Solvent Crossflow Heat Exchanger

User Manual

Version 2.0.0

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Revision Log

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Version 2015.03.00	03/31/2015	Initial release.
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To obtain support for the products within this package, please send an e-mail to ccsi-support@acceleratecarboncapture.org.

Solvent Crossflow Heat Exchanger

1.0 INSTALLATION REQUIREMENTS

This product requires Aspen Plus® V8.4 or newer. As such, the supported environments are limited to:

- Windows® XP SP3
- Windows Vista® Business SP2
- Windows Vista Ultimate SP2
- Windows 7 Ultimate (32- and 64-Bit)
- Windows 7 Professional (32- and 64-Bit)
- Windows 8

2.0 INTRODUCTION

The heat exchanger model can be used to optimize the size of the heat exchangers and their log-mean temperature difference (LMTD) to minimize capital and operating expenses. The model consists of the "HeatCalc.bkp" file. This manual was written using Aspen Plus V8.4.

2.1 Features List

This product sizes a non-flashing plate and frame heat exchanger for amine scrubbing. As this product consists of a calculator block and an optimization block, it does not interfere with convergence of the flowsheet. In addition to exchanger size, many other quantities of interest are reported, such as pressure drop, flow length, and velocity.

3.0 TUTORIAL

This tutorial assumes basic knowledge of the Aspen Plus software. Consult the Aspen Plus documentation **"Getting Started Building and Running a Process Model"** for additional information.

The provided file is a template. This tutorial will explain how to cut and paste the necessary components into an existing process simulation, herein referred to as "the destination file."

3.1 Setup: Property Sets

The heat exchanger calculator block depends on property sets. These need to be verified as present with the correct units.

1. Open the “HeatCalc.bkp” file.
2. In the navigation pane, navigate to “Analysis” → “EXPROP” → “Results.” The results should be like Table 25.
3. Confirm that the units match for the property sets by navigating to “Property Sets,” clicking each “Property Set” listed in Table 26, and then checking the value in the “Units” column.
4. In the “HeatCalc.bkp” file, navigate to “Property Sets,” and then select all.
5. Click “Copy.”
6. In the destination file, navigate to “Property Sets” and then click “Paste.”

Table 1: EXPROP Results

TEMP K	MOLEFLOW MEA kmol/sec	MOLEFLOW CO2 kmol/sec	LIQUID KMX Watt/m-K	LIQUID CPMX J/kg-K	LIQUID MUMX Pa-sec	LIQUID RHOMX kg/cum	VAPOR RHOMX kg/cum	LIQUID SIGMAMX N/m
313	7	3.15	5.54E-01	3.11E+03	1.57E-03	1.10E+03	4.96E-02	7.07E-02
313	7	3.85	6.02E-01	3.01E+03	1.62E-03	1.13E+03	2.98E-01	7.43E-02
323	7	3.15	5.61E-01	3.12E+03	1.29E-03	1.10E+03	8.30E-02	6.90E-02
323	7	3.85	6.07E-01	3.03E+03	1.33E-03	1.12E+03	5.45E-01	7.24E-02
333	7	3.15	5.66E-01	3.13E+03	1.09E-03	1.09E+03	1.36E-01	6.73E-02
333	7	3.85	6.09E-01	3.04E+03	1.12E-03	1.12E+03	9.70E-01	7.06E-02
343	7	3.15	5.69E-01	3.14E+03	9.27E-04	1.08E+03	2.23E-01	6.56E-02
343	7	3.85	6.07E-01	3.05E+03	9.59E-04	1.11E+03	1.69E+00	6.87E-02
353	7	3.15	5.71E-01	3.16E+03	8.02E-04	1.07E+03	3.64E-01	6.39E-02
353	7	3.85	5.99E-01	3.07E+03	8.30E-04	1.10E+03	2.85E+00	6.68E-02
363	7	3.15	5.71E-01	3.18E+03	7.04E-04	1.06E+03	6.02E-01	6.22E-02
363	7	3.85	5.84E-01	3.09E+03	7.27E-04	1.09E+03	4.67E+00	6.50E-02
373	7	3.15	5.68E-01	3.20E+03	6.24E-04	1.06E+03	1.01E+00	6.05E-02
373	7	3.85	5.63E-01	3.11E+03	6.43E-04	1.08E+03	7.41E+00	6.30E-02
383	7	3.15	5.62E-01	3.22E+03	5.60E-04	1.05E+03	1.72E+00	5.87E-02
383	7	3.85	5.36E-01	3.14E+03	5.73E-04	1.07E+03	1.13E+01	6.11E-02
393	7	3.15	5.50E-01	3.24E+03	5.06E-04	1.04E+03	2.95E+00	5.70E-02
393	7	3.85	5.04E-01	3.17E+03	5.14E-04	1.05E+03	1.67E+01	5.91E-02
403	7	3.15	5.33E-01	3.28E+03	4.60E-04	1.03E+03	5.04E+00	5.52E-02
403	7	3.85	4.69E-01	3.20E+03	4.63E-04	1.04E+03	2.37E+01	5.70E-02
413	7	3.15	5.08E-01	3.31E+03	4.20E-04	1.02E+03	8.41E+00	5.33E-02
413	7	3.85	4.34E-01	3.24E+03	4.18E-04	1.03E+03	3.23E+01	5.49E-02

