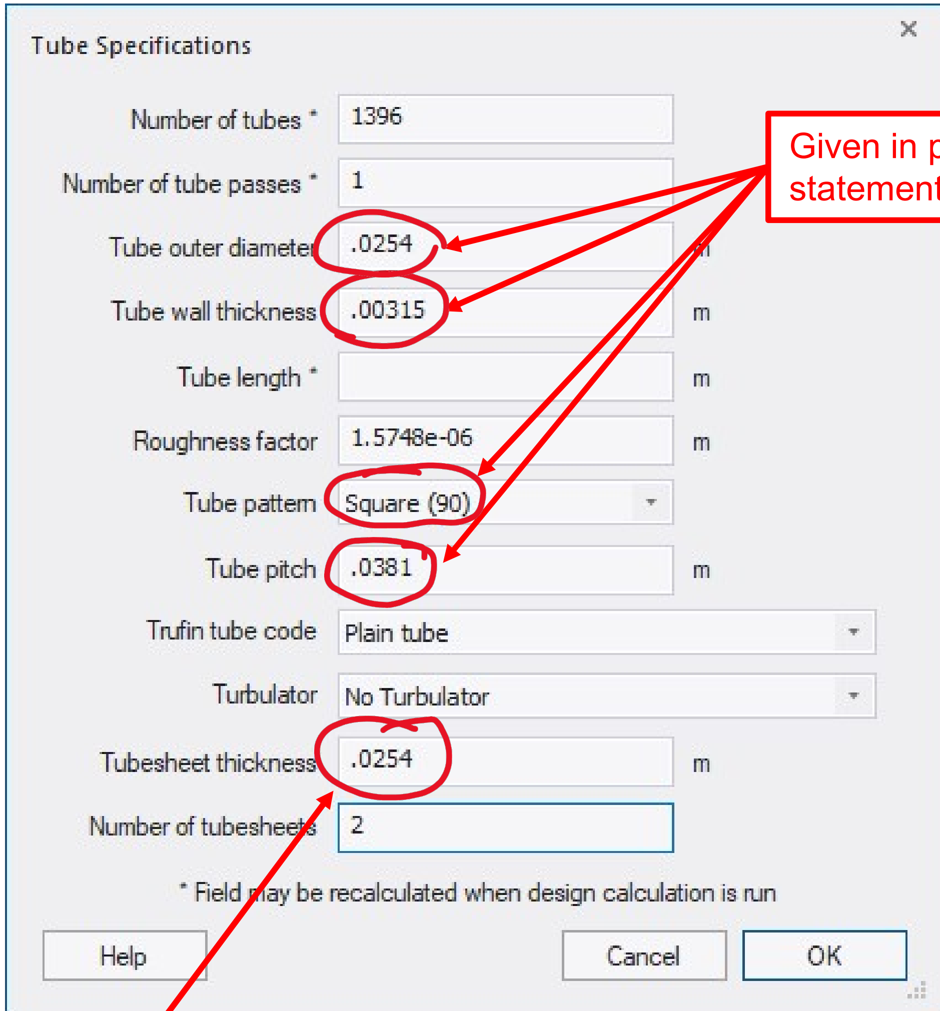


Design Constraints



CCTherm Configuration Group -> General Dropdown -> Design Constraints

Tube Specs

