

# ***SUPPLEMENTAL MATERIAL***

## ***Globally Optimal Design Optimization of Conventional and Intensified Shell and Tube Condensers using Complete Set Trimming***

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### **Part A**

#### **Nomenclature**

##### **Parameters**

$\widehat{\%A}_{exc}$	excess area (%)
$\widehat{af}$	annualization factor (dimensionless)
$\widehat{b}_{EF}$	height of external fins (m)
$\widehat{C}$	correlation parameter (dimensionless)
$\widehat{C}_{De}$	volumetric expansion coefficient (dimensionless)
$\widehat{C}_p$	heat capacity (J/(kg·K))
$\widehat{EC}$	electricity cost (\$/kWh)
$\widehat{F}_{SC}$	heat exchanger structure factor (dimensionless)

$\hat{g}$	gravitational acceleration (m/s <sup>2</sup> )
$\widehat{Hour}$	operating time of the equipment for one year (h/yr)
$\hat{i}$	annual interest rate (dimensionless)
$\hat{k}$	thermal conductivity (W/(m·K))
$\hat{m}$	mass flow rate (kg/s)
$\widehat{ny}$	lifetime of the equipment (yr)
$\hat{P}_{CF}$	the pitch correction factor for flow direction (dimensionless)
$\widehat{Pr}$	Prandtl number (dimensionless)
$\hat{Q}$	heat load (W)
$\widehat{Rf}$	fouling factor (m <sup>2</sup> ·K/W)
$\hat{s}$	specific gravity of fluid (dimensionless)
$\hat{T}$	temperature (K)
$\hat{T}_h$	saturation temperature of the hot stream (K)
$\hat{t}$	thickness of fins (m)
$\hat{Y}$	Chisholm related parameters of two-phase flow (dimensionless)
$\widehat{LMTD}$	logarithmic mean temperature difference (K)
$\hat{\alpha}$	cost coefficient (dimensionless)
$\hat{\beta}$	cost coefficient (dimensionless)
$\hat{\beta}_{IF}$	volumetric expansion coefficient (dimensionless)
$\hat{\eta}$	efficiency of the pump (dimensionless)
$\hat{\mu}$	dynamic viscosity (Pa·s)
$\frac{\hat{\mu}_b}{\hat{\mu}_w}$	ratio between fluid dynamic viscosity (dimensionless)
$\hat{\rho}$	density (kg/m <sup>3</sup> )
$\widehat{\Phi}^2$	average two-phase pressure-drop multiplier (dimensionless)
$\widehat{\Phi}$	viscosity correction factor (dimensionless)

### Variables

$A$	heat transfer area (m <sup>2</sup> )
$Ar$	flow area in shell-side (m <sup>2</sup> )
$a1$	relevant parameters of coiled-wire insert (dimensionless)
$a2$	relevant parameters of coiled-wire insert (dimensionless)
$a3$	relevant parameters of coiled-wire insert (dimensionless)
$a4$	relevant parameters of coiled-wire insert (dimensionless)
$C_A$	capital cost (\$)
$C_f$	correction coefficient of shell-side friction factor (dimensionless)
$C_{fs}$	smooth tube fanning friction factor (dimensionless)
$C_P$	cooling fluid pumping cost (\$/yr)
$d$	diameter (m)
$d_{t,e,r}$	effective root tube diameter (m)
$Dotl$	the centers of the tube bundle diameter (m)
$E_{CI}$	Coiled-Wire diameter (m)
$e_{IF}$	height of internal fins (m)

$f$	friction factor (dimensionless)
$FAR$	free area ratio (dimensionless)
$f_{s,1}$	relevant parameters of externally finned tube (dimensionless)
$f_{s,2}$	relevant parameters of externally finned tube (dimensionless)
$F_{TC}$	correction factor related to the tube bundle (dimensionless)
$func(geo)$	geometry function of internal fins (dimensionless)
$G$	condensation rate per unit length (kg/(s·m))
$G_s$	shell-side mass flux (kg/(s·m <sup>2</sup> ))
$H$	twisted-tapes pitch (m)
$h$	convective heat transfer coefficient (W/(m <sup>2</sup> ·K))
$J_H$	modified Colburn factor of shell-side heat transfer (dimensionless)
$K_{lay}$	layout parameter (dimensionless)
$L$	tube length (m)
$L_{bb}$	diametral clearance between the tube bundle and the shell (m)
$lbc$	baffle spacing (m)
$L_{csw}$	modified characteristic length for swirling flows (m)
$L_{TI}$	swirl length (m)
$ltp$	tube pitch (m)
$m$	parameters related to fin efficiency (dimensionless)
$N$	number of external fins per unit length (m)
$N_b$	number of baffles (dimensionless)
$N_{pt}$	number of tube passes (dimensionless)
$N_{tp}$	number of tubes per pass (dimensionless)
$N_{tt}$	total number of tubes (dimensionless)
$Nu$	Nusselt number (dimensionless)
$\Delta p$	pressure-drop (Pa)
$P_{CI}$	Coiled-Wire helical pitch (m)
$P_{IF}$	fin pitch (m)
$P_{mod}$	modified non-dimensional axial pitch (dimensionless)
$Re$	Reynolds number (dimensionless)
$rp$	tube pitch ratio (dimensionless)
$r_1$	radius of the bare tube (m)
$r_2$	modified fin radius (m)
$r_{2c}$	radius of the fin tube outside (m)
$SA_{act}$	enhanced geometrical area (m <sup>2</sup> )
$SA_i$	tube inside area (m <sup>2</sup> )
$S_{HB}$	cross flow (m <sup>2</sup> )
$S_{TI}$	dimensionless swirl parameter (dimensionless)
$TAC$	total annualized cost (\$/yr)
$U$	overall heat transfer coefficient (W/(m <sup>2</sup> ·K))
$v$	velocity (m/s)
$v_{t,TI}$	swirl velocity (m/s)
$W$	relevant parameters of Internally Finned (dimensionless)
$X$	relevant parameters of Internally Finned (dimensionless)

$Y$	relevant parameters of Internally Finned (dimensionless)
$y$	twist ratio (dimensionless)
$Z$	relevant parameters of Internally Finned (dimensionless)
$\alpha_{CI}$	helical angle of coiled wire to tube axis ( $^{\circ}$ )
$\alpha_{IF}$	helical angle of internal fins ( $^{\circ}$ )
$\beta_{HB}$	helical angle of helical baffle ( $^{\circ}$ )
$\delta$	thickness of twisted tape (m)
$\eta_f$	fin efficiency of the external fins (dimensionless)
$\eta_{tot}$	surface overall efficiency (dimensionless)
$\psi$	parameters related to fin efficiency (dimensionless)

### Subscripts

$c$	cold stream
$CI$	data related to coiled-wire Insert
$coolant$	cooling fluid
$e$	external
$EF$	data related to externally finned tube
$eq$	equivalent
$extra$	extra
$fins$	finned
$fin$	finned
$h$	hot stream
$HB$	data related to helical baffle
$hy$	hydraulic
$i$	inner
$IF$	data related to internally finned tube
$in$	inlet
$LO$	liquid phase only
$max$	upper bound
$min$	lower bound
$out$	outlet
$per$	per unit length
$prime$	prime
$PT$	data related to smooth tube
$r$	root
$req$	required
$s$	shell side
$t$	tube side
$tot$	total
$TI$	data related to twisted-tape insert
$tube$	tube
$v$	vapor
$VO$	vapor phase only
$water$	water

## Part B

Detailed models not presented in the body of the article.

### **Conventional Horizontal Condenser Models - Condensation in the Shell Side:**

Without loss of generality, we use the same equations employed by Pereira et al. (2021). The tube-side heat transfer coefficient is given by (there is no phase change of the cold stream):

$$h_t = \frac{\hat{C} \hat{k}_t Re_t^{0.8} \widehat{Pr}_t^{0.4}}{d_{t,i}} \quad (\text{SB1})$$

where  $\hat{k}_t$  is the cooling fluid's thermal conductivity,  $\hat{C}$  is equal to 0.024,  $Re_t$  is the tube-side Reynolds number and  $\widehat{Pr}_t$ , is the cooling fluid Prandtl number. One can substitute this choice with the Gnielinski (1975) correlation or others.

The tube-side pressure drop ( $Pa$ ) (Darcy-Weisbach correlation):

$$\frac{\Delta p_t}{\hat{\rho}_t \hat{g}} = \frac{f_t Npt L v_t^2}{2 \hat{g} d_{t,i}} \quad (\text{SB2})$$

where  $\hat{g}$  is the gravity acceleration ( $m/s^2$ ), and the tube-side friction factor is given by:

$$f_t = 0.014 + \frac{1.056}{Re_t^{0.42}} \quad (\text{SB3})$$

The tube-side velocity is given by:

$$v_t = \frac{4 \hat{m}_t}{Ntp \pi \hat{\rho}_t d_{t,i}^2} \quad (\text{SB4})$$

where  $\hat{m}_t$  is tube-side stream mass flow rate ( $kg/s$ ), the number of tubes per pass ( $Ntp$ ) is given by:

$$Ntp = \frac{Ntt}{Npt} \quad (\text{SB5})$$

where  $Npt$  is number of tube passes.

In equation (SB5), total number of tubes ( $Ntt$ ) is given by:

$$Ntt = \text{round} \left( \frac{\pi d_s^2}{4 ltp^2 Klay F_{TC} \widehat{F}_{SC}} \right) \quad (\text{SB6})$$

where  $Klay$  is a constant equal to 0.866 for triangular layout and 1 for square layout,  $F_{TC}$  is a correction factor,  $\widehat{F}_{SC}$  is a factor that depends on the heat exchanger structure,  $ltp$  is tube pitch ( $m$ ). The factor  $F_{TC}$  is equal to 1.08 for  $Npt = 1$ , 1.11 for  $Npt = 2$ , 1.45 for  $Npt = 4$  or 6 and  $d_s \geq 0.635$  m, and 1.18 for  $Npt = 4$  or 6 and  $d_s > 0.635$  m.  $\widehat{F}_{SC}$  is equal to 1.0 for fixed tube sheet, 1.15 for floating head, 1.05 for U-tube, and 1.09 for U-tube with pitch ratio 1.25 and outer tube diameter 0.025 m.

In turn, the shell-side heat transfer coefficient (Nusselt model) is given by:

$$h_s = 0.954 \left[ \frac{\hat{\rho}_s (\hat{\rho}_s - \hat{\rho}_{s,v}) \hat{g} \hat{k}_s^3 L}{\hat{m}_s \hat{\mu}_s} \right]^{\frac{1}{3}} Ntt^{\frac{2}{9}} \quad (\text{SB7})$$

where  $\hat{\rho}_s$ ,  $\hat{\mu}_s$ , and  $\hat{k}_s$  are the density, viscosity, and thermal conductivity of the condensate, respectively,  $\hat{\rho}_{s,v}$  is the vapor density, and  $\hat{m}_s$  is the mass flow rate of the condensing vapor.

The shell-side pressure drop ( $Pa$ ) (Kern, 1950; Serth, 2007) is given by:

$$\Delta p_s = \widehat{\Phi}_{vo}^2 \widehat{\rho}_{s,v} f_s \frac{d_s (Nb + 1)}{d_{s,eq}} \left( \frac{v_s^2}{2} \right) \quad (\text{SB8})$$

where  $\widehat{\Phi}_{vo}^2$  is average two-phase pressure-drop multiplier equal to 0.5, and  $Nb$  is the number of baffles, and  $f_s$  is the shell-side friction factor, which is given by:

$$f_s = 1.728 Re_s^{-0.188} \quad (\text{SB9})$$

$Re_s$  is the shell-side Reynolds number, given by:

$$Re_s = \frac{d_{s,eq} v_s \widehat{\rho}_{s,v}}{\widehat{\mu}_{s,v}} \quad (\text{SB10})$$

where  $\widehat{\mu}_{s,v}$  is vapor dynamic viscosity of the condensing vapor ( $Pa \cdot s$ ).