TEMP K	MOLEFLOW MEA kmol/sec	MOLEFLOW CO2 kmol/sec	LIQUID KMX Watt/m-K	LIQUID CPMX J/kg-K	LIQUID MUMX Pa-sec	LIQUID RHOMX kg/cum	VAPOR RHOMX kg/cum	LIQUID SIGMAMX N/m
423	7	3.15	4.75E-01	3.36E+03	3.85E-04	1.00E+03	1.35E+01	5.14E-02
423	7	3.85	3.99E-01	3.29E+03	3.79E-04	1.01E+03	4.27E+01	5.28E-02

Table 2: Property Sets

Name	Physical Properties	Units	Qualifiers
CONDUC-L	KMX	Watt/m-K	Phase=Liquid
CPMX	CPMX	J/kg-K	Phase=Liquid
MDOT-V	MASSFLMX	kg/sec	Phase=Vapor
MU-L	MUMX	Pa-sec	Phase=Liquid
MU-V	MUMX	Pa-sec	Phase=Vapor
RHO-L	RHOMX	kg/cum	Phase=Liquid
RHO-V	RHOMX	kg/cum	Phase=Vapor
SURFT	SIGMAMX	N/m	Phase=Liquid

3.2 Setup: Flowsheet

Before moving the calculator blocks, the template streams must be renamed to the destination stream names.

1. Click the "Main Flowsheet" tab at the top to view the flowsheet of Figure 64.

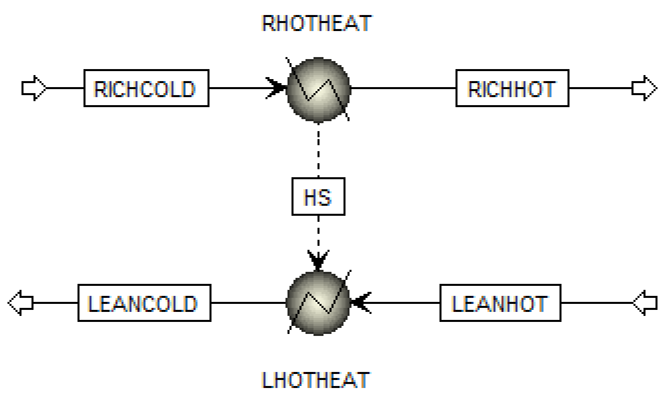

Figure 1: Linked heater blocks.

2. Rename the heat and material streams by right-clicking and selecting "Rename" to match the corresponding stream names of the destination flowsheet.
3. Navigate to "Flowsheeting Options" → "Calculator" → "C-HX" → "Results," and then select the "Define Variable" tab. Verify that the results are similar to those of Table 27. If not, check the Property Set Units.