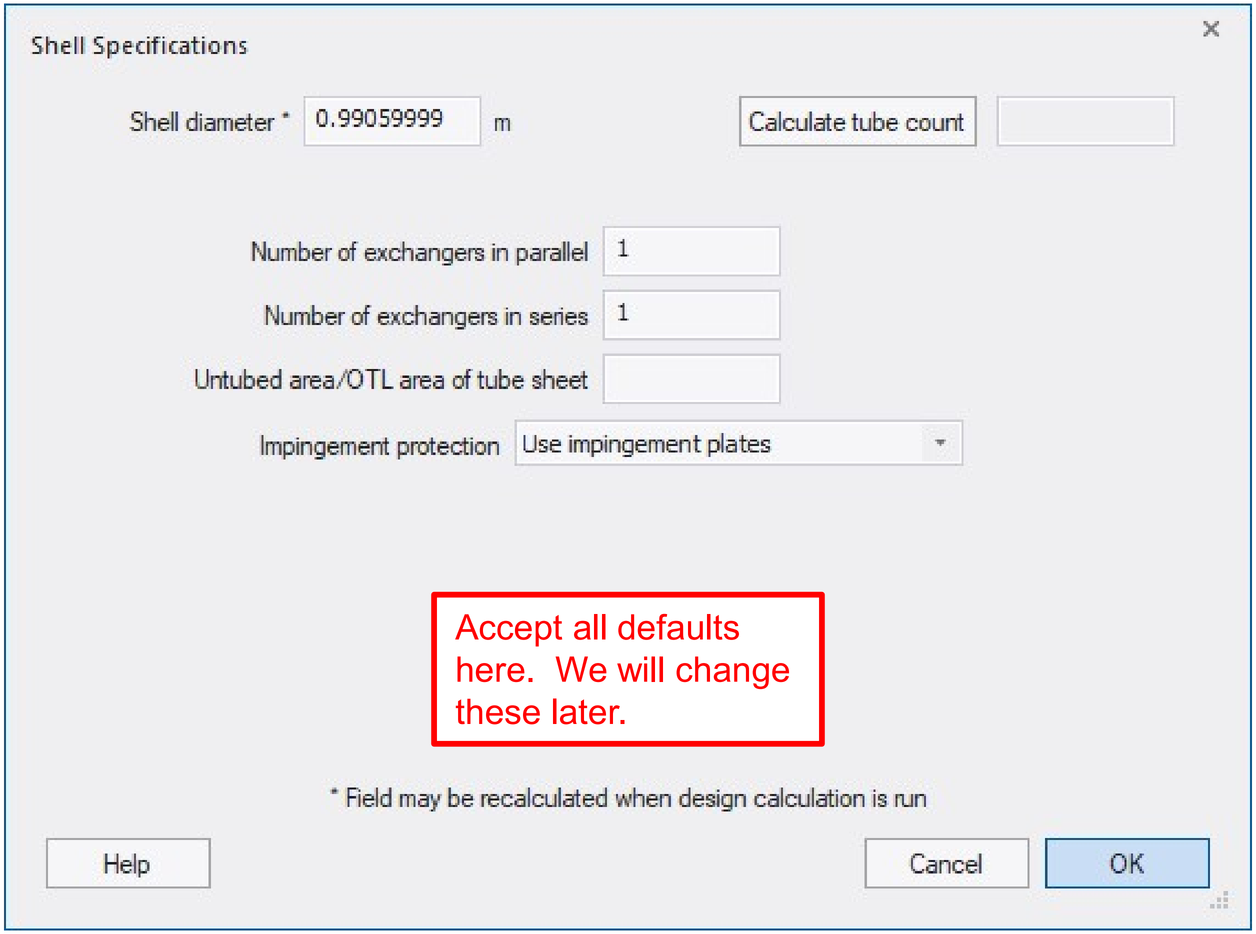


Given in problem statement

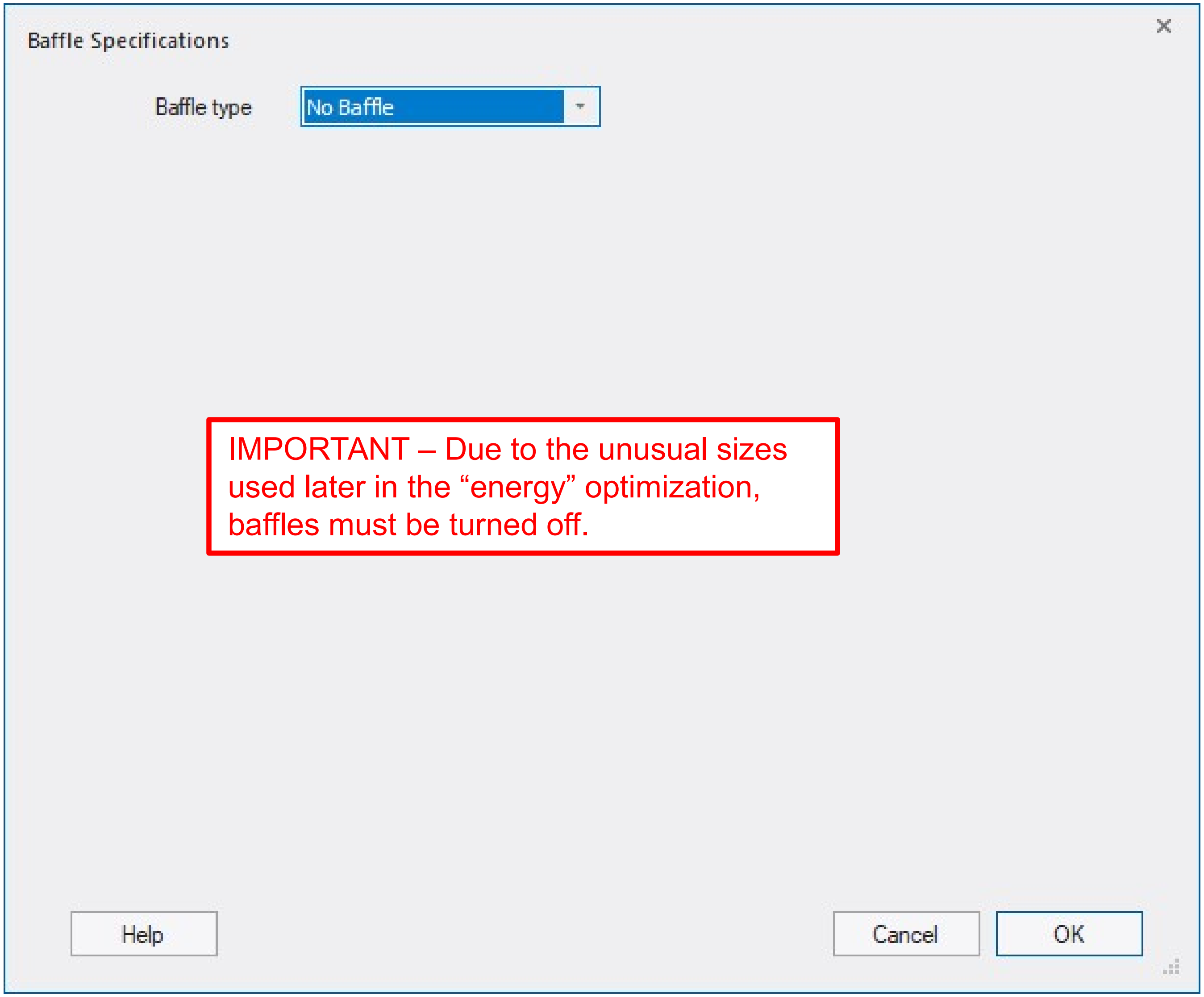
Increase tubesheet thickness to 0.0254 m