$v_s$  is the shell-side velocity ( $m/s$ ), given by:

$$v_s = \frac{\widehat{m}_s}{\widehat{\rho}_{s,v} Ar} \quad (\text{SB11})$$

$\widehat{m}_s$  is shell-side stream mass flow rate ( $kg/s$ ), and finally,  $d_{eq}$  is the equivalent diameter ( $m$ ), given by:

$$d_{s,eq} = \frac{4 ltp^2}{\pi d_{t,e}} - d_{t,e} \quad (\text{Square pattern}) \quad (\text{SB12})$$

$$d_{s,eq} = \frac{3.46 ltp^2}{\pi d_{t,e}} - d_{t,e} \quad (\text{Triangular pattern}) \quad (\text{SB13})$$

The free area between adjacent baffles  $FAR$ , flow area in shell-side  $Ar$  ( $m^2$ ) and the baffle spacing  $lbc$  ( $m^2$ ) are given by:

$$Ar = d_s FAR lbc \quad (\text{SB14})$$

$$FAR = 1 - \frac{1}{rp} \quad (\text{SB15})$$

$$lbc = \frac{L}{Nb + 1} \quad (\text{SB16})$$

### ***Conventional Horizontal Condenser Models - Condensation in the Tube Side:***

The tube-side heat transfer is taken from Kern (1950):

$$ht \left( \frac{\widehat{\mu}_t^2}{\widehat{k}_t^3 \widehat{\rho}_t^2 \widehat{g}} \right)^{\frac{1}{3}} = 1.51 \left( \frac{4G}{\widehat{\mu}_t} \right)^{-\frac{1}{3}} \quad (\text{SB17})$$

where  $\widehat{\rho}_t$ ,  $\widehat{\mu}_t$ , and  $\widehat{k}_t$  are the density, viscosity and thermal conductivity of the condensate, and  $G$  is the condensation rate per unit length, given by:

$$G = \frac{\widehat{m}_t}{0.5L Ntt} \quad (\text{SB18})$$

The tube-side pressure drop ( $Pa$ ) is given by:

$$\Delta p_t = \widehat{\Phi}_{LO}^2 \Delta p_{t,LO} \quad (\text{SB19})$$

where  $\widehat{\Phi}_{LO}^2$  is the phase flow correction factor.  $\Delta p_{t,LO}$  is considered to be the one corresponding to the liquid phase only. We use the correlation of Darcy-Weisbach for calculation.

The phase flow correction factor is given by:

$$\widehat{\Phi}_{LO}^2 = 1 + (\widehat{Y}^2 - 1) \quad (\text{SB20})$$

Chisholm parameter for two-phase flow is given by:

$$\widehat{Y} = \left( \frac{\widehat{\rho}_t}{\widehat{\rho}_{t,v}} \right)^{0.5} \left( \frac{\widehat{\mu}_{t,v}}{\widehat{\mu}_t} \right)^{0.125} \quad (\text{SB21})$$

For the shell-side model for evaluation of the heat transfer coefficient, without loss of generality, we use the Kern Model.

### ***Conventional Vertical Condenser Models - Condensation in the Shell Side:***

The shell-side heat transfer coefficient is given by (Kern, 1950):

$$h_s \left( \frac{\widehat{\mu}_s^2}{\widehat{k}_s^3 \widehat{\rho}_s^2 \widehat{g}} \right)^{\frac{1}{3}} = 1.47 \left( \frac{4G}{\widehat{\mu}_s} \right)^{\frac{1}{3}} \quad (\text{SB22})$$

where  $G$  is the condensation rate per unit length:

$$G = \frac{\widehat{m}_s}{\pi N t t d_{t,e}} \quad (\text{SB23})$$

The shell-side pressure drop ( $Pa$ ) is given by:

$$\Delta p_s = \widehat{\Phi}_{LO}^2 \Delta P_{s,LO} \quad (\text{SB24})$$

where  $\widehat{\Phi}_{LO}^2$  is two phase flow correction factor;  $\Delta p_{s,LO}$  is shell-side pressure drop in the presence of liquid phase only. They are taken from Kern (1950) and Kapale et al. (2006).

In turn, the two phase flow correction factor is given by:

$$\widehat{\Phi}_{LO}^2 = 1 + (\widehat{Y}^2 - 1) \quad (\text{SB25})$$

where  $\widehat{Y}$  is Chisholm related parameters of two-phase flow:

$$\widehat{Y} = \left( \frac{\widehat{\rho}_s}{\widehat{\rho}_{s,v}} \right)^{0.5} \left( \frac{\widehat{\mu}_{s,v}}{\widehat{\mu}_s} \right)^{0.1157} \quad (\text{SB26})$$

The shell-side pressure drop is given by:

$$\Delta p_{s,LO} = \frac{f_s G s^2 d_s (N b + 1)}{2000 d_{s,eq} \widehat{s}_s \widehat{\phi}_s} \quad (\text{SB27})$$

where  $f_s$  is shell-side friction factor;  $G s$  is shell-side mass flux ( $kg/(s \cdot m^2)$ );  $d_{eq}$  is Equivalent diameter ( $m$ );  $\widehat{s}_s$  is shell-side specific gravity of fluid;  $\widehat{\phi}_s$  is shell-side viscosity correction factor.

$$G s = \frac{\widehat{m}_s}{A r} \quad (\text{SB28})$$

$$f_s = \exp[0.576 - 0.19 \ln(Re_s)] + C_f \quad (\text{SB29})$$

where  $C_f$  is the correction coefficient, and the value is shown in the Table SB1 according to Kapale et al. (2006).

**Table SB1:** The value of correlation coefficient  $C_f$

Tube pitch ratio	Tube layout			
	Triangular		Square	
	$Re_s < 10^4$	$Re_s > 10^4$	$Re_s < 10^4$	$Re_s > 10^4$
1.25	0.3752	0.1609	0.0767	0.1578
1.33	0.2873	0.1296	-0.0026	0.1129
1.50	0.1581	0.0854	-0.1180	0.0428

For the equivalent diameter, we use equation (SB12) and (SB13), the flow area in shell-side, we use equation (SB14).

$$\hat{s}_s = \frac{\hat{\rho}_s}{\hat{\rho}_{water}} \quad (SB30)$$

$$\hat{\phi}_s = \left( \frac{\hat{\mu}_s}{\hat{\mu}_{water}} \right)^{0.14} \quad (SB31)$$

For the calculation of tube-side coefficient, we use the Kern model. For the models of tube-side pressure drop, we use the correlation of Darcy-Weisbach for calculation.

### ***Conventional Vertical Condenser Models— Condensation in the Tube Side:***

The tube-side heat transfer coefficient is given by (Serth, 2007):

$$h_t = 1.47 \left[ \frac{\hat{\rho}_t (\hat{\rho}_t - \hat{\rho}_{t,v}) \hat{g} \hat{k}_t^3}{\hat{\mu}_t^2 Re_t} \right]^{\frac{1}{3}} \quad (SB32)$$

Tube-side Reynolds number is given by:

$$Re_t = \frac{4G}{\hat{\mu}_t} \quad (SB33)$$

where  $G$  is the condensation rate per unit length:

$$G = \frac{\hat{m}_t}{\pi N t t d_{t,i}} \quad (SB34)$$

For the models of tube-side pressure drop, we use equation (SB19).

We use Kern model for shell-side heat transfer coefficient and the pressure drop model adopts  $\Delta p_{s,LO}$  from equation (SB27).

The detailed models of intensification technologies used in this paper are as follows.

### ***Intensification Models***

The intensification methods used in this article include twisted-tape inserts (Jiang et al., 2014), internally finned tubes (Yang et al., 2020), coiled-wire inserts (Jiang et al., 2014), externally finned tubes (Yang et al., 2020), and a helical baffle (Yang et al., 2020). The above intensification technologies are only applicable to the cooling fluid, i.e. stream without phase change. In Table SB2, we provide abbreviations for intensification techniques and the side of implementation techniques.

**Table SB2:** Brief information for intensification technology

Name	Abbreviation	Side of applying intensification technology
Twisted-tape Insert	TI	Tube side
Internally Finned tube	IF	Tube side
Coiled-wire Insert	CI	Tube side
Externally Finned tube	EF	Shell side
Helical Baffle	HB	Shell side

### ***Tube with Twisted-Tape Insert***

The model of tube with Twisted-tape Insert (TI) is taken from Jiang et al.(2014).

Tube-side heat transfer coefficient:

$$h_{t,TI} = \hat{k}_t \frac{Nu_{t,TI}}{d_{t,i}} \quad (\text{SB35})$$

where  $Nu_{t,TI}$  is tube-side Nusselt number:

For  $Re_t < 10^4$  and  $S_{TI} < 2000$ :

$$Nu_{t,TI} = 0.106 S_{TI}^{0.767} \widehat{Pr}_t^{0.3} \quad (\text{SB36})$$

$$\widehat{Pr}_t = \frac{\widehat{c}_p \hat{\mu}_t}{\hat{k}_t} \quad (\text{SB37})$$

For  $Re_t \geq 10^4$  and  $S_{TI} \geq 2000$ :

$$Nu_{t,TI} = 0.023 Re_t^{0.8} \widehat{Pr}_t^{0.4} \left(1 + \frac{0.769}{y}\right) \left(\frac{\pi}{\pi - \frac{4\delta}{d_{t,i}}}\right)^{0.8} \left(\frac{\pi + 2 - \frac{2\delta}{d_{t,i}}}{\pi - \frac{4\delta}{d_{t,i}}}\right)^{0.2} \quad (\text{SB38})$$

For  $Re_t < 10^4$  and  $S_{TI} \geq 2000$  or  $Re_t \geq 10^4$  and  $S_{TI} < 2000$ :

$$Nu_{t,TI} = 0.5 \left[ \begin{array}{l} 0.106 S_{TI}^{0.767} \widehat{Pr}_t^{0.3} \\ + 0.023 Re_t^{0.8} \widehat{Pr}_t^{0.4} \left(1 + \frac{0.769}{y}\right) \left(\frac{\pi}{\pi - \frac{4\delta}{d_{t,i}}}\right)^{0.8} \left(\frac{\pi + 2 - \frac{2\delta}{d_{t,i}}}{\pi - \frac{4\delta}{d_{t,i}}}\right)^{0.2} \end{array} \right] \quad (\text{SB39})$$

where  $S_{TI}$  is dimensionless swirl parameter;  $\delta$  denotes the thickness of twisted tape;  $y$  is twist ratio.

$$S_{TI} = \frac{Re_t}{\sqrt{y}} \frac{\pi}{\pi - \frac{4\delta}{d_{t,i}}} \left[1 + \left(\frac{\pi}{2y}\right)^2\right]^{0.5} \quad (\text{SB40})$$

$$y = \frac{H}{d_{t,i}} \quad (\text{SB41})$$

Tube-side pressure drop:

For  $S_{TI} < 2000$ :

$$\Delta p_t = Npt f_{t,TI} \frac{L_{TI}}{d_{t,i}} \left( \frac{\hat{\rho}_t v_{t,TI}^2}{2} \right) \quad (\text{SB42})$$

For  $S_{TI} \geq 2000$ :

$$\Delta p_t = Npt f_{t,TI} \frac{L}{d_{t,i}} \left( \frac{\hat{\rho}_t v_t^2}{2} \right) \quad (\text{SB43})$$

where  $f_{t,TI}$  is tube-side friction factor;  $v_{t,TI}$  is swirl velocity;  $L_{TI}$  is swirl length.