Table 3: C-HX Results

Variable	Value Written	Description	Units
EXCAP	4.38E-01	exchanger CAPEX	\$/tonne CO_2
RPUMPOP	6.83E-02	rich pump CAPEX	\$/tonne CO_2
RPUMPCAP	3.58E-02	rich pump OPEX	\$/tonne CO_2
TAC	5.42E-01	total annualized capital	\$/tonne CO_2
AREA	4.25E+03	exchanger area	m^2
LMTD	1.52E+01	log mean temperature difference	K
U	5.17E+03	overall heat transfer coefficient	W/K–m^2
DPRICH	9.43E+04	rich-side pressure drop	Pa
DPLEAN	9.17E+04	lean-side pressure drop	Pa
LPLATE	2.80E+00	plate length	m
VRICH	4.43E-01	rich-side fluid velocity	m/sec
VLEAN	4.72E-01	lean-side fluid velocity	m/sec

3.3 Setup: Calculator Blocks

Now that the property sets exist and the stream names agree, the calculator blocks can be imported.

1. In the “HeatCalc.bkp” file, navigate to “Flowsheeting Options” → “Calculator,” and then select “C-HX.” Click “Copy.”
2. In the destination file, navigate to “Flowsheeting Options” → “Calculator.”
3. Click “Paste.”

3.4 Setup: Optimization Block

This block functions similarly to Solver in Excel®. The provided optimization block minimizes the total annualized capital of the exchanger and the rich pump by varying the total width (NW) of the exchanger.

1. Return to the “HeatCalc.bkp” file, navigate to “Model Analysis Tools” → “Optimization,” and then select “O-TAC.” Click “Copy.”
2. Navigate to “Model Analysis Tools” → “Optimization” in the destination file.
3. Click “Paste.”

3.5 Running the Simulation

Aspen Plus will sequence the calculator and optimization blocks after the flowsheet calculations, meaning the heat exchanger model has no impact on flowsheet convergence. Running the simulation is no different from running the simulation before adding in the heat exchanger model.

4.0 USAGE INFORMATION

4.1 Support

Support can be obtained from ccsi-support@acceleratecarboncapture.org or by filling out the “Submit Feedback/Request Support” form available on the product distribution page.

4.2 Restrictions

This model works with any non-flashing solvent in a plate and frame heat exchanger. Note that the heat transfer coefficient assumes turbulence and 45° herringbone plates. Additional restricting assumptions include:

- a plate spacing of 2 mm
- a plate thickness of 6 mm
- plate material of 304 stainless steel
- assumptions on capital and electricity cost

4.3 Known Issues

- The exchanger and pump sizing is continuous, while in reality it is discrete.

5.0 DEBUGGING

- If the provided file does not yield similar results to those described here, then:
  - check the Property Set Units
  - check that the Streams are properly named
  - use the four provided debugging outputs to troubleshoot

5.1 How to Debug

Always run the simulation with the control panel visible. The output will notify the user about potential problems and errors. For problems specific to C-HX, the four debugging output parameters (OUT1, OUT2, OUT3, and OUT4) can be used to check intermediate values.

5.2 Reporting Issues

To report an issue, please send an email to ccsi-support@acceleratecarboncapture.org.

6.0 MODEL HISTORY

6.1 Block Descriptions

C-HX

This block sizes and costs a non-flashing plate and frame heat exchanger.

Variables

The variables defined are listed in Table 28. As variable names are limited to seven characters, the following shorthand is used:

- CR = cold, rich
- HR = hot, rich
- HL = hot, lean
- CL = cold, lean

Table 4: C-HX Variable Definitions

Variable	Information Flow	Definition
EXCAP	Export variable	Parameter Parameter no. = 311
RPUMPOP	Export variable	Parameter Parameter no. = 312
RPUMPCAP	Export variable	Parameter Parameter no. = 313
TAC	Export variable	Parameter Parameter no. = 315
AREA	Export variable	Parameter Parameter no. = 310
LMTD	Export variable	Parameter Parameter no. = 314
U	Export variable	Parameter Parameter no. = 319
DPRICH	Export variable	Parameter Parameter no. = 316
DPLEAN	Export variable	Parameter Parameter no. = 317
LPLATE	Export variable	Parameter Parameter no. = 318
VRICH	Export variable	Parameter Parameter no. = 320
VLEAN	Export variable	Parameter Parameter no. = 321
OUT1	Export variable	Parameter Parameter no. = 300
OUT2	Export variable	Parameter Parameter no. = 301
OUT3	Export variable	Parameter Parameter no. = 303
OUT4	Export variable	Parameter Parameter no. = 304
TCR	Import variable	Stream-Var Stream = RICHCOLD; Substream = MIXED; Variable = TEMP; Units = K
THL	Import variable	Stream-Var Stream = LEANWRM; Substream = MIXED; Variable = TEMP; Units = K
THR	Import variable	Stream-Var Stream = RICHWRM1; Substream = MIXED; Variable = TEMP; Units = K

Variable	Information Flow	Definition
TCL	Import variable	Stream-Var Stream = LEANCOLD; Substream = MIXED; Variable = TEMP; Units = K
MCR	Import variable	Stream-Var Stream = RICHCOLD; Substream = MIXED; Variable = MASS-FLOW; Units = kg/sec
MHL	Import variable	Stream-Var Stream = LEANWRM; Substream = MIXED; Variable = MASS-FLOW; Units = kg/sec
MHR	Import variable	Stream-Var Stream = RICHWRM1; Substream = MIXED; Variable = MASS-FLOW; Units = kg/sec
MCL	Import variable	Stream-Var Stream = LEANCOLD; Substream = MIXED; Variable = MASS-FLOW; Units = kg/sec
MUCR	Import variable	Stream-Prop Stream = RICHCOLD; Prop-Set = MU-L; Units = Pa-sec
MUHL	Import variable	Stream-Prop Stream = LEANWRM; Prop-Set = MU-L; Units = Pa-sec
MUHR	Import variable	Stream-Prop Stream = RICHWRM1; Prop-Set = MU-L; Units = Pa-sec
MUCL	Import variable	Stream-Prop Stream = LEANCOLD; Prop-Set = MU-L; Units = Pa-sec
RHOCR	Import variable	Stream-Prop Stream = RICHCOLD; Prop-Set = RHO-L; Units = kg/cum
RHOHL	Import variable	Stream-Prop Stream = LEANWRM; Prop-Set = RHO-L; Units = kg/cum
RHOHR	Import variable	Stream-Prop Stream = RICHWRM1; Prop-Set = RHO-L; Units = kg/cum
RHOCL	Import variable	Stream-Prop Stream = LEANCOLD; Prop-Set = RHO-L; Units = kg/cum
CPCR	Import variable	Stream-Prop Stream = RICHCOLD; Prop-Set = CPMX; Units = J/kg-K
CPHL	Import variable	Stream-Prop Stream = LEANWRM; Prop-Set = CPMX; Units = J/kg-K
CPHR	Import variable	Stream-Prop Stream = RICHWRM1; Prop-Set = CPMX; Units = J/kg-K
CPCL	Import variable	Stream-Prop Stream = LEANCOLD; Prop-Set = CPMX; Units = J/kg-K
KCR	Import variable	Stream-Prop Stream = RICHCOLD; Prop-Set = CONDUC-L; Units = Watt/m-K
KHL	Import variable	Stream-Prop Stream = LEANWRM; Prop-Set = CONDUC-L; Units = Watt/m-K
KHR	Import variable	Stream-Prop Stream = RICHWRM1; Prop-Set = CONDUC-L; Units = Watt/m-K
KCL	Import variable	Stream-Prop Stream = LEANCOLD; Prop-Set = CONDUC-L; Units = Watt/m-K
DUTY	Import variable	Heat-Duty Stream = WRMHS; Units = Watt
CO2RM	Import variable	Mole-Flow Stream = PRODUCT1; Substream = MIXED; Component = CO2; Units = kmol/sec
NW	Import variable	Parameter Parameter no. = 366; Initial value = 1962.13

All of the variables defined in the "Define" tab of the calculator block input are included in Table 29 in addition to all the variables defined in the "Calculate" tab.