This is a TEMA spec on tubesheet thickness. Generally, it must match the tube OD.

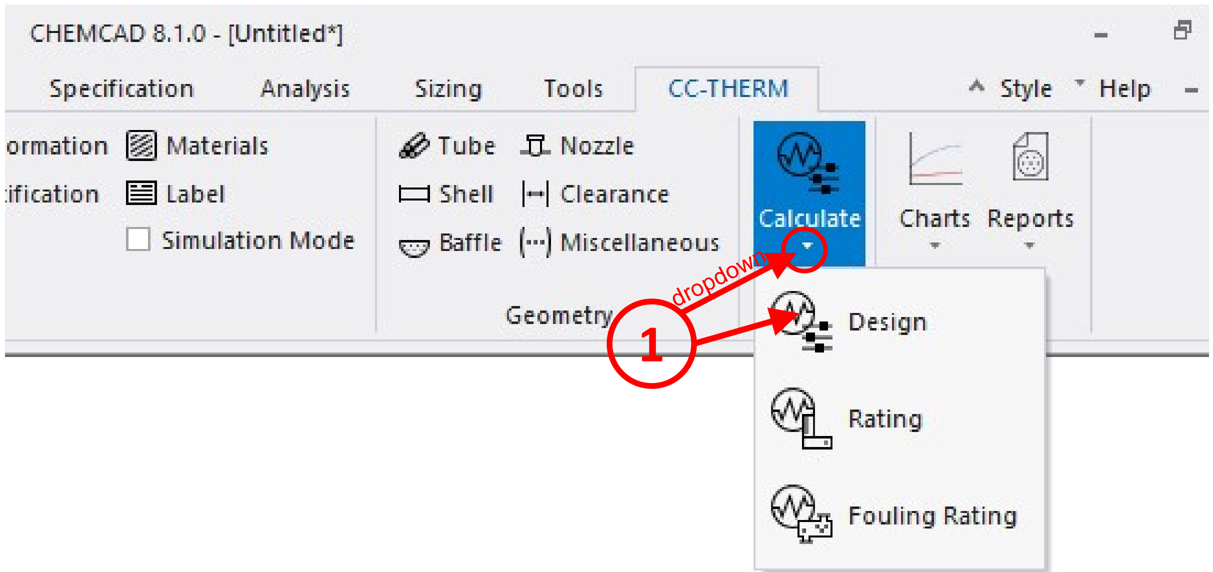
Shell Specs

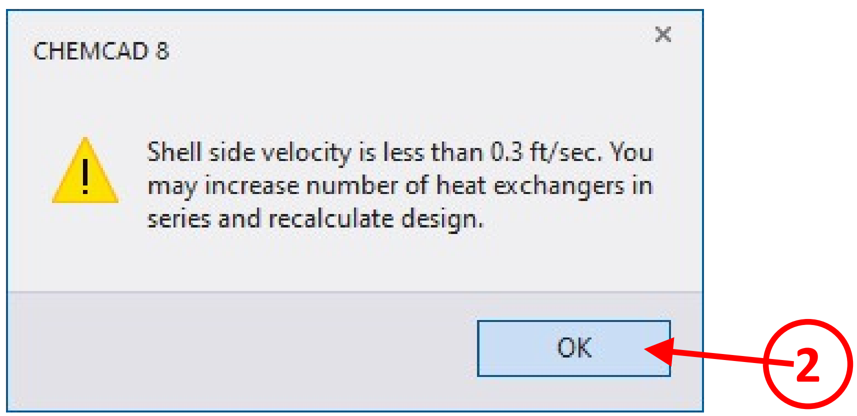

Shell Specifications
Shell diameter *
0.99059999
m
Calculate tube count
Number of exchangers in parallel
1
Number of exchangers in series
1
Untubed area/OTL area of tube sheet
Impingement protection
Use impingement plates
Accept all defaults here. We will change these later.
* Field may be recalculated when design calculation is run
Help
Cancel
OK