For  $S_{TI} < 2000$ :

$$f_{t,TI} = 4 \frac{15.767}{Re_{t,TI}} \left( \frac{\pi + 2 - \frac{2\delta}{d_{t,i}}}{\pi - \frac{4\delta}{d_{t,i}}} \right)^2 (1 + 10^{-6} S_{TI}^{2.55})^{1/6} \quad (\text{SB44})$$

For  $S_{TI} \geq 2000$ :

$$f_{t,TI} = 4 \frac{0.0791}{Re_t^{0.25}} \left( 1 + \frac{2.752}{y^{1.29}} \right) \left( \frac{\pi}{\pi - \frac{4\delta}{d_{t,i}}} \right)^{1.75} \left( \frac{\pi + 2 - \frac{2\delta}{d_{t,i}}}{\pi - \frac{4\delta}{d_{t,i}}} \right)^{1.25} \quad (\text{SB45})$$

where  $Re_t$  denotes Reynolds number under non-enhanced conditions;  $Re_{t,TI}$  is Reynolds number under enhanced conditions.

$$Re_{t,TI} = \frac{\hat{\rho}_t v_{t,TI} d_{t,i}}{\hat{\mu}_t} \quad (\text{SB46})$$

$$v_{t,TI} = v_t \frac{\pi}{\pi - \frac{4\delta}{d_{t,i}}} \left[ 1 + \left( \frac{\pi}{2y} \right)^2 \right]^{0.5} \quad (\text{SB47})$$

$$L_{TI} = L \left[ 1 + \left( \frac{\pi}{2y} \right)^2 \right]^{0.5} \quad (\text{SB48})$$

### ***Tube with Internally Finned Tube***

The model of Internally Finned tube (IF) is adopted from Yang et al. (2020). The correlations of Internally Finned tube (IF) are divided into two parts:  $Re_t \leq 2100$  and  $Re_t > 2100$ .

For  $Re_t \leq 2100$ :

Tube-side heat transfer coefficient:

$$h_{t,IF}^3 + \frac{W X^2 - 200X Z}{Z X^2} h_{t,IF}^2 + \frac{10^4 Z - 200X W}{Z X^2} h_{t,IF} + \frac{10^4 W Y - 1}{Z X^2 Y} = 0 \quad (\text{SB49})$$

where  $X$ ,  $Y$ ,  $Z$ ,  $W$  denote relevant parameters.

$$X = \frac{100d_{t,i}}{2.25 \cdot 19.2\hat{k}_t} \left(\frac{\hat{t}_{IF}}{P_{IF}}\right)^{-0.5} Re_{t,IF}^{-0.26} \widehat{Pr}_t^{-\frac{1}{3}} \left(\frac{d_{t,hy,IF}}{L}\right)^{-\frac{1}{3}} \left(\frac{\hat{\mu}_b}{\hat{\mu}_w}\right)^{-\frac{1}{3}} \ln(Re_{t,IF}) \quad (SB50)$$

where  $\frac{\hat{\mu}_b}{\hat{\mu}_w}$  is the ratio between fluid dynamic viscosity at bulk fluid temperature and tube wall temperature. In this article, we consider this value to be 1;  $d_{t,hy,IF}$  is hydraulic diameter.  $Re_{t,IF}$  is Reynolds number under enhanced conditions;  $\hat{t}_{IF}$  denotes the thickness of internal fins, with a value used of 0.0007;  $P_{IF}$  is fin pitch.

$$Y = \frac{\hat{\mu}_t^2}{\hat{g} \hat{\rho}_t^2 d_{t,hy,IF}^2 \hat{\beta}_{IF} (\hat{T}_{h,in} - \hat{T}_{c,in})} \quad (SB51)$$

where  $\hat{\beta}_{IF}$  denotes volumetric expansion coefficient.

$$Z = \frac{\widehat{Rf}_t d_{t,e}}{d_{t,i}} + \frac{d_{t,e} \ln\left(\frac{d_{t,e}}{d_{t,i}}\right)}{2\hat{k}_{tube}} + \frac{1}{h_s} \quad (SB52)$$

$$W = \frac{d_{t,e}}{d_{t,i}} \quad (SB53)$$

$$d_{t,hy,IF} = 4 \left( \frac{0.25\pi d_{t,i}^2 - N_{IF} e_{IF} \hat{t}_{IF}}{\pi d_{t,i} + 2N_{IF} e_{IF}} \right) \quad (SB54)$$

where  $N_{IF}$  denotes the number of external fins per unit length;  $e_{IF}$  denotes height of internal fins.

$$Re_{t,IF} = \frac{\hat{\rho}_t v_t d_{t,hy,IF}}{\hat{\mu}_t} \quad (SB55)$$

$$P_{IF} = \frac{\pi d_{t,i}}{N_{IF} \tan \alpha_{IF}} \quad (SB56)$$

where  $\alpha_{IF}$  denotes helical angle of internal fins.

Tube-side pressure drop:

$$\Delta p_t = Npt f_{t,IF} \frac{L}{d_{t,i}} \left( \frac{\hat{\rho}_t v_t^2}{2} \right) \quad (SB57)$$

where tube-side friction factor of IF:

$$f_{t,IF} = 4 \frac{16.4}{Re_{t,IF}} \left( \frac{d_{t,hy,IF}}{d_{t,i}} \right)^{1.4} \quad (SB58)$$

For  $Re_t > 2100$ :

Tube-side heat transfer coefficient:

$$h_{t,IF} = \hat{k}_t \frac{Nu_{t,IF}}{d_{t,i}} \quad (SB59)$$

where  $Nu_{t,IF}$  is Nusselt number of IF.

$$Nu_{t,IF} = Nu_{t,PT} \left( \frac{L_{CSW}}{d_{t,i}} \right)^{-0.5} \left( \frac{0.25\pi d_{t,i}^2}{0.25\pi d_{t,i}^2 - N_{IF} e_{IF} \hat{t}_{IF}} \right)^{0.8} \text{func}(\text{geo}) \quad (SB60)$$

where  $Nu_{t,PT}$  is smooth tube Nusselt number;  $L_{csw}$  is modified characteristic length for swirling flows;  $func(geo)$  is geometry function of internal fins.

For  $2300 \leq Re_t \leq 5 \times 10^6$ :

$$Nu_{t,PT} = \frac{\frac{f_{t,PT}}{8} (Re_t - 1000) \widehat{Pr}_t}{1 + 12.7 \left(\frac{f_{t,PT}}{8}\right)^{0.5} \left(\widehat{Pr}_t^{\frac{2}{3}} - 1\right)} \quad (SB61)$$

For  $2300 \leq Re_t$  and  $Pr_t > 5$ :

$$Nu_{t,PT} = 3.66 + \frac{0.0668 \frac{d_{t,i}}{L} Re_t \widehat{Pr}_t}{1 + 0.04 \left(\frac{d_{t,i}}{L} Re_t \widehat{Pr}_t\right)^{\frac{2}{3}}} \quad (SB62)$$

For  $2300 \leq Re_t$  and  $0.6 \leq Pr_t < 5$ :

$$Nu_{t,PT} = 1.86 \left(\frac{Re_t \widehat{Pr}_t}{L d_{t,i}}\right)^{\frac{1}{3}} \quad (SB63)$$

where  $f_{t,PT}$  is Smooth tube friction factor; in addition, the minimum value of  $Nu_{t,PT}$  is 3.66.

For  $2100 < Re_t < 3380$ :

$$f_{t,PT} = 0.0488 \quad (SB64)$$

For  $Re_t \geq 3380$ :

$$f_{t,PT} = 0.014 + \frac{1.056}{Re_t^{0.42}} \quad (SB65)$$

For  $e_{IF}/d_{t,i} \leq 0.02$ :

$$L_{csw} = d_{t,i} \left\{ 1 - 1.577 P_{mod}^{0.64} \left(\frac{2e_{IF}}{d_{t,i}}\right)^{0.53} \left[ \left(\frac{\pi}{N_{IF}} - \frac{\hat{t}_{IF}}{d_{t,i}}\right) \cos \alpha_{IF} \right]^{0.28} \right\} \quad (SB66)$$

For  $0.02 < e_{IF}/d_{t,i} \leq 0.03$ :

$$L_{csw} = d_{t,i} \left\{ 1 - 0.994 P_{mod}^{0.89} \left(\frac{2e_{IF}}{d_{t,i}}\right)^{0.44} \left[ \left(\frac{\pi}{N_{IF}} - \frac{\hat{t}_{IF}}{d_{t,i}}\right) \cos \alpha_{IF} \right]^{0.41} \right\} \quad (SB67)$$

where  $P_{mod}$  is modified non-dimensional axial pitch.

$$P_{mod} = \frac{N_{IF} \sin \alpha_{IF}}{\pi} \quad (SB68)$$

$$func(geo) = \left(\frac{SA_{act}}{SA_i}\right) \left\{ 1 - 0.059 P_{mod}^{-0.31} \left[ \left(\frac{\pi}{N_{IF}} - \frac{\hat{t}_{IF}}{d_{t,i}}\right) \cos \alpha_{IF} \right]^{-0.66} \right\} \quad (SB69)$$

where  $SA_{act}$  is enhanced geometrical area;  $SA_i$  is tube inside area.

$$SA_{act} = N_{t,t} L (\pi d_{t,i} + 2N_{IF} e_{IF}) \quad (SB70)$$

$$SA_i = N_{t,t} L \pi d_{t,i} \quad (SB71)$$

Tube-side pressure drop:

$$\Delta p_t = N_{p,t} f_{t,IF} \frac{L}{d_{t,i}} \left(\frac{\hat{\rho}_t v_t^2}{2}\right) \quad (SB72)$$

where tube-side friction factor of IF:

$$f_{t,IF} = f_{t,PT} \left( \frac{L_{CSW}}{d_{t,i}} \right)^{-1.25} \left( \frac{0.25\pi d_{t,i}^2}{0.25\pi d_{t,i}^2 - N_{IF} e_{IF} \hat{t}_{IF}} \right)^{1.75} \quad (SB73)$$

### **Tube with Coiled-Wire Insert**

The model of tube with Coiled-wire Insert (CI) is taken from Jiang et al. (2014).  
Tube-side heat transfer coefficient:

$$h_{t,CI} = \hat{k}_t \frac{Nu_{t,CI}}{d_{t,i}} \quad (SB74)$$

where  $Nu_{t,CI}$  is Nusselt number of CI.

For  $Re_t \leq 1000$ :

$$Nu_{t,CI} = 1.86 Re_t^{\frac{1}{3}} \widehat{Pr}_t^{\frac{1}{3}} \left( \frac{P_{CI}}{d_{t,i}} \right)^{-\frac{1}{3}} \left[ \frac{\cos \alpha_{CI} - \left( \frac{E_{CI}}{d_{t,i}} \right)^2}{\cos \alpha_{CI} + \frac{E_{CI}}{d_{t,i}}} \right]^{\frac{1}{3}} \quad (SB75)$$

For  $1000 < Re_t < 80000$ :

$$Nu_{t,CI} = 0.132 \left( \frac{P_{CI}}{d_{t,i}} \right)^{-0.372} Re_t^{0.72} \widehat{Pr}_t^{0.37} \quad (SB76)$$

For  $80000 < Re_t < 250000$ :

$$Nu_{t,CI} = Nu_{t,PT} \left\{ 1 + \left[ 2.64 Re_t^{0.036} \left( \frac{E_{CI}}{d_{t,i}} \right)^{0.212} \left( \frac{P_{CI}}{d_{t,i}} \right)^{-0.21} \left( \frac{a_{CI}}{90^\circ} \right)^{0.29} \widehat{Pr}_t^{-0.024} \right]^7 \right\}^{\frac{1}{7}} \quad (SB77)$$

where  $\alpha_{CI}$  is helical angle of coiled wire to tube axis (degrees);  $E_{CI}$  denotes Coiled-Wire diameter;  $P_{CI}$  denotes Coiled-Wire helical pitch;  $Nu_{t,PT}$  is smooth tube Nusselt number.

$$\alpha_{CI} = \frac{180}{\pi} \tan^{-1} \left( \frac{\pi d_{t,i}}{P_{CI}} \right) \quad (SB78)$$

$$Nu_{t,PT} = \frac{Re_t \widehat{Pr}_t \frac{C_{fs}}{2}}{1 + 12.7 \sqrt{\frac{C_{fs}}{2}} \left( \widehat{Pr}_t^{\frac{2}{3}} - 1 \right)} \quad (SB79)$$

where  $C_{fs}$  is smooth tube fanning friction factor.

$$C_{fs} = (1.58 \ln Re_s - 3.28)^{-2} \quad (SB80)$$

Tube-side pressure drop:

$$\Delta p_t = N_{pt} f_{t,CI} \frac{L}{d_{t,i}} \left( \frac{\hat{\rho}_t v_t^2}{2} \right) \quad (SB81)$$

where  $f_{CI}$  is tube-side friction factor of CI.