Table 5: C-HX Variable Description

Variable	I/O	Description	Units
EXCAP	O	Annualized exchanger CAPEX	\$/tonne CO_2
AREA	O	Exchanger area	m^2
RPUMPOP	O	Annualized rich pump OPEX	\$/tonne CO_2
RPUMPCAP	O	Annualized rich pump CAPEX	\$/tonne CO_2
TAC	O	Total annualized capital cost of exchanger and rich pump	\$/tonne CO_2
LMTD	O	LMTD of warm exchanger	K
U	O	Overall heat transfer coefficient	W/K-m^2
DPRICH	O	Pressure drop of rich stream	Pa
DPLEAN	O	Pressure drop of lean stream	Pa
LPLATE	O	Plate length	m
VRICH	O	Velocity of rich stream	m/sec
VLEAN	O	Velocity of lean stream	m/sec
OUT1	O	Debugging output	arbitrary
OUT2	O	Debugging output	arbitrary
OUT3	O	Debugging output	arbitrary
OUT4	O	Debugging output	arbitrary
TCR	I	Temperature of CR	K
THL	I	Temperature of HL	K
THR	I	Temperature of HR	K
TCL	I	Temperature of CL	K
MCR	I	Mass flow of CR	kg/sec
MHL	I	Mass flow of HL	kg/sec
MHR	I	Mass flow of HR	kg/sec
MCL	I	Mass flow of CL	kg/sec
MUCR	I	Liquid viscosity of CR	Pa–sec
MUHL	I	Liquid viscosity of HL	Pa–sec
MUHR	I	Liquid viscosity of HR	Pa-sec
MUCL	I	Liquid viscosity of CL	Pa-sec
RHOCR	I	Liquid density of CR	kg/m^3
RHOHL	I	Liquid density of HL	kg/m^3
RHOHR	I	Liquid density of HR	kg/m^3
RHOCL	I	Liquid density of CL	kg/m^3
CPCR	I	Liquid heat capacity of CR	J/kg–K

Variable	I/O	Description	Units
CPHL	I	Liquid heat capacity of HL	J/kg–K
CPHR	I	Liquid heat capacity of HR	J/kg–K
CPCL	I	Liquid heat capacity of CL	J/kg–K
KCR	I	Liquid thermal conductivity of CR	W/m–K
KHL	I	Liquid thermal conductivity of HL	W/m–K
KHR	I	Liquid thermal conductivity of HR	W/m–K
KCL	I	Liquid thermal conductivity of CL	W/m–K
DUTY	I	Heat duty	W
CO2RM	I	Mole flow of CO_2 in stripper overhead	kmol/sec
VCLW	O	Volumetric flowrate of CL	m^3/sec
NW	I	Total exchanger width	m
PLATESPACE	I	Plate spacing	m
GRICH	O	Mass flux of rich stream	kg/m^2–sec
GLEAN	O	Mass flux of lean stream	kg/m^2–sec
VELCR	O	Velocity of CR	m/sec
VELCL	O	Velocity of CL	m/sec
VELHR	O	Velocity of HR	m/sec
VELHL	O	Velocity of HL	m/sec
DIAM	I	Equivalent diameter	m
RECR	O	Reynolds number of CR	—
RECL	O	Reynolds number of CL	—
REHR	O	Reynolds number of HR	—
REHL	O	Reynolds number of HL	—
PRCR	O	Prandtl number of CR	—
PRCL	O	Prandtl number of CL	—
PRHR	O	Prandtl number of HR	—
PRHL	O	Prandtl number of HL	—
HCR	O	Heat transfer coefficient of CR	W/m^2–K
HCL	O	Heat transfer coefficient of CL	W/m^2–K
HHR	O	Heat transfer coefficient of HR	W/m^2–K
HHL	O	Heat transfer coefficient of HL	W/m^2–K
KPLATE	I	Plate thermal conductivity	W/m^2–K
PLATETHICK	I	Plate thickness	m
HPLATE	O	Plate heat transfer coefficient	W/m^2–K
UCOLD	O	Cold side overall heat transfer coefficient	W/m^2–K
UHOT	O	Hot side overall heat transfer coefficient	W/m^2–K