Baffle Specs



Calculate: Design





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                              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

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
```

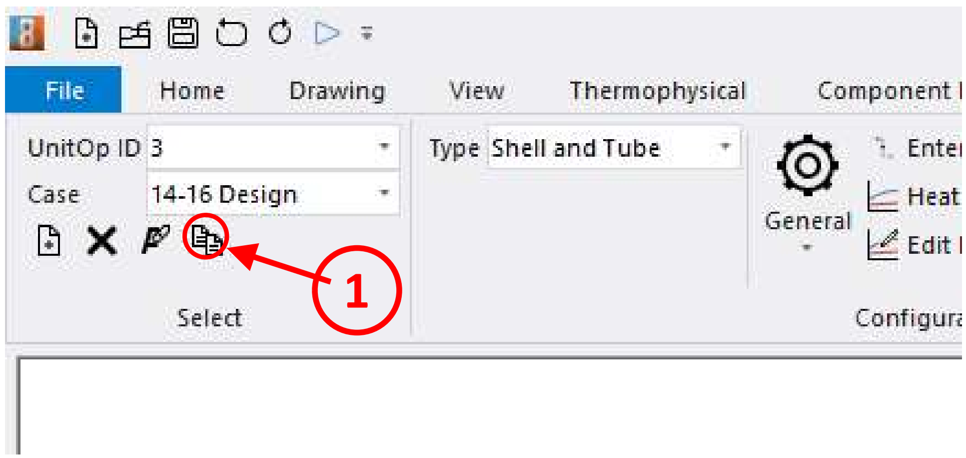
Low Reynolds Number.

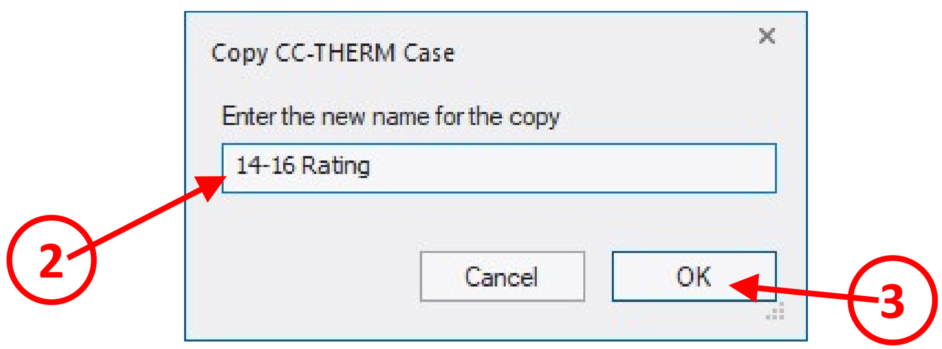
```
Resistances:
 Shell-side Film                               m2-K/W        0.04073
 Shell-side Fouling                            m2-K/W        0.00000
 Tube Wall                                     m2-K/W        0.00008
 Tube-side Fouling                             m2-K/W        0.00000
 Tube-side 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

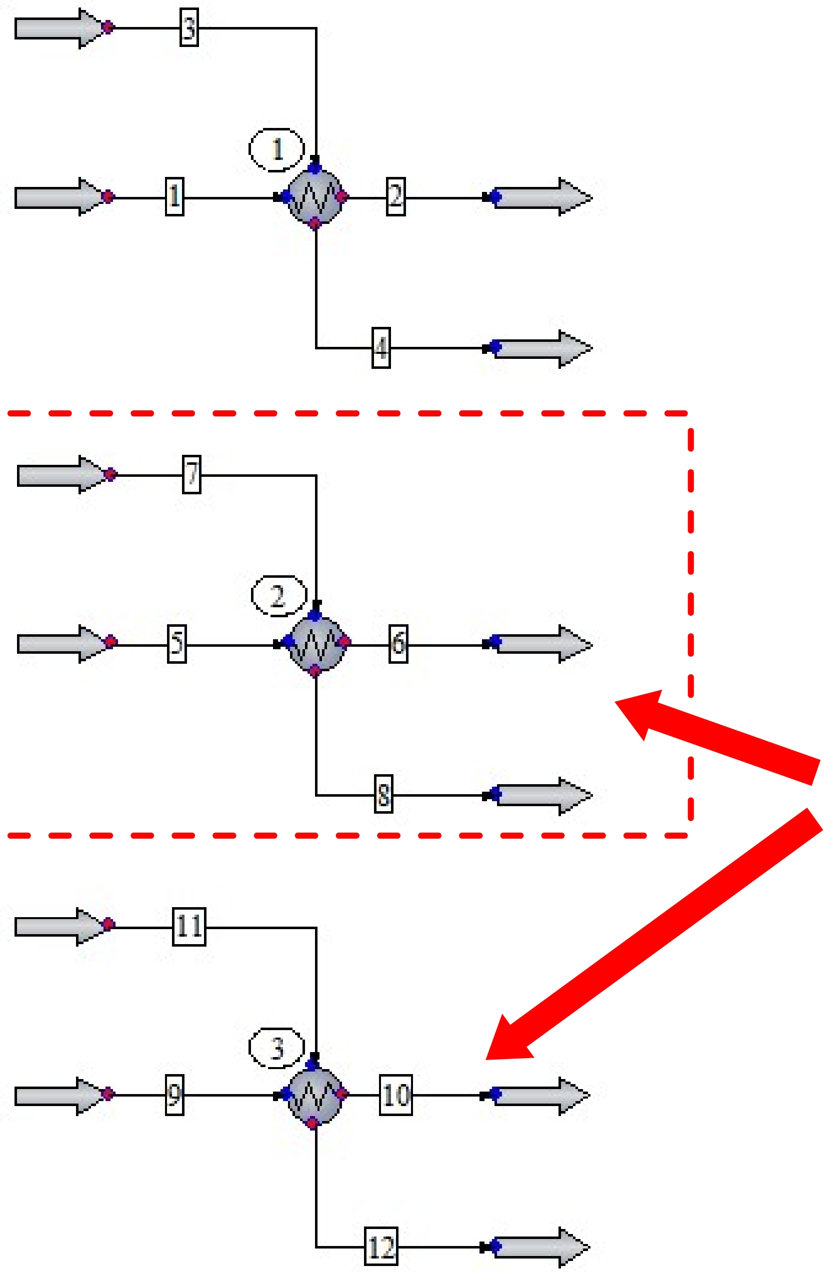
Create a copy of your CCTherm design. This guards against loosing your work through mistakes. In the CCTherm “Select” Group -> Click “Copy CCTherm Case”