For  $Re_t \leq 310$ :

$$f_{Cl} = 4 \frac{16}{Re_t} \quad (SB82)$$

For  $310 < Re_t \leq 30000$ :

$$f_{Cl} = 4 \times 9.35 \left( \frac{P_{Cl}}{E_{Cl}} \right)^{-1.16} Re_t^{-0.217} \quad (SB83)$$

For  $30000 < Re_t \leq 250000$ :

$$f_{t,Cl} = 4C_{fs} \left\{ 1.036 + \left[ 30.15 Re_t^{a1} \left( \frac{E_{Cl}}{d_{t,i}} \right)^{a2} \left( \frac{P_{Cl}}{d_{t,i}} \right)^{a3} \left( \frac{\alpha_{Cl}}{90^\circ} \right)^{a4} \right]^{\frac{15}{16}} \right\} \quad (SB84)$$

where  $a1, a2, a3, a4$ , denote relevant parameters.

$$a1 = 0.67 - 0.06 \left( \frac{P_{Cl}}{d_{t,i}} \right) - 0.49 \left( \frac{\alpha_{Cl}}{90^\circ} \right) \quad (SB85)$$

$$a2 = 1.37 - 0.157 \left( \frac{P_{Cl}}{d_{t,i}} \right) \quad (SB86)$$

$$a3 = -1.66 \times 10^{-6} Re_t^{-0.33} \left( \frac{\alpha_{Cl}}{90^\circ} \right) \quad (SB87)$$

$$a4 = 4.59 + 4.11 \times 10^{-6} Re_t^{-0.15} \left( \frac{P_{Cl}}{d_{t,i}} \right) \quad (SB88)$$

### ***Shell with Externally Finned Tube***

The model of Externally Finned tube (EF) is adopted from Yang et al. (2020).

Shell-side heat transfer coefficient:

$$h_{s,EF} = \frac{\hat{k}_s J_H \widehat{Pr}_s^{\frac{1}{3}}}{d_{s,eq,EF}} \quad (SB89)$$

where  $J_H$  is the modified Colburn factor of shell-side heat transfer;  $d_{s,eq,EF}$  is shell-side equivalent diameter:

$$J_H = 0.5 \left( 1 + \frac{lbc}{d_s} \right) (0.08 Re_{s,EF}^{0.6821} + 0.7 Re_{s,EF}^{0.1772}) \quad (SB90)$$

where  $Re_{t,EF}$  is Reynolds number under enhanced conditions.

$$Re_{s,EF} = \frac{\hat{\rho}_s v_{s,EF} d_{s,eq,EF}}{\hat{\mu}_s} \quad (SB91)$$

where  $v_{s,EF}$  is shell-side velocity.

$$v_{s,EF} = \frac{\hat{m}_s}{\hat{r}_s lbc \left[ (d_s - Dotl) + \frac{Dotl - d'_{t,e,r}}{\hat{P}_{CF} ltp} (ltp - d'_{t,e,r}) - 2N_{EF} \hat{b}_{EF} \hat{t}_{EF} \right]} \quad (SB92)$$

where  $Dotl$  is the centers of the tube bundle diameter;  $d_{t,e,r}$  is effective root tube diameter;  $\hat{P}_{CF}$  denotes the pitch correction factor for flow direction, and the value is 1 for triangular and square layouts.

$$Dotl = d_s - Lbb \quad (SB93)$$

where  $Lbb$  is the diametral clearance between the tube bundle and the shell, only for fixed tube-sheet.

$$Lbb = 0.0128 + 0.0048d_s \quad (SB94)$$

$$d'_{t,e,r} = [d_{t,e,r}^2 + 4N_{EF} \hat{b}_{EF} \hat{t}_{EF} (d_{t,e,r} + \hat{b}_{EF})]^{0.5} \quad (SB95)$$

where  $d_{t,e,r}$  is root tube diameter;  $N_{EF}$  denotes the number of external fins per unit length;  $\hat{b}_{EF}$  denotes the height of external fins, and the value is 0.001841;  $\hat{t}_{EF}$  denotes thickness of external fins, and the value is 0.000317.

$$d_{t,e,r} = d_{t,e} \quad (SB96)$$

$$d_{s,eq,EF} = C_{De} \frac{lt p^2}{d'_{t,e,r}} - d'_{t,e,r} \quad (SB97)$$

where  $C_{De}$  denotes volumetric expansion coefficient, and equals  $\pi/4$  in square layout and  $2\sqrt{3}/\pi$  in triangular layout.

Shell-side pressure drop:

$$\Delta p_s = \frac{f_{s,EF} \hat{\rho}_s v_{s,EF}^2 d_s (Nb + 1)}{2 d_{s,eq,EF}} \quad (SB98)$$

where shell-side friction factor:

$$f_{s,EF} = 144 \left[ f_{s,1} - 1.25 \left( 1 - \frac{lb c}{d_s} \right) (f_{s,1} - f_{s,2}) \right] \quad (SB99)$$

where  $f_{s,1}, f_{s,2}$  denote relevant parameters, and the calculation formulas are as follows:

$$f_{s,1} = (0.0076 + 0.000166d_s) Re_{s,EF}^{-0.123} \quad (SB100)$$

$$f_{s,2} = (0.0076 + 5.8 \times 10^{-5} d_s) Re_{s,EF}^{-0.157} \quad (SB101)$$

The calculation of heat transfer area also varies with the intensification of Externally Finned, and the following equations are used.

$$A_{tot,per} = A_{fins,per} + A_{prime,per} \quad (SB102)$$

$$A_{fins,per} = N_{EF} \frac{\pi}{2} (d_{fin}^2 - d_{t,e}^2) + N_{EF} \pi d_{fin} \hat{t}_{EF} \quad (SB103)$$

$$A_{prime,per} = \pi d_{t,e} (1 - N_{EF} \hat{t}_{EF}) \quad (SB104)$$

The fin diameter ( $d_{fin}$ ) is given by:

$$d_{fin} = d_{t,e} + 2\hat{b}_{EF} \quad (SB105)$$

where  $\hat{t}_{EF}$  and  $\hat{b}_{EF}$  are the fin thickness and height, respectively.

The fin efficiency of the external fins is evaluated by (Serth and Lestina, 2014):

$$\eta_f = \frac{\tanh(m \psi)}{m \psi} \quad (SB106)$$

The values of  $m$  and  $\psi$  are calculated by:

$$m = \sqrt{\frac{2 h_s}{\hat{k}_{fin} \hat{t}_{EF}}} \quad (SB107)$$

$$\psi = \hat{b}_{EF} \left( 1 + \frac{\hat{t}_{EF}}{2 \hat{b}_{EF}} \right) \left\{ 1 + 0.35 \ln \left( \frac{d_{t,e} + 2 \hat{b}_{EF}}{d_{t,e}} \right) \right\} \quad (\text{SB108})$$

where  $\hat{k}_{fin}$  is the fin's thermal conductivity.

The surface overall efficiency is given by:

$$\eta_{tot} = 1 - \frac{A_{fins,per}}{A_{tot,per}} (1 - \eta_f) \quad (\text{SB109})$$

### **Shell with Helical Baffle**

The model of shell side with Helical Baffle (HB) is adopted from Yang et al. (2020).

Shell-side heat transfer coefficient:

$$h_{s,HB} = \frac{\hat{k}_s Nu_{s,HB}}{d_{s,eq,HB}} \quad (\text{SB110})$$

where  $Nu_{s,HB}$  is Nusselt number of HB;  $d_{s,eq,HB}$  is shell-side equivalent diameter.

$$d_{s,eq,HB} = C_{De} \frac{lt_p^2}{d_{t,e}} - d_{t,e} \quad (\text{SB111})$$

The value of  $C_{De}$  is shown at the below of equation (SB97).

For  $\beta_{HB} = 20^\circ$ :

$$Nu_{s,HB} = 0.275 Re_{s,HB}^{0.542} \widehat{Pr}_s^{\frac{1}{3}} \quad (\text{SB112})$$

For  $\beta_{HB} = 30^\circ$ :

$$Nu_{s,HB} = 0.365 Re_{s,HB}^{0.516} \widehat{Pr}_s^{\frac{1}{3}} \quad (\text{SB113})$$

For  $\beta_{HB} = 40^\circ$ :

$$Nu_{s,HB} = 0.455 Re_{s,HB}^{0.488} \widehat{Pr}_s^{\frac{1}{3}} \quad (\text{SB114})$$

For  $\beta_{HB} = 50^\circ$ :

$$Nu_{s,HB} = 0.326 Re_{s,HB}^{0.512} \widehat{Pr}_s^{\frac{1}{3}} \quad (\text{SB115})$$

where  $Re_{s,HB}$  is Reynolds number under enhanced conditions.

$$Re_{s,HB} = \frac{\hat{\rho}_s v_{s,HB} d_{s,eq,HB}}{\hat{\mu}_s} \quad (\text{SB116})$$

where  $v_{s,HB}$  is shell-side velocity.

$$v_{s,HB} = \frac{\hat{m}_s}{\hat{\rho}_s S_{HB}} \quad (\text{SB117})$$

where  $S_{HB}$  is cross flow.

$$S_{HB} = 0.5 lb c_{HB} \left[ d_s - Dotl + \frac{Dotl - d_{t,e}}{\widehat{Pr}_{CF} ltp} (ltp - d_{t,e}) \right] \quad (\text{SB118})$$

where  $lbc_{HB}$  is Baffle spacing; For the models of *Dotl*, *Lbb*, we use equation (SB93) - (SB94); The value of  $\hat{P}_{CF}$  is shown at the below of equation (SB92).

$$lbc_{HB} = \sqrt{2}d_s \tan b_{HB} \quad (SB119)$$

where  $\beta_{HB}$  denotes helical angle of helical baffle.

Shell-side pressure drop:

$$\Delta p_s = \frac{f_{s,HB} \hat{\rho}_s v_{s,HB}^2 d_s (Nb + 1)}{2 d_{s,eq,HB}} \quad (SB120)$$

where  $f_{s,HB}$  is shell-side friction factor.

For  $\beta_{HB} = 20^\circ$ :

$$f_{s,HB} = 11Re_{s,HB}^{-0.715} \quad (SB121)$$

For  $\beta_{HB} = 30^\circ$ :

$$f_{s,HB} = 13.5Re_{s,HB}^{-0.774} \quad (SB122)$$

For  $\beta_{HB} = 40^\circ$ :

$$f_{s,HB} = 34.7Re_{s,HB}^{-0.806} \quad (SB123)$$

For  $\beta_{HB} = 50^\circ$ :

$$f_{s,HB} = 47.9Re_{s,HB}^{-0.849} \quad (SB124)$$

## References

- Gnielinski V., 1975. Neue Gleichungen für den Wärme- und den Stoffübergang in turbulent durchströmten Rohren und Kanälen. *Forschung im Ingenieurwesen A* 41, 8-16.
- Jiang N., J. D. Shelley, R. Smith, 2014. New models for conventional and heat exchangers enhanced with tube inserts for heat exchanger network retrofit. *Applied Thermal Engineering* 70, 944-956.
- Kapale U.C., S. Chand, 2006. Modeling for shell-side pressure drop for liquid flow in shell-and-tube heat exchanger. *International Journal of Heat and Mass Transfer* 49, 601-610.
- Kern D. Q., 1950. *Process heat transfer*.
- Pereira I. P. S., M. J. Bagajewicz, A. L. H. Costa, 2021. Global optimization of the design of horizontal shell and tube condensers. *Chemical Engineering Science*, 236, 116474.
- Serth R. W., 2007. *Process heat transfer: principles and applications*, 1st ed. ed. Elsevier, Oxford .:
- Serth R. W., T. G. Lestina, 2014. *Process Heat Transfer: Principles, Applications and Rules of Thumb*. Academic press.
- Yang Z., Y. Ma, N. Zhang, R. Smith, 2020. Design optimization of shell and tube heat exchangers sizing with heat transfer enhancement. *Computers & Chemical Engineering* 137, 106821.