Variable	I/O	Description	Units
DELTC	O	Cold side temperature approach	K
DELTH	O	Cold side temperature approach	K
FCR	O	Fanning friction factor of CR	—
FCL	O	Fanning friction factor of CL	—
FHR	O	Fanning friction factor of HR	—
FHL	O	Fanning friction factor of HL	—
DPCR	O	Pressure drop per length of CR	Pa/m
DPCL	O	Pressure drop per length of CL	Pa/m
DPHR	O	Pressure drop per length of HR	Pa/m
DPHL	O	Pressure drop per length of HL	Pa/m
ACOST	I	CAPEX of exchanger area	$\$/m^2$
ECOST	I	Cost of electricity	$/MWh
ALPHA	I	Converts PEC to total capital requirement	—
BETA	I	Lang factor (annualizes cost)	—
CFACTOR	I	Capacity factor	—
PETA	I	Pump efficiency	—
PCOST	I	Pump CAPEX	$/W
CO2RMA	O	CO_2 removed per annum	tonne/annum
VCR	O	Volumetric flowrate of CR	m^3/sec

Fortran Code

The first part of the code calculates and maps all necessary properties for the model calculations. The next part calculates the exchanger size. The last part calculates the economics and formats miscellaneous outputs.

If a comment line ends with a number in parentheses, e.g., (1), then there is a comment in this documentation. The comment shows the equation in a more readable format, explains all variables, and elucidates the equation origin.

```
C Brent Sherman
C 2014-11-17
C PURPOSE: Size a non-flashing plate and frame heat exchanger
C                    and cost it and the rich pump.
C Numbers in parentheses refer to comments in documentation.


C --- Calculations begin ---
C Set plate spacing (m).
      PSPACE=0.002
```

```
C Calculate mass flux (kg/sec-m2). (1)
      GRICH=MCR/(PSPACE*NW)
      GLEAN=MHL/(PSPACE*NW)
C Calculate stream velocity (m/sec). (2)
      VELCR=GRICH/(RHOCR)
      VELCL=GLEAN/(RHOCL)
      VELHR=GRICH/(RHOHR)
      VELHL=GLEAN/(RHOHL)
C Output velocities of rich and lean sides.
      VRICH=VELCR
      VLEAN=VELHR
C Calculate the Reynolds number. (3)
      DIAM=2*PSPACE
      RECR=GRICH*DIAM/MUCR
      RECL=GLEAN*DIAM/MUCL
      REHR=GRICH*DIAM/MUHR
      REHL=GLEAN*DIAM/MUHL

C Calculate the Prandtl number. (4)
      PRCR=(CPCR*MUCR)/KCR
      PRCL=(CPCL*MUCL)/KCL
      PRHR=(CPHR*MUHR)/KHR
      PRHL=(CPHL*MUHL)/KHL
C Calculate the heat transfer coefficient (W/m2-K). (5)
C h=Nu*ki/D
      HCR=(0.3*KCR/DIAM)*(PRCR**0.333)*(RECR**0.663)
      HCL=(0.3*KCL/DIAM)*(PRCL**0.333)*(RECL**0.663)
      HHR=(0.3*KHR/DIAM)*(PRHR**0.333)*(REHR**0.663)
      HHL=(0.3*KHL/DIAM)*(PRHL**0.333)*(REHL**0.663)
C Set wall thermal conductivity (W/m-K)
      KPLATE=16
C Set Plate thickness in m.
      PTHK=0.0006
```

```
C Calculate the plate heat transfer coefficient (W/m2-K).
      HPLATE=KPLATE/PTHK
C Calculate the overall heat transfer coefficients (W/m2-K). (6)
      UCOLD=(1/HCR)+(1/HCL)+(1/HPLATE)
      UCOLD=1/UCOLD
      UHOT=(1/HHR)+(1/HHL)+(1/HPLATE)
      UHOT=1/UHOT
C Calculate the temperature approaches (K).
      DELTC=TCL-TCR
      DELTH=THL-THR
C Calculate the area (m2). (7)
      AREA=-DUTY/((UHOT*DELTC-UCOLD*DELTH)
     .           /DLOG((UHOT*DELTC)/(UCOLD*DELTH)))

C LMTD (K)
      LMTD=(DELTC-DELTH)/DLOG(DELTC/DELTH)
C Overall heat transfer coefficient (W/K-m2) (8)
      U=-DUTY/(AREA*LMTD)

C --- Economic Calculations Begin ---
C Calculate plate length (m).
      LPLATE=AREA/NW
C Calculate Fanning friction factor for turbulent flow. (9)
      FCR=1.441*RECR**-0.206
      FCL=1.441*RECL**-0.206
      FHR=1.441*REHR**-0.206
      FHL=1.441*REHL**-0.206
C Calculate the pressure drop per length (Pa/m). (10)
      DPCR=(2*FCR*GRICH**2)/(RHOCR*DIAM)
      DPCL=(2*FCL*GLEAN**2)/(RHOCL*DIAM)
      DPHR=(2*FHR*GRICH**2)/(RHOHR*DIAM)
      DPHL=(2*FHL*GLEAN**2)/(RHOHL*DIAM)
C Calculate the rich-, and lean-side pressure drop (Pa). (11)
```

```
      DPRICH=((DPCR+DPHR)/2)*LPLATE
      DPLEAN=((DPCL+DPHL)/2)*LPLATE
C Economic parameters.
      ACOST=231.61
      ECOST=100
      ALPHA=5
      BETA=0.2
      CFACTOR=0.90
      PETA=0.65
      PCOST=0.4135

C Exchanger CAPEX ($/tonne CO2)
C Convert CO2 removed from kmol/sec to tonne/sec. (12)
      CO2RMA=CO2RM*44/1D3
      EXCAP=(AREA*ACOST*ALPHA*BETA)
     .                /(CO2RMA*3600*24*365*CFACTOR)

C Calculate pump CAPEX ($/tonne CO2). (13)
      VCR=MCR/RHOCR
      RPUMPCAP=(DPRICH*VCR/PETA)
     .          *PCOST*ALPHA*BETA
     .           /(CO2RMA*3600*24*365*CFACTOR)

C Calculate pump OPEX ($/tonne CO2). (14)
      RPUMPOP=(DPRICH*VCR/PETA)
     .                       *ECOST/(3600*1D6)/CO2RMA

C Calculate Total annualized capital ($/tonne CO2). (15)
      TAC=EXCAP+RPUMPOP+RPUMPCAP

C Debugging outputs (16)
      OUT1= FCR
      OUT2= DPCR
```

```
OUT3= DPHR
OUT4= LPLATE
```