Level 3 – Shell and Tube Simulation

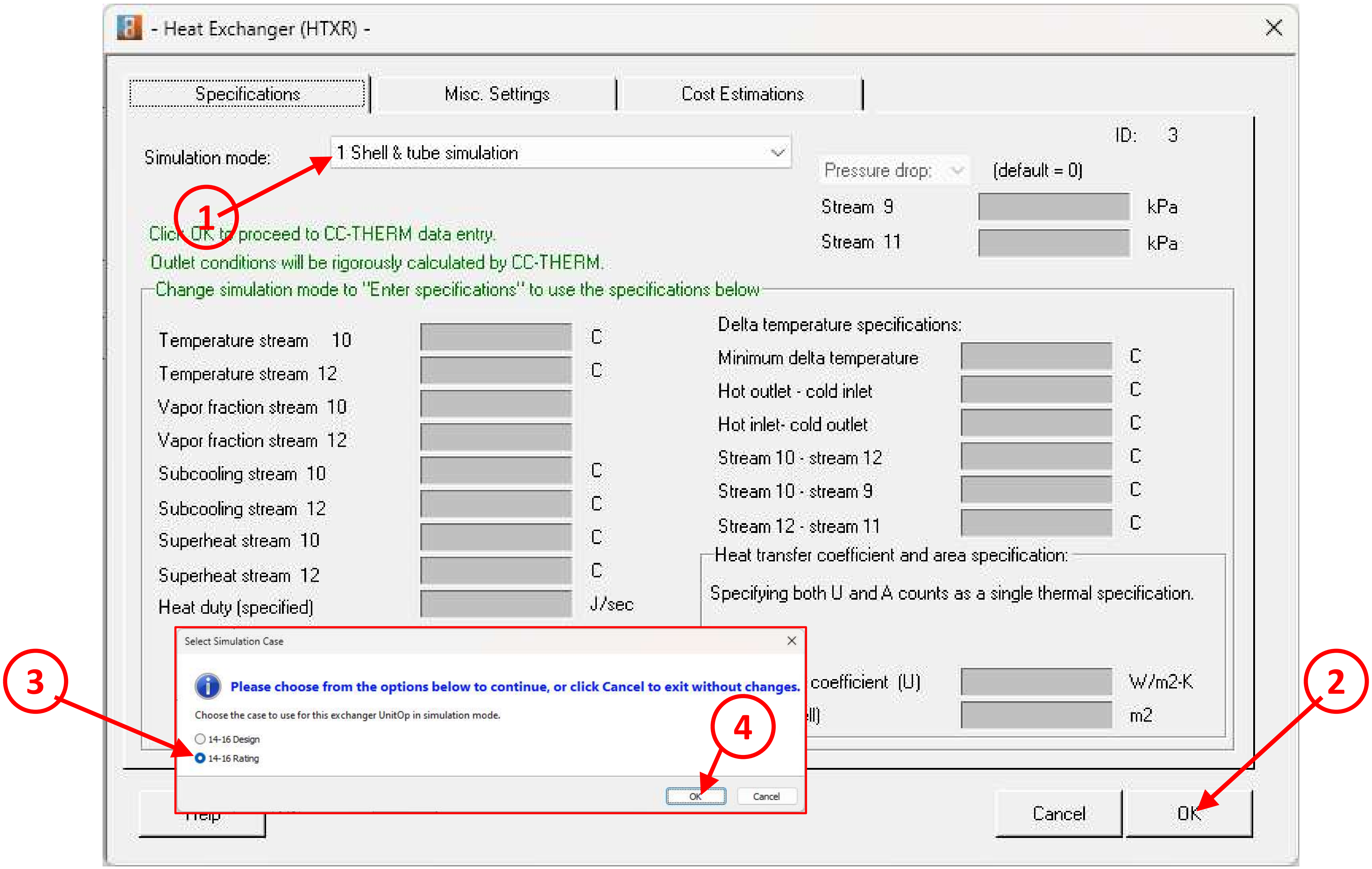
Copy and Paste Exchanger 2 (creating exchanger 3)