## Part C

The preliminary runs using floating heads used to validate the set trimming are shown in Table SC1 and SC2. The literature values in these table are derived from Pereira et al. (2021). From table SC1, one can conclude that the areas of the vertical condensers are larger than those of horizontal condensers, because for shell-side condensation, the optimal coefficient is 43.1% higher in horizontal than in vertical condensers, and for tube-side condensation condensers it is 100.1% higher.

**Table SC1: Example 1: Results for minimizing area (floating head)**

	HS	HT	VS	VT	HS-literature value
Heat transfer area (m <sup>2</sup> )	100.6	90.2	145.4	181.7	100.6
Tube-side velocity (m/s)	2.2	22.3	2.4	22.9	2.2
Shell-side velocity (m/s)	24.3	1.3	10.5	1.0	24.3
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	776	867	542	433	776
Tube-side pressure drop (kPa)	40.9	2.1	69.9	5.5	48.9
Shell-side pressure drop (kPa)	16.7	79.1	9.3	108.2	16.7

In Table SC2, the heat exchange area of the vertical condenser was greater than that of the horizontal condenser for the same condensing position. Additionally, the pressure drop of the vertical condenser is significantly higher than that of the horizontal condenser.

**Table SC2: Example 2: Results for minimizing area (floating head)**

	HS	HT	VS	VT	HS-literature value
Area (m <sup>2</sup> )	118.2	126.4	138.9	170.0	118.2
Tube-side velocity (m/s)	2.9	17.5	2.9	25.5	2.9
Shell-side velocity (m/s)	21.6	2.1	10.1	1.4	21.6
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,339	1,281	1,151	937	1,339
Tube-side pressure drop (Pa)	25,938	3,583	32,731	16,374	36,076
Shell-side pressure drop (Pa)	18,413	103,180	11,512	101,295	18,413

The detailed results of Example 1 are presented in Tables SC3-SC16, where Tables SC3, SC5, SC6, and SC9 are the design solutions for minimizing area using the general models, tube-side intensification models, and shell-side intensification models, respectively. Tables SC11, SC12, and SC15 show the design data for minimizing TAC using tube-side intensification models and shell-side intensification models, respectively. Other Tables show velocities, heat transfer coefficients and pressure drop values.

Note: According to the representation of the overall heat transfer coefficients in equations (10) and (11), the indication of the heat transfer area in the following tables corresponds to Eq. (2). The indication of tube area in the following tables corresponds the area used in the evaluation for the heat exchanger investment. They are the same in all options except for the externally finned heat exchangers. In these cases, the tube area is evaluated by equation (3).

The result display of Example 2 is the same as Example 1, numbered SC17- SC30.

The design results of the cooling fluid pressure reduction limit of 20kPa for Example 1 are shown in Tables SC31- SC42. The design results of the cooling fluid pressure reduction limit of 40kPa for Example 1 are shown in Tables SC43- SC54. The design results of the cooling fluid pressure reduction limit of 60kPa for Example 1 are shown in Tables SC55- SC66.

The design results of the cooling fluid pressure reduction limit of 20kPa for Example 2 are shown in Tables SC67- SC78. The design results of the cooling fluid pressure reduction limit of 40kPa for Example 2 are shown in Tables SC79- SC90. The design results of the cooling fluid pressure reduction limit of 60kPa for Example 2 are shown in Tables SC91- SC102.

**Table SC3:** Example 1: Design solutions with general models for minimizing area

	HS	HT	VS	VT	ILP-HS
Heat transfer area (m <sup>2</sup> )	100.6	90.2	145.4	186.9	100.6
Total number of tubes	547	736	690	1084	547
Tube diameter (m)	0.016	0.016	0.022	0.018	0.016
Tube length (m)	3.659	2.439	3.049	3.049	3.659
Tube pitch ratio	1.33	1.25	1.33	1.33	1.33
Tube layout	Triangular	Triangular	Triangular	Square	Triangular
Number of tube passes	2	1	6	1	2
Shell diameter (m)	0.591	0.635	0.940	0.991	0.591
Number of baffles	6	5	3	10	6

**Table SC4:** Example 1: Other results for the above design solutions

	HS	HT	VS	VT	ILP-HS
Tube-side velocity (m/s)	2.2	22.3	2.4	11.1	2.2
Shell-side velocity (m/s)	24.3	1.3	10.5	1.0	24.3
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,077.3	2,044.4	9,713.5	747.1	10,077.3
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,334.6	7,677.4	748.2	4,874.4	1,334.6
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	775.5	866.9	541.8	436.3	775.5
Tube-side pressure drop (Pa)	40,913.3	2,101.7	69,877.2	660.5	48,932
Shell-side pressure drop (Pa)	16,727.3	79,098.0	9,335.0	108,221.9	16,727

**Table SC5:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	39,582.4	41,308.3	43,314.2	41,859.5
Heat transfer area (m <sup>2</sup> )	99.3	95.7	66.9	100.2
Tube area (m <sup>2</sup> )	99.3	95.7	66.9	100.2
Total number of tubes	360	227	546	581
Tube diameter (m)	0.018	0.022	0.016	0.018
Tube length (m)	4.877	6.098	2.439	3.049
Tube pitch ratio	1.33	1.5	1.33	1.33
Tube layout	Square	Square	Square	Square
Number of tube passes	2	2	2	2
Shell diameter (m)	0.540	0.591	0.591	0.686
Number of baffles	9	10	4	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC6:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	53,484.4	56,503.6	56,127.6	56,009.8
Heat transfer area (m <sup>2</sup> )	144.6	141.5	92.5	144.2
Tube area (m <sup>2</sup> )	144.6	141.5	92.5	144.2
Total number of tubes	755	591	671	602
Tube diameter (m)	0.020	0.025	0.018	0.025
Tube length (m)	3.049	3.049	2.439	3.049
Tube pitch ratio	1.5	1.33	1.33	1.25
Tube layout	Triangular	Square	Square	Square
Number of tube passes	6	6	2	4
Shell diameter (m)	0.940	0.991	0.737	0.940
Number of baffles	5	6	4	3
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.044179	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC7:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.5	2.4	2.2	2.5
Shell-side velocity (m/s)	28.4	17.0	26.0	17.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,670.3	17,349.6	9,791.3	13,515.1
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,331.3	1,294.6	1,159.3	1,266.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	788.0	815.4	710.9	779.9
Tube-side pressure drop (Pa)	55,450.3	86,434.6	91,136.7	103,719.6
Shell-side pressure drop (Pa)	18,199.3	4,241.1	9,723.1	4,998.1

**Table SC8:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	2.7	2.0	1.3	1.9
Shell-side velocity (m/s)	11.7	17.4	20.8	13.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	11,173.1	13,836.8	3,0087.5	9,923.2
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	746.9	741.5	693.3	746.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	543.4	552.1	531.2	544.4
Tube-side pressure drop (Pa)	104,637.3	66,846.5	76,001.2	69,450.8
Shell-side pressure drop (Pa)	9359.2	15,085.0	16,498.3	7,824.8

**Table SC9:** Example 1: Design solutions with shell-side intensification models for minimizing  $C_A$ 

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	36,548.4	34,842.7	39,065.4	62,646.9	60,196.1	71,372.8
Heat transfer area (m <sup>2</sup> )	89.9	51.0	86.7	176.2	101.0	184.2
Tube area (m <sup>2</sup> )	89.9	51.0	86.7	176.2	101.0	184.2
Total number of tubes	733	311	419	920	847	890
Tube diameter (m)	0.016	0.022	0.018	0.020	0.016	0.018
Tube length (m)	2.439	2.439	3.659	3.049	2.439	3.659
Tube pitch ratio	1.25	1.5	1.25	1.25	1.25	1.25
Tube layout	Triangular	Triangular	Square	Square	Triangular	Square
Number of tube passes	1	1	1	1	1	1
Shell diameter (m)	0.591	0.635	0.540	0.889	0.635	0.787
Number of baffles	5	18	6	7	4	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	20°

**Table SC10:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	22.4	23.5	28.8	10.1	19.4	13.6
Shell-side velocity (m/s)	1.4	2.6	2.7	1.0	1.1	2.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,041.6	1,534.1	1,939.7	739.5	653.7	699.6
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,986.6	4,377.9	13,169.4	5,184.9	5,312.9	10,956.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	870.0	787.4	905.2	445.4	398.0	435.7
Tube-side pressure drop (Pa)	2,116.4	1,360.9	4,003.5	465.9	1,654.5	1,106.2
Shell-side pressure drop (Pa)	83,847.2	48,599.1	27,986.0	92,672.2	45,511.4	29,281.6

**Table SC11:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	11,727.3	12,238.5	13,149.7	13,018.3
Heat transfer area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Tube area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Total number of tubes	594	216	588	150
Tube diameter (m)	0.016	0.032	0.016	0.038
Tube length (m)	3.659	4.877	2.439	6.098
Tube pitch ratio	1.5	1.5	1.5	1.33
Tube layout	Square	Square	Triangular	Square
Number of tube passes	1	2	1	2
Shell diameter (m)	0.686	0.838	0.635	0.737
Number of baffles	5	20	3	8
Twisted-Tapes pitch (m)	\	\	\	0.131850
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC12:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	15,350.2	16,494.9	18,310.0	17,427.2
Heat transfer area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Tube area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Total number of tubes	886	409	588	858
Tube diameter (m)	0.018	0.032	0.016	0.018
Tube length (m)	3.049	3.659	3.659	3.049
Tube pitch ratio	1.5	1.25	1.5	1.5
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	2	4	1	2
Shell diameter (m)	0.889	0.991	0.635	0.940
Number of baffles	4	6	5	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC13:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.0	1.0	1.0	1.2
Shell-side velocity (m/s)	13.3	28.7	14.4	15.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,418.4	8,023.5	5,036.0	5,934.5
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,352.1	1,188.5	1,178.5	1,180.8
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	717.6	740.8	657.4	716.5
Tube-side pressure drop (Pa)	5,167.4	4,754.4	11,641.6	13,474.9
Shell-side pressure drop (Pa)	2,517.3	18,902.7	2,355.6	2,886.4

**Table SC14:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.0	1.1	1.0	1.3
Shell-side velocity (m/s)	10.3	17.9	14.4	11.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,191.3	8,345.9	5,036.0	7,788.1
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	760.6	712.1	637.9	752.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	510.3	524.3	446.4	528.7
Tube-side pressure drop (Pa)	6,932.4	9,561.2	17,464.9	26,599.3
Shell-side pressure drop (Pa)	6,561.0	19,751.8	12,046.1	3,644.7

**Table SC15:** Example 1: Design solutions with shell-side intensification models for minimizing  $TAC$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	12,268.9	10,608.5	10,976.4	24,690.2	17,952.1	19160.5
Heat transfer area (m <sup>2</sup> )	93.2	55.9	92.3	176.2	105.6	186.4
Tube area (m <sup>2</sup> )	93.2	55.9	92.3	176.2	105.6	186.4
Total number of tubes	676	250	669	920	626	901
Tube diameter (m)	0.018	0.030	0.018	0.020	0.018	0.018
Tube length (m)	2.439	2.439	2.439	3.049	3.049	3.659
Tube pitch ratio	1.25	1.5	1.25	1.25	1.5	1.25
Tube layout	Square	Triangular	Triangular	Square	Triangular	Triangular
Number of tube passes	1	2	1	1	1	1
Shell diameter (m)	0.686	0.787	0.635	0.889	0.737	0.737
Number of baffles	4	9	3	7	10	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC16:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.9	28.0	18.1	10.1	19.3	13.4
Shell-side velocity (m/s)	1.0	1.1	2.0	1.0	1.0	1.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,987.3	1,426.5	1,980.4	739.5	622.1	702.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,473.9	2,430.5	6,390.6	5,184.9	2,918.0	5,499.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	836.4	735.4	853.5	445.4	385.0	420.5
Tube-side pressure drop (Pa)	1,176.4	2,319.4	1,197.5	465.9	1,676.5	1,083.4
Shell-side pressure drop (Pa)	26,552.4	8,132.7	1,638.6	92,672.2	17,029.3	1,663.6