Code Comments

1. The mass flux is calculated using Equation 1,

$$G = \frac{\dot{m}}{\delta \times nW} \tag{1}$$

where G is mass flux (kg/m^2–sec), $\dot{m}$ is mass flow rate (kg/sec), δ is plate spacing (m), n is number of plates, and W is plate width (m).

2. The velocity is calculated from the mass flux using Equation 2,

$$v = \frac{G}{\rho} \tag{2}$$

where v is velocity (m/sec) and ρ is liquid density (kg/m^3).

3. The Reynolds number Re is calculated using Equation 3,

$$Re = \frac{G}{\mu D} \tag{3}$$

where μ is the liquid viscosity (Pa–sec), and D is the equivalent diameter (m), which is twice the plate spacing.

4. The Prandtl number Pr is calculated in Equation 4,

$$Pr = \frac{C_p \mu}{k} \tag{4}$$

where C_p is the liquid heat capacity (J/kg–K), and k is the liquid thermal conductivity (W/m–K).

5. The heat transfer coefficient h (W/m^2–K) is calculated using Equation 5,

$$h = \frac{Nu * k}{D} = 0.3\frac{k}{D}Pr^{0.333}Re^{0.663} \tag{5}$$

where Nu is the Nusselt number. This assumes herringbone plates with 45° corrugation angle (Ayub, 2003).