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”

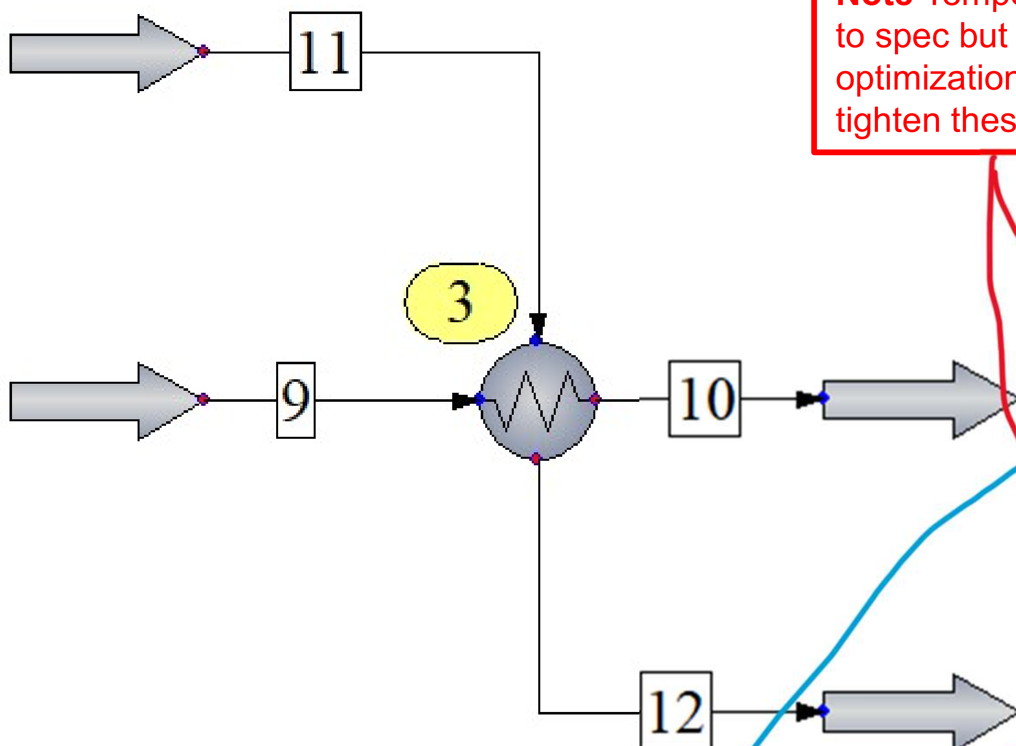


Run the Simulation

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

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

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



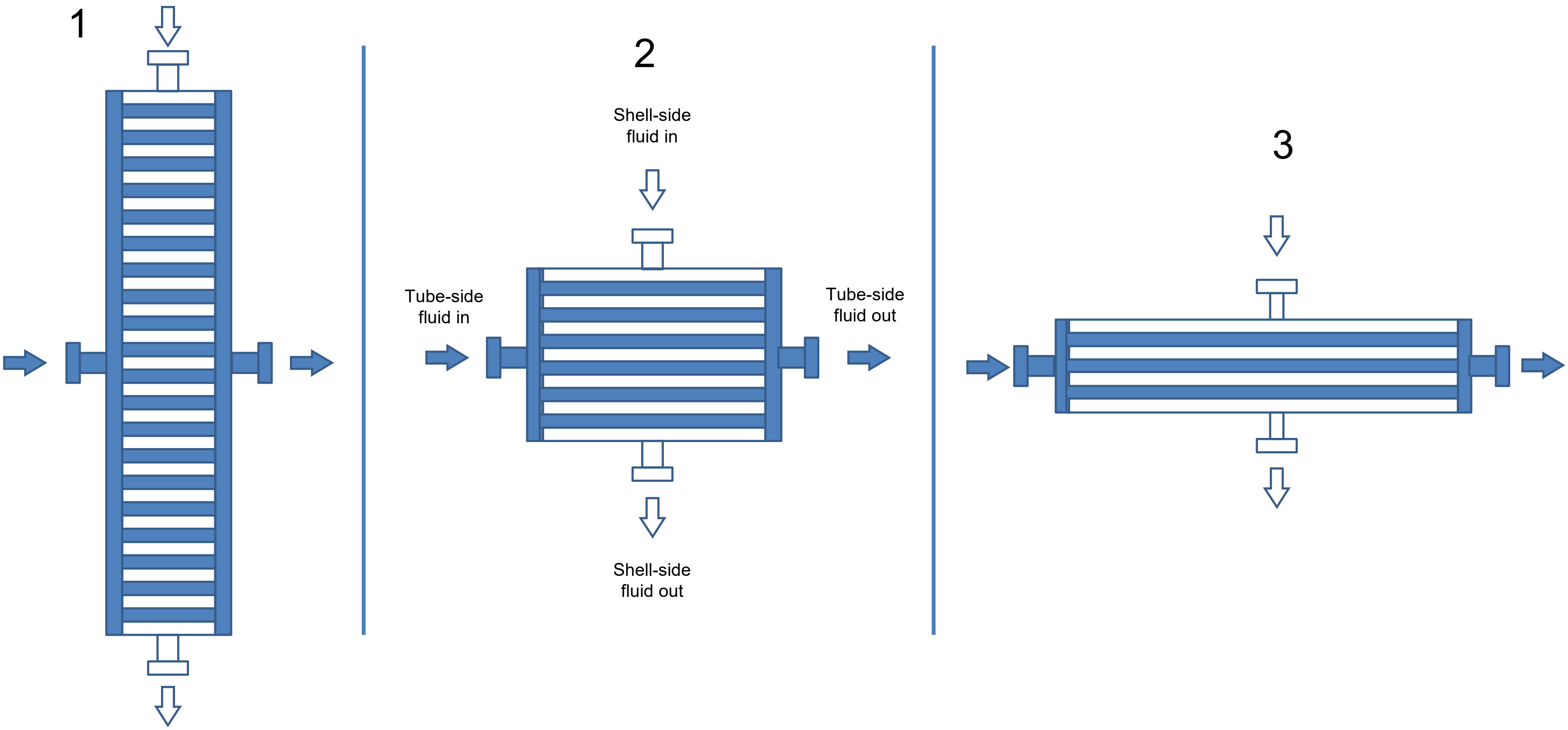