**Table SC17:** Example 2: Design solutions for general optimization

	HS	HT	VS	VT	ILP-HS
Heat transfer area (m <sup>2</sup> )	118.2	126.4	138.9	171.5	118.2
Total number of tubes	617	550	604	678	617
Tube diameter (m)	0.020	0.020	0.020	0.022	0.020
Tube length (m)	3.049	3.659	3.659	3.659	3.049
Tube pitch ratio	1.25	1.25	1.5	1.25	1.25
Tube layout	Triangular	Triangular	Square	Triangular	Triangular
Number of tube passes	2	1	2	1	2
Shell diameter (m)	0.737	0.686	0.940	0.838	0.737
Number of baffles	4	5	5	4	4

**Table SC18:** Example 2: Other results of the design solutions

	HS	HT	VS	VT	ILP-HS
Tube-side velocity (m/s)	2.9	17.5	2.9	11.2	2.9
Shell-side velocity (m/s)	21.6	2.1	10.1	1.4	21.6
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,510.3	11,293.6	5,604.9	3,692.9	5,510.3
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,866.4	3,696.9	3,687.0	2,869.8	6,866.4
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,338.6	1,280.8	1,151.0	932.0	1,338.6
Tube-side pressure drop (Pa)	25,837.8	3,583.4	32,731.8	1,428.8	36,076.0
Shell-side pressure drop (Pa)	18,413.0	103,180.4	11,512.6	109,392.2	18,413.0

**Table SC19:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$ 

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	45,391.0	42,761.1	41,046.9	45,530.2
Heat transfer area (m <sup>2</sup> )	117.8	99.9	62.6	111.3
Tube area (m <sup>2</sup> )	117.8	99.9	62.6	111.3
Total number of tubes	615	326	297	484
Tube diameter (m)	0.020	0.020	0.022	0.020
Tube length (m)	3.049	4.877	3.659	3.659
Tube pitch ratio	1.25	1.5	1.33	1.33
Tube layout	Square	Triangular	Square	Square
Number of tube passes	2	1	1	1
Shell diameter (m)	0.737	0.591	0.591	0.686
Number of baffles	4	8	5	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.002491	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	45°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC20:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	50,976.0	49,833.6	47,314.9	52,167.7
Heat transfer area (m <sup>2</sup> )	136.2	121.0	74.8	131.9
Tube area (m <sup>2</sup> )	136.2	121.0	74.8	131.9
Total number of tubes	474	574	542	459
Tube diameter (m)	0.030	0.022	0.018	0.025
Tube length (m)	3.049	3.049	2.439	3.659
Tube pitch ratio	1.33	1.5	1.5	1.5
Tube layout	Triangular	Square	Triangular	Triangular
Number of tube passes	4	2	1	2
Shell diameter (m)	0.991	0.940	0.686	0.889
Number of baffles	3	4	3	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.003
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.002491	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC21:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.9	2.7	2.4	2.8
Shell-side velocity (m/s)	21.5	18.1	26.0	18.6
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,524.6	10,908.2	29,599.5	6,803.8
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,815.4	6,922.8	5,798.2	6,867.9
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,333.7	1,578.2	1,709.3	1,420.6
Tube-side pressure drop (Pa)	26,382.4	98,792.8	98,705.0	40,221.0
Shell-side pressure drop (Pa)	19,735.0	12,948.6	18,004.6	12,837.3

**Table SC22:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	2.8	2.4	2.1	3.0
Shell-side velocity (m/s)	10.3	10.1	13.9	10.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,943.8	10,320.4	21,729.4	6,651.2
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,893.0	3,742.0	3,433.6	3,624.4
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,171.9	1,321.1	1,371.3	1,216.0
Tube-side pressure drop (Pa)	29,268.1	93,677.7	59,565.5	55,685.8
Shell-side pressure drop (Pa)	19,387.7	8,585.6	16,641.0	13,723.7

**Table SC23:** Example 2: Design solutions with shell-side intensification models for minimizing  $C_A$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	47,368.2	38,240.7	50,617.4	62,603.4	47,674.0	60,667.5
Heat transfer area (m <sup>2</sup> )	124.3	57.2	119.8	176.1	75.5	150.3
Tube area (m <sup>2</sup> )	124.3	57.2	119.8	176.1	75.5	150.3
Total number of tubes	901	427	391	1,149	405	523
Tube diameter (m)	0.018	0.018	0.032	0.016	0.025	0.025
Tube length (m)	2.439	2.439	3.049	3.049	2.439	3.659
Tube pitch ratio	1.25	1.33	1.25	1.33	1.25	1.25
Tube layout	Triangular	Triangular	Square	Triangular	Triangular	Square
Number of tube passes	1	1	2	1	1	1
Shell diameter (m)	0.737	0.54	0.940	0.787	0.686	0.838
Number of baffles	3	4	3	4	4	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC24:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	14.0	29.4	16.1	14.9	13.8	10.7
Shell-side velocity (m/s)	2.0	2.7	2.4	1.5	2.6	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	11,629.7	9,067.1	9,484.9	3,846.2	3,274.1	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,726.8	3,944.8	3,784.8	2,975.7	3,403.1	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,271.8	1,423.1	1,314.5	908.7	1,083.3	1,075.5
Tube-side pressure drop (Pa)	1,912.1	7,003.6	2,554.9	3,256.6	1,121.0	1,079.4
Shell-side pressure drop (Pa)	73,567.3	109,047.8	4,194.0	104,933.2	94,238.0	9,476.3

**Table SC25:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	15,014.4	14,676.1	13,596.3	15,463.9
Heat transfer area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Tube area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Total number of tubes	400	590	282	467
Tube diameter (m)	0.022	0.022	0.032	0.025
Tube length (m)	4.877	3.049	2.439	3.659
Tube pitch ratio	1.33	1.5	1.25	1.25
Tube layout	Square	Square	Square	Triangular
Number of tube passes	1	1	1	1
Shell diameter (m)	0.686	0.94	0.787	0.737
Number of baffles	7	9	3	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC26:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	16,758.5	16,167.7	16,010.5	17,248.0
Heat transfer area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Tube area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Total number of tubes	788	681	317	794
Tube diameter (m)	0.018	0.022	0.03	0.02
Tube length (m)	3.659	3.049	3.049	3.049
Tube pitch ratio	1.5	1.5	1.5	1.5
Tube layout	Square	Triangular	Square	Square
Number of tube passes	1	1	1	1
Shell diameter (m)	0.889	0.94	0.94	0.991
Number of baffles	5	4	4	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC27:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.7	1.2	1.0	1.4
Shell-side velocity (m/s)	18.7	20.3	20.2	17.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,621.2	4,747.9	13,161.9	3,521.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,244.0	6,753.6	5,320.8	6,813.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,180.9	1,287.4	1,571.0	1,173.3
Tube-side pressure drop (Pa)	7,367.6	5,440.7	8,218.8	6,640.1
Shell-side pressure drop (Pa)	15,293.5	18,957.7	8,565.4	15,848.2

**Table SC28:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.5	1.0	1.1	1.4
Shell-side velocity (m/s)	10.7	10.1	10.1	11.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,309.3	4,282.0	9,577.8	3,751.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,889.8	3,961.4	3,404.5	4,039.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	976.2	1,099.9	1,286.5	1,046.7
Tube-side pressure drop (Pa)	5,408.1	4,814.6	6,111.4	8,019.3
Shell-side pressure drop (Pa)	13,637.6	12,630.8	5,981.7	15,392.3

**Table SC29:** Example 2: Design solutions with shell-side intensification models for minimizing *TAC*

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	18,311.5	14,230.0	14,306.9	25,757.4	17,673.7	18,159.8
Heat transfer area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Tube area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Total number of tubes	424	419	391	1269	291	523
Tube diameter (m)	0.032	0.022	0.032	0.016	0.030	0.025
Tube length (m)	3.659	2.439	3.049	3.049	3.659	3.659
Tube pitch ratio	1.25	1.5	1.25	1.33	1.5	1.25
Tube layout	Triangular	Triangular	Square	Square	Triangular	Square
Number of tube passes	4	1	2	1	1	1
Shell diameter (m)	0.940	0.737	0.940	0.889	0.838	0.838
Number of baffles	3	3	3	3	5	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC30:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	29.7	18.2	16.1	13.5	12.5	10.7
Shell-side velocity (m/s)	1.0	1.2	2.4	1.1	1.1	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,355.4	9,010.1	9,484.9	3,975.7	3,148.9	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,013.2	1,767.5	3,784.8	2,171.8	1,383.3	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,017.2	1,185.5	1,314.5	824.0	872.8	1,075.5
Tube-side pressure drop (Pa)	18,134.6	2,194.5	2,554.9	2,745.7	1,086.4	1,079.4
Shell-side pressure drop (Pa)	14,616.7	11,267.7	4,194.0	34,623.7	9,260.5	9,476.3

**Table SC31:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$ 

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	41,138.6	43,190.2	45,959.8	43,307.1
Heat transfer area (m <sup>2</sup> )	104.2	101.2	72.1	104.5
Tube area (m <sup>2</sup> )	104.2	101.2	72.1	104.5
Total number of tubes	425	176	588	248
Tube diameter (m)	0.016	0.03	0.016	0.022
Tube length (m)	4.877	6.098	2.439	6.098
Tube pitch ratio	1.5	1.25	1.5	1.33
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	1	2	1	1
Shell diameter (m)	0.540	0.591	0.635	0.540
Number of baffles	9	10	3	11
Twisted-Tapes pitch (m)	\	\	\	0.103275
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC32:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	54,755.8	57,343.4	63,576.8	NA
Heat transfer area (m <sup>2</sup> )	148.9	144.2	108.1	
Tube area (m <sup>2</sup> )	148.9	144.2	108.1	
Total number of tubes	622	602	588	
Tube diameter (m)	0.025	0.025	0.016	
Tube length (m)	3.049	3.049	3.659	
Tube pitch ratio	1.25	1.25	1.5	
Tube layout	Triangular	Square	Triangular	
Number of tube passes	4	4	1	
Shell diameter (m)	0.889	0.94	0.635	
Number of baffles	3	3	5	
Twisted-Tapes pitch (m)	\	\	\	
Twisted-Tapes thickness (m)	\	\	\	
Coiled-Wire helical pitch (m)	\	0.044179	\	
Coiled-Wire diameter (m)	\	0.001411	\	
Number of internal fins per unit length	\	\	50	
Helical angle of internal fins	\	\	35°	
Height of internal fins (m)	\	\	0.000332	

**Table SC33:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.4	1.5	1.0	1.3
Shell-side velocity (m/s)	21.2	28.4	14.4	27.3
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,082.5	10,275.2	5,036.0	7,273.0
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,381.3	1,223.5	1,178.5	1,320.4
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	757.6	770.3	657.4	764.0
Tube-side pressure drop (Pa)	12,451.3	15,094.3	11,641.6	18,101.2
Shell-side pressure drop (Pa)	10,068.3	15,719.3	2,355.6	15,971.7

**Table SC34:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.3	1.3	1.0	NA
Shell-side velocity (m/s)	13.7	13.0	14.4	
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,781.6	10,197.3	5,036.0	
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	754.3	746.1	637.9	
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	524.0	545.4	446.4	
Tube-side pressure drop (Pa)	12,880.4	19,625.9	17,464.9	
Shell-side pressure drop (Pa)	19,650.7	7,824.8	12,046.1	

**Table SC35:** Example 1: Design solutions with shell-side intensification models for minimizing  $C_A$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	NA	34,860.6	39,532.7	NA	62,365.6	71,436.9
Heat transfer area (m <sup>2</sup> )		51.0	88.0		105.6	184.4
Tube area (m <sup>2</sup> )		51.0	88.0		105.6	184.4
Total number of tubes		512	522		626	891
Tube diameter (m)		0.018	0.022		0.018	0.018
Tube length (m)		1.829	2.439		3.049	3.659
Tube pitch ratio		1.33	1.25		1.5	1.33
Tube layout		Triangular	Square		Triangular	Square
Number of tube passes		1	1		1	1
Shell diameter (m)		0.591	0.737		0.737	0.838
Number of baffles		3	3		10	4
Number of external fins per unit length		210	\		210	\
Helical angle of helical baffle		\	20°		\	20°