6. The overall heat transfer coefficient U_i of the hot or cold side (W/m^2–K) is calculated using Equation 6,

$$\frac{1}{U_i} = \frac{1}{h_1} + \frac{1}{h_2} + \frac{1}{h_{plate}} \tag{6}$$

   where h_1 is the heat transfer coefficient of the rich stream (W/m^2–K), h_2 is the heat transfer coefficient of the lean stream (W/m^2–K), and h_{plate} is the heat transfer coefficient of the plate (W/m^2–K) equal to the plate thermal conductivity divided by plate thickness.

7. The exchanger area A (m^2) is calculated using Equation 7,

$$A = \frac{Q}{\frac{U_{hot}\Delta T_{cold} - U_{cold}\Delta T_{hot}}{\ln\left(\frac{U_{hot}\Delta T_{cold}}{U_{cold}\Delta T_{hot}}\right)}} \tag{7}$$

   where Q is the duty (W), U_{hot} (U_{cold}) is the overall heat transfer coefficient of the hot (cold) side (W/m^2–K), and ΔT_{hot} (ΔT_{cold}) is the hot- (cold-) side temperature approach (K).

8. The overall heat transfer coefficient U (W/m^2–K) is calculated using Equation 8.

$$U = \frac{Q}{A\Delta T_{LMTD}} \tag{8}$$

9. The Fanning friction factor f_f is calculated using Equation 9.

$$f_f = 1.441 Re^{-0.206} \tag{9}$$

10. The pressure drop per length $\Delta P/L$ (Pa/m) is calculated using Equation 10,

$$\frac{\Delta P}{L} = \frac{2 f_f G^2}{\rho D} \tag{10}$$

   where L is the length (m). This is calculated for each stream.

11. The pressure drop of the rich and lean sides ΔP (Pa) is calculated using Equation 11.

$$\Delta P_{rich} = \frac{\left(\frac{\Delta P}{L}\right)_{CR} + \left(\frac{\Delta P}{L}\right)_{HR}}{2} \times L \tag{11}$$

   The equivalent equation is used for the lean side pressure drop.

12. The exchanger CAPEX *EXCAP* ($/tonne CO_2) is calculated using Equation 12,

$$EXCAP = \frac{A \times \$A \times \alpha\beta}{\dot{m}_{CO_2} \times 3600 \times 24 \times 365 \times C} \quad (12)$$

where *$A* is the cost per unit area ($/m²), α is the conversion of PEC to total capital requirement, β is the Lang factor, $\dot{m}_{CO_2}$ is the mass flowrate of CO_2 leaving the stripper overhead (tonne/sec), and *C* is the capacity factor, which accounts for 10% plant downtime. The purchased equipment cost (PEC) came from vendor quotes. It is assumed to vary linearly with area.

13. The rich pump CAPEX *RPUMPCAP* ($/tonne CO_2) is calculated using Equation 13,

$$RPUMPCAP = \frac{\left(\frac{\Delta P_{rich} \times Q_{CR}}{\eta}\right) \times \$P \times \alpha\beta}{\dot{m}_{CO_2} \times 3600 \times 24 \times 365 \times C} \quad (13)$$

where Q_{CR} is the volumetric flowrate of the cold, rich stream (m^3/sec), η is the pump efficiency, and *$P* is the cost of the pump ($/W).

14. The rich pump operating cost RPUMPOP ($/tonne CO_2) is calculated using Equation 14,

$$RPUMPOP = \frac{\left(\frac{\Delta P_{rich} \times Q_{CR}}{\eta}\right) \times COE}{\dot{m}_{CO_2} \times 3600 \times 10^5} \quad (14)$$

where *COE* is the cost of electricity ($/MWh).

15. The total annualized capital *TAC* ($/tonne CO_2) is calculated using Equation 15.

$$TAC = EXCAP + RPUMPOP + RPUMPCAP \quad (15)$$

16. The following four outputs were used for debugging: OUT1, OUT2, OUT3, and OUT4. They are available for displaying intermediate values. Change the variable on the right side of the equal sign to the variable or expression to display.

7.0 REFERENCES

Ayub, Z.H. Plate Heat Exchanger Literature Survey and New Heat Transfer and Pressure Drop Correlations for Refrigerant Evaporators. *Heat Transf Eng* **2003**, *24*, 3–16.