Note Temperatures are close to spec but for more precise optimization, we will need to tighten these up.

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

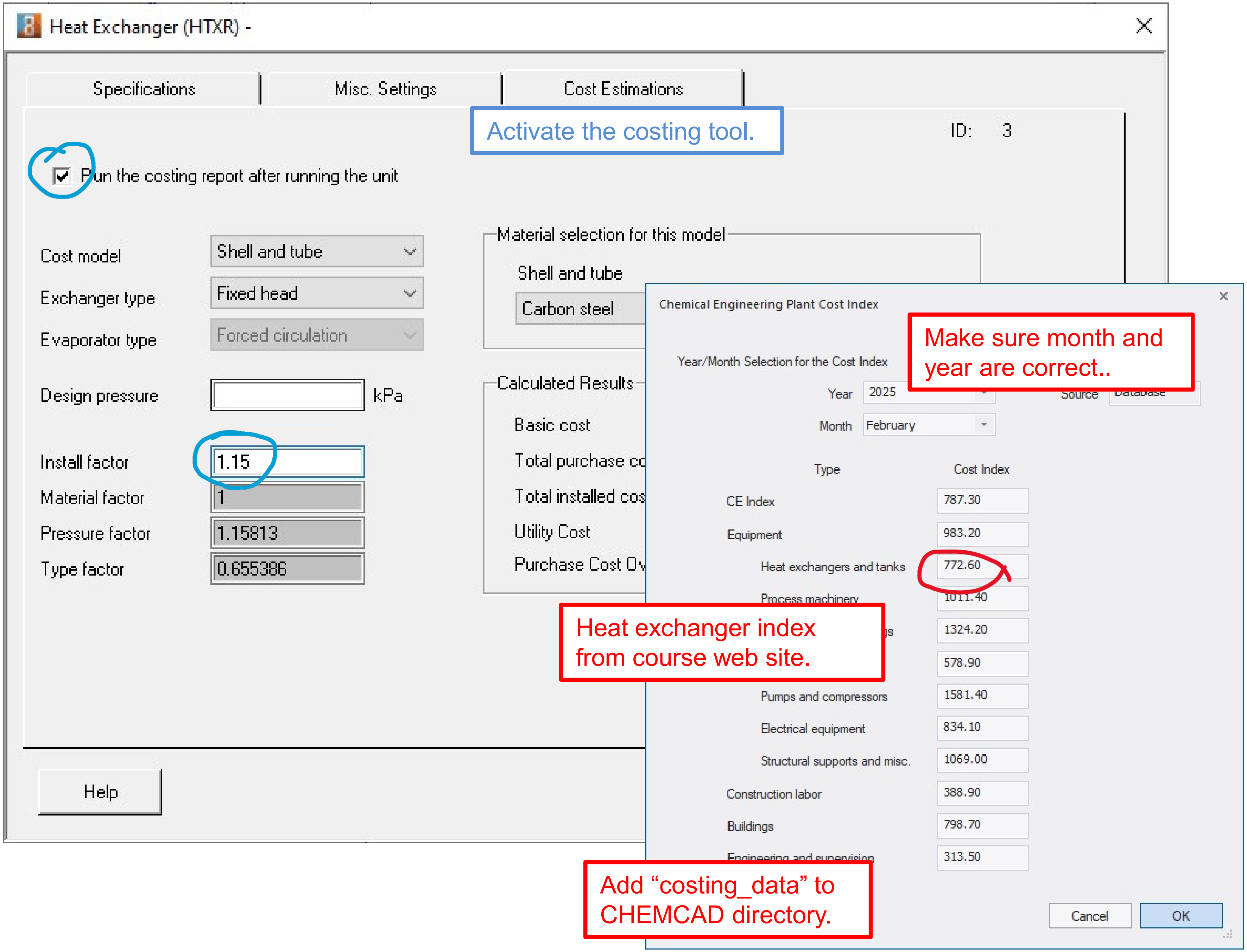
Note Outlet pressures give average pressure close to spec. Recall from problem statement that the average absolute pressure on both the tube side and the shell side is 1010 kPa.