**Table SC36:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	NA	23.6	14.0	NA	19.3	13.6
Shell-side velocity (m/s)		1.0	2.3		1.0	1.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))		1,645.8	1,823.2		622.1	699.8
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))		4,397.4	10,745.2		2,918.0	7,197.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))		792.4	890.9		385.0	427.0
Tube-side pressure drop (Pa)		1,418.2	560.4		1,676.5	1,104.1
Shell-side pressure drop (Pa)		18,648.9	18,464.1		17,029.3	8,204.3

**Table SC37:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	11,727.3	12,238.5	13,149.7	13,018.3
Heat transfer area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Tube area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Total number of tubes	594	216	588	150
Tube diameter (m)	0.016	0.032	0.016	0.038
Tube length (m)	3.659	4.877	2.439	6.098
Tube pitch ratio	1.5	1.5	1.5	1.33
Tube layout	Square	Square	Triangular	Square
Number of tube passes	1	2	1	2
Shell diameter (m)	0.686	0.838	0.635	0.737
Number of baffles	5	20	3	8
Twisted-Tapes pitch (m)	\	\	\	0.131850
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC38:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	15,350.2	16,494.9	18,310.0	NA
Heat transfer area (m <sup>2</sup> )	152.8	150.4	108.1	
Tube area (m <sup>2</sup> )	152.8	150.4	108.1	
Total number of tubes	886	409	588	
Tube diameter (m)	0.018	0.032	0.016	
Tube length (m)	3.049	3.659	3.659	
Tube pitch ratio	1.5	1.25	1.5	
Tube layout	Triangular	Square	Triangular	
Number of tube passes	2	4	1	
Shell diameter (m)	0.889	0.991	0.635	
Number of baffles	4	6	5	
Twisted-Tapes pitch (m)	\	\	\	
Twisted-Tapes thickness (m)	\	\	\	
Coiled-Wire helical pitch (m)	\	0.056402	\	
Coiled-Wire diameter (m)	\	0.001411	\	
Number of internal fins per unit length	\	\	50	
Helical angle of internal fins	\	\	35°	
Height of internal fins (m)	\	\	0.000332	

**Table SC39:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.0	1.0	1.0	1.2
Shell-side velocity (m/s)	13.3	28.7	14.4	15.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,418.4	8,023.5	5,036.0	5,934.5
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,352.1	1,188.5	1,178.5	1,180.8
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	717.6	740.8	657.4	716.5
Tube-side pressure drop (Pa)	5,167.4	4,754.4	11,641.6	13,474.9
Shell-side pressure drop (Pa)	2,517.3	18,902.7	2,355.6	2,886.4

**Table SC40:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.0	1.1	1.0	NA
Shell-side velocity (m/s)	10.3	17.9	14.4	
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,191.3	8,345.9	5,036.0	
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	760.6	712.1	637.9	
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	510.3	524.3	446.4	
Tube-side pressure drop (Pa)	6,932.4	9,561.2	17,464.9	
Shell-side pressure drop (Pa)	6,561.0	19,751.8	12,046.1	

**Table SC41:** Example 1: Design solutions with shell-side intensification models for minimizing *TAC*

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	NA	10,608.5	10,976.4	NA	17,952.1	19,160.4
Heat transfer area (m <sup>2</sup> )		55.9	92.3		105.6	186.4
Tube area (m <sup>2</sup> )		55.9	92.3		105.6	186.4
Total number of tubes		250	669		626	901
Tube diameter (m)		0.03	0.018		0.018	0.018
Tube length (m)		2.439	2.439		3.049	3.659
Tube pitch ratio		1.5	1.25		1.5	1.25
Tube layout		Triangular	Triangular		Triangular	Triangular
Number of tube passes		2	1		1	1
Shell diameter (m)		0.787	0.635		0.737	0.737
Number of baffles		9	3		10	4
Number of external fins per unit length		210	\		210	\
Helical angle of helical baffle		\	30°		\	30°

**Table SC42:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	NA	1.1	2.0	NA	1.0	1.5
Shell-side velocity (m/s)		1,426.5	1,980.4		622.1	702.4
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))		2,430.5	6,390.6		2,918.0	5,499.1
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))		735.4	853.5		385.0	420.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))		2,319.4	1,197.5		1,676.5	1,083.4
Tube-side pressure drop (Pa)		8,132.7	1,638.6		17,029.3	1,663.6
Shell-side pressure drop (Pa)		1.1	2.0		1.0	1.5

**Table SC43:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	40,809.1	42,915.2	44,538.5	42,482.6
Heat transfer area (m <sup>2</sup> )	103.1	100.3	69.3	102.0
Tube area (m <sup>2</sup> )	103.1	100.3	69.3	102.0
Total number of tubes	306	291	402	370
Tube diameter (m)	0.022	0.018	0.018	0.018
Tube length (m)	4.877	6.098	3.049	4.877
Tube pitch ratio	1.5	1.5	1.5	1.33
Tube layout	Square	Square	Triangular	Square
Number of tube passes	2	1	1	1
Shell diameter (m)	0.686	0.54	0.591	0.54
Number of baffles	7	11	5	9
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.044179	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC44:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	54,755.8	57,343.4	63,386.6	56,901.3
Heat transfer area (m <sup>2</sup> )	148.9	144.2	107.7	147.0
Tube area (m <sup>2</sup> )	148.9	144.2	107.7	147.0
Total number of tubes	622	602	296	614
Tube diameter (m)	0.025	0.025	0.038	0.025
Tube length (m)	3.049	3.049	3.049	3.049
Tube pitch ratio	1.25	1.25	1.33	1.33
Tube layout	Triangular	Square	Triangular	Triangular
Number of tube passes	4	4	4	4
Shell diameter (m)	0.889	0.94	0.991	0.94
Number of baffles	3	3	4	3
Twisted-Tapes pitch (m)	\	\	\	0.103275
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.044179	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC45:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.8	1.5	1.1	1.5
Shell-side velocity (m/s)	13.3	20.3	18.6	28.4
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,730.0	10,956.7	25,724.2	8,766.7
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,284.1	1,368.1	1,166.7	1,339.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	757.3	802.8	766.6	774.8
Tube-side pressure drop (Pa)	22,226.0	38,547.1	34,458.1	27,560.2
Shell-side pressure drop (Pa)	2,300.5	7,397.7	4,530.7	18,199.3

**Table SC46:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.3	1.3	1.0	1.5
Shell-side velocity (m/s)	13.7	13.0	12.4	10.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,781.6	10,197.3	21,736.3	8,068.8
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	754.3	746.1	677.1	751.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	524.0	545.4	529.4	538.9
Tube-side pressure drop (Pa)	12,880.4	19,625.9	32,626.5	39,758.3
Shell-side pressure drop (Pa)	19,650.7	7,824.8	9,283.1	8,102.0

**Table SC47:** Example 1: Design solutions with shell-side intensification models for minimizing  $C_A$ 

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	37,641.3	34,860.6	39,065.4	NA	60,463.2	71,372.8
Heat transfer area (m <sup>2</sup> )	93.2	51.0	86.7		101.6	184.2
Tube area (m <sup>2</sup> )	93.2	51.0	86.7		101.6	184.2
Total number of tubes	676	512	419		542	890
Tube diameter (m)	0.018	0.018	0.018		0.02	0.018
Tube length (m)	2.439	1.829	3.659		3.049	3.659
Tube pitch ratio	1.25	1.33	1.25		1.25	1.25
Tube layout	Square	Triangular	Square		Triangular	Square
Number of tube passes	1	1	1		1	1
Shell diameter (m)	0.686	0.591	0.54		0.635	0.787
Number of baffles	4	3	6		5	4
Number of external fins per unit length	\	210	\		210	\
Helical angle of helical baffle	\	\	30°		\	20°

**Table SC48:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.9	23.6	28.8	NA	17.1	13.6
Shell-side velocity (m/s)	1.0	1.0	2.7		1.0	2.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,987.3	1,645.8	1,939.7		620.0	699.6
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,473.9	4,397.4	13,169.4		4,824.0	10,956.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	836.4	792.4	905.2		402.4	435.7
Tube-side pressure drop (Pa)	1,176.4	1,418.2	4,003.5		1,143.5	1,106.2
Shell-side pressure drop (Pa)	26,552.4	18,648.9	27,986.0		39,883.7	29,281.6

**Table SC49:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	11,727.3	12,238.5	13,149.7	13,018.3
Heat transfer area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Tube area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Total number of tubes	594	216	588	150
Tube diameter (m)	0.016	0.032	0.016	0.038
Tube length (m)	3.659	4.877	2.439	6.098
Tube pitch ratio	1.5	1.5	1.5	1.33
Tube layout	Square	Square	Triangular	Square
Number of tube passes	1	2	1	2
Shell diameter (m)	0.686	0.838	0.635	0.737
Number of baffles	5	20	3	8
Twisted-Tapes pitch (m)	\	\	\	0.131850
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC50:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	15,350.2	16,494.9	18,310.0	17,427.2
Heat transfer area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Tube area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Total number of tubes	886	409	588	858
Tube diameter (m)	0.018	0.032	0.016	0.018
Tube length (m)	3.049	3.659	3.659	3.049
Tube pitch ratio	1.5	1.25	1.5	1.5
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	2	4	1	2
Shell diameter (m)	0.889	0.991	0.635	0.94
Number of baffles	4	6	5	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC51:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.0	1.0	1.0	1.2
Shell-side velocity (m/s)	13.3	28.7	14.4	15.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,418.4	8,023.5	5,036.0	5,934.5
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,352.1	1,188.5	1,178.5	1,180.8
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	717.6	740.8	657.4	716.5
Tube-side pressure drop (Pa)	5,167.4	4,754.4	11,641.6	13,474.9
Shell-side pressure drop (Pa)	2,517.3	18,902.7	2,355.6	2,886.4

**Table SC52:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.0	1.1	1.0	1.3
Shell-side velocity (m/s)	10.3	17.9	14.4	11.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,191.3	8,345.9	5,036.0	7,788.1
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	760.6	712.1	637.9	752.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	510.3	524.3	446.4	528.7
Tube-side pressure drop (Pa)	6,932.4	9,561.2	17,464.9	26,599.3
Shell-side pressure drop (Pa)	6,561.0	19,751.8	12,046.1	3,644.7

**Table SC53:** Example 1: Design solutions with shell-side intensification models for minimizing  $TAC$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	12,268.9	10,608.5	10,976.4	NA	17,952.1	19,160.4
Heat transfer area (m <sup>2</sup> )	93.2	55.9	92.3		105.6	186.4
Tube area (m <sup>2</sup> )	93.2	55.9	92.3		105.6	186.4
Total number of tubes	676	250	669		626	901
Tube diameter (m)	0.018	0.03	0.018		0.018	0.018
Tube length (m)	2.439	2.439	2.439		3.049	3.659
Tube pitch ratio	1.25	1.5	1.25		1.5	1.25
Tube layout	Square	Triangular	Triangular		Triangular	Triangular
Number of tube passes	1	2	1		1	1
Shell diameter (m)	0.686	0.787	0.635		0.737	0.737
Number of baffles	4	9	3		10	4
Number of external fins per unit length	\	210	\		210	\
Helical angle of helical baffle	\	\	30°		\	30°

**Table SC54:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.9	28.0	18.1	NA	19.3	13.4
Shell-side velocity (m/s)	1.0	1.1	2.0		1.0	1.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,987.3	1,426.5	1,980.4		622.1	702.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,473.9	2,430.5	6,390.6		2,918.0	5,499.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	836.4	735.4	853.5		385.0	420.5
Tube-side pressure drop (Pa)	1,176.4	2,319.4	1,197.5		1,676.5	1,083.4
Shell-side pressure drop (Pa)	26,552.4	8,132.7	1,638.6		17,029.3	1,663.6