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

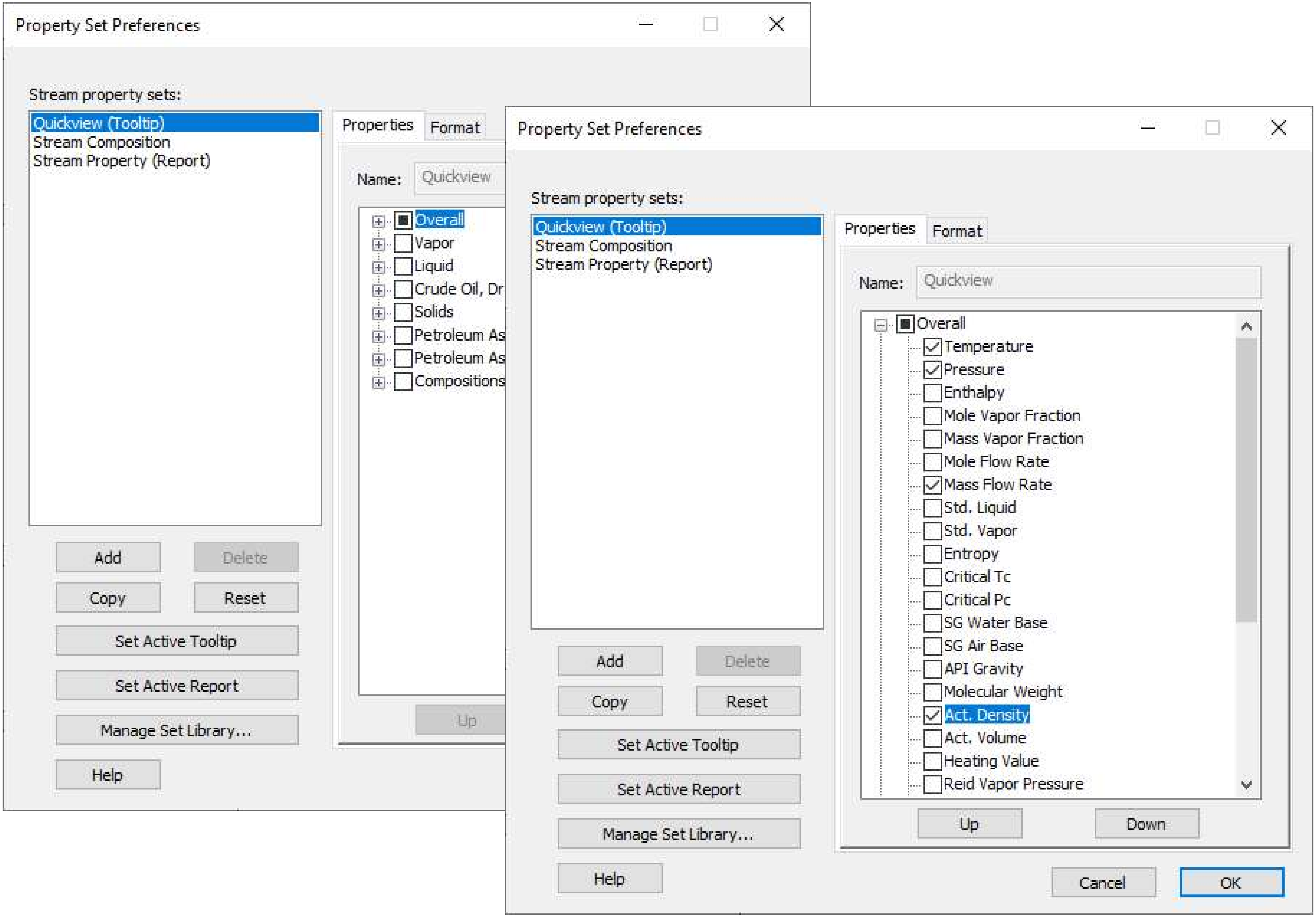


This affects cost to push fluids.

Update Cost Index and Run Costing



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



Questions?