**Table SC55:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	39,582.4	41,814.0	43,699.4	41,917.1
Heat transfer area (m <sup>2</sup> )	99.3	97.1	67.7	100.3
Tube area (m <sup>2</sup> )	99.3	97.1	67.7	100.3
Total number of tubes	360	317	368	291
Tube diameter (m)	0.018	0.02	0.016	0.018
Tube length (m)	4.877	4.877	3.659	6.098
Tube pitch ratio	1.33	1.5	1.5	1.5
Tube layout	Square	Square	Square	Square
Number of tube passes	2	2	1	1
Shell diameter (m)	0.54	0.635	0.54	0.54
Number of baffles	9	13	6	11
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC56:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	54,191.7	57,068.9	60,812.7	56,009.8
Heat transfer area (m <sup>2</sup> )	147.0	143.3	102.3	144.2
Tube area (m <sup>2</sup> )	147.0	143.3	102.3	144.2
Total number of tubes	614	748	267	602
Tube diameter (m)	0.025	0.02	0.04	0.025
Tube length (m)	3.049	3.049	3.049	3.049
Tube pitch ratio	1.33	1.25	1.33	1.25
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	6	4	4	4
Shell diameter (m)	0.94	0.838	0.991	0.94
Number of baffles	3	3	4	3
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.003
Coiled-Wire helical pitch (m)	\	0.044179	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000586	\

**Table SC57:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.5	2.2	1.7	2.0
Shell-side velocity (m/s)	28.4	25.2	19.8	20.3
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,670.3	15,988.9	7,566.4	10,623.9
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,331.3	1,294.3	1,215.7	1,368.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	788.0	806.2	710.9	800.4
Tube-side pressure drop (Pa)	55,450.3	59,320.7	40,070.3	52,463.5
Shell-side pressure drop (Pa)	18,199.3	13,233.4	4,716.0	7,397.7

**Table SC58:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.9	1.8	1.0	1.8
Shell-side velocity (m/s)	10.5	14.6	12.4	13.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	8,080.1	12,582.9	29,269.6	9,224.2
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	751.0	744.6	665.5	746.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	539.0	545.9	526.4	541.7
Tube-side pressure drop (Pa)	41,112.7	47,604.3	55,809.6	56,507.7
Shell-side pressure drop (Pa)	8,102.0	11,159.3	8,772.9	7,824.8

**Table SC59:** Example 1: Design solutions with shell-side intensification models for minimizing  $C_A$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	37,145.5	34,842.7	39,065.4	NA	60,196.1	71,372.8
Heat transfer area (m <sup>2</sup> )	91.7	51.0	86.7		101.0	184.2
Tube area (m <sup>2</sup> )	91.7	51.0	86.7		101.0	184.2
Total number of tubes	748	311	419		847	890
Tube diameter (m)	0.016	0.022	0.018		0.016	0.018
Tube length (m)	2.439	2.439	3.659		2.439	3.659
Tube pitch ratio	1.33	1.5	1.25		1.25	1.25
Tube layout	Triangular	Triangular	Square		Triangular	Square
Number of tube passes	1	1	1		1	1
Shell diameter (m)	0.635	0.635	0.54		0.635	0.787
Number of baffles	6	18	6		4	4
Number of external fins per unit length	\	210	\		210	\
Helical angle of helical baffle	\	\	30°		\	20°

**Table SC60:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	22.0	23.5	28.8	NA	19.4	13.6
Shell-side velocity (m/s)	1.3	2.6	2.7		1.1	2.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,055.5	1,534.1	1,939.7		653.7	699.6
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,561.0	4,377.9	13,169.4		5,312.9	10,956.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	853.1	787.4	905.2		398.0	435.7
Tube-side pressure drop (Pa)	2,044.5	1,360.9	4,003.5		1,654.5	1,106.2
Shell-side pressure drop (Pa)	59,612.8	48,599.1	27,986.0		45,511.4	29,281.6

**Table SC61:** Example 1: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	11,727.3	12,238.5	13,149.7	13,018.3
Heat transfer area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Tube area (m <sup>2</sup> )	109.2	105.9	72.1	109.2
Total number of tubes	594	216	588	150
Tube diameter (m)	0.016	0.032	0.016	0.038
Tube length (m)	3.659	4.877	2.439	6.098
Tube pitch ratio	1.5	1.5	1.5	1.33
Tube layout	Square	Square	Triangular	Square
Number of tube passes	1	2	1	2
Shell diameter (m)	0.686	0.838	0.635	0.737
Number of baffles	5	20	3	8
Twisted-Tapes pitch (m)	\	\	\	0.131850
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC62:** Example 1: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	15,350.2	16,494.9	18,310.0	17,427.2
Heat transfer area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Tube area (m <sup>2</sup> )	152.8	150.4	108.1	147.9
Total number of tubes	886	409	588	858
Tube diameter (m)	0.018	0.032	0.016	0.018
Tube length (m)	3.049	3.659	3.659	3.049
Tube pitch ratio	1.5	1.25	1.5	1.5
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	2	4	1	2
Shell diameter (m)	0.889	0.991	0.635	0.94
Number of baffles	4	6	5	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC63:** Example 1: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.0	1.0	1.0	1.2
Shell-side velocity (m/s)	13.3	28.7	14.4	15.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,418.4	8,023.5	5,036.0	5,934.5
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,352.1	1,188.5	1,178.5	1,180.8
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	717.6	740.8	657.4	716.5
Tube-side pressure drop (Pa)	5,167.4	4,754.4	11,641.6	13,474.9
Shell-side pressure drop (Pa)	2,517.3	18,902.7	2,355.6	2,886.4

**Table SC64:** Example 1: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.0	1.1	1.0	1.3
Shell-side velocity (m/s)	10.3	17.9	14.4	11.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,191.3	8,345.9	5,036.0	7,788.1
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	760.6	712.1	637.9	752.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	510.3	524.3	446.4	528.7
Tube-side pressure drop (Pa)	6,932.4	9,561.2	17,464.9	26,599.3
Shell-side pressure drop (Pa)	6,561.0	19,751.8	12,046.1	3,644.7

**Table SC65:** Example 1: Design solutions with shell-side intensification models for minimizing *TAC*

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	12,268.9	10,608.5	10,976.4	NA	17952.1	19160.45
Heat transfer area (m <sup>2</sup> )	93.2	55.9	92.3		105.6	186.4
Tube area (m <sup>2</sup> )	93.2	55.9	92.3		105.6	186.4
Total number of tubes	676	250	669		626	901
Tube diameter (m)	0.018	0.03	0.018		0.018	0.018
Tube length (m)	2.439	2.439	2.439		3.049	3.659
Tube pitch ratio	1.25	1.5	1.25		1.5	1.25
Tube layout	Square	Triangular	Triangular		Triangular	Triangular
Number of tube passes	1	2	1		1	1
Shell diameter (m)	0.686	0.787	0.635		0.737	0.737
Number of baffles	4	9	3		10	4
Number of external fins per unit length	\	210	\		210	\
Helical angle of helical baffle	\	\	30°		\	30°

**Table SC66:** Example 1: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.9	28.0	18.1	NA	19.3	13.4
Shell-side velocity (m/s)	1.0	1.1	2.0		1.0	1.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,987.3	1,426.5	1,980.4		622.1	702.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,473.9	2,430.5	6,390.6		2,918.0	5,499.1
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	836.4	735.4	853.5		385.0	420.5
Tube-side pressure drop (Pa)	1,176.4	2,319.4	1,197.5		1,676.5	1,083.4
Shell-side pressure drop (Pa)	26,552.4	8,132.7	1,638.6		17,029.3	1,663.6

**Table SC67:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$ 

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	47,451.9	46,881.7	42,813.7	47,915.4
Heat transfer area (m <sup>2</sup> )	124.5	112.1	66.0	118.6
Tube area (m <sup>2</sup> )	124.5	112.1	66.0	118.6
Total number of tubes	591	195	287	469
Tube diameter (m)	0.022	0.03	0.03	0.022
Tube length (m)	3.049	6.098	2.439	3.659
Tube pitch ratio	1.33	1.5	1.33	1.5
Tube layout	Triangular	Triangular	Triangular	Square
Number of tube passes	2	1	1	1
Shell diameter (m)	0.787	0.686	0.737	0.838
Number of baffles	3	8	3	5
Twisted-Tapes pitch (m)	\	\	\	0.103275
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.002491	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC68:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	54,445.7	54,579.5	50,241.3	55,085.0
Heat transfer area (m <sup>2</sup> )	147.9	135.5	80.6	141.2
Tube area (m <sup>2</sup> )	147.9	135.5	80.6	141.2
Total number of tubes	772	393	478	737
Tube diameter (m)	0.02	0.03	0.022	0.02
Tube length (m)	3.049	3.659	2.439	3.049
Tube pitch ratio	1.5	1.33	1.5	1.5
Tube layout	Square	Square	Triangular	Triangular
Number of tube passes	2	2	1	1
Shell diameter (m)	0.991	0.94	0.787	0.889
Number of baffles	5	4	3	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC69:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.4	1.7	1.2	2.2
Shell-side velocity (m/s)	13.0	12.5	17.4	11.4
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,613.8	6,043.0	16,267.2	5,237.0
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,755.4	6,653.2	5,341.6	6,820.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,275.2	1,419.8	1,609.7	1,331.1
Tube-side pressure drop (Pa)	16,050.6	19,417.8	13,570.5	19,827.7
Shell-side pressure drop (Pa)	6,349.2	4,727.5	6,942.4	3,555.8

**Table SC70:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	2.3	1.7	1.5	1.9
Shell-side velocity (m/s)	11.5	11.3	12.1	10.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,605.8	5,549.9	15,986.0	4,860.2
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,001.3	3,657.3	3,520.5	3,939.9
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,116.2	1,184.3	1,366.5	1,129.2
Tube-side pressure drop (Pa)	17,369.1	16,452.0	19,364.5	16,056.8
Shell-side pressure drop (Pa)	15,392.3	14,150.5	11,757.5	17,500.5

**Table SC71:** Example 2: Design solutions with shell-side intensification models for minimizing  $C_A$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	55,795.6	43,109.1	50,617.4	NA	54,952.2	60,667.5
Heat transfer area (m <sup>2</sup> )	152.5	66.5	119.8		90.1	150.3
Tube area (m <sup>2</sup> )	152.5	66.5	119.8		90.1	150.3
Total number of tubes	995	279	391		363	523
Tube diameter (m)	0.016	0.032	0.032		0.022	0.025
Tube length (m)	3.049	2.439	3.049		3.659	3.659
Tube pitch ratio	1.33	1.33	1.25		1.5	1.25
Tube layout	Square	Triangular	Square		Triangular	Square
Number of tube passes	1	2	2		1	1
Shell diameter (m)	0.787	0.787	0.94		0.686	0.838
Number of baffles	3	3	3		5	4
Number of external fins per unit length		210	\		210	\
Helical angle of helical baffle		\	30°		\	30°

**Table SC72:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.2	22.5	16.1	NA	21.0	10.7
Shell-side velocity (m/s)	1.2	1.5	2.4		1.3	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	12,949.4	7,867.9	9,484.9		2,998.7	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,322.4	2,034.1	3,784.8		1,916.2	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,051.1	1,252.9	1,314.5		915.5	1,075.5
Tube-side pressure drop (Pa)	4,172.7	3,708.4	2,554.9		4,230.2	1,079.4
Shell-side pressure drop (Pa)	18,795.7	18,284.3	4,194.0		19,412.6	9,476.3

**Table SC73:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	15,014.4	14,676.1	13,596.3	15,463.9
Heat transfer area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Tube area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Total number of tubes	400	590	282	467
Tube diameter (m)	0.022	0.022	0.032	0.025
Tube length (m)	4.877	3.049	2.439	3.659
Tube pitch ratio	1.33	1.5	1.25	1.25
Tube layout	Square	Square	Square	Triangular
Number of tube passes	1	1	1	1
Shell diameter (m)	0.686	0.94	0.787	0.737
Number of baffles	7	9	3	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC74:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	16,758.5	16,167.7	16,010.5	17,248.0
Heat transfer area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Tube area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Total number of tubes	788	681	317	794
Tube diameter (m)	0.018	0.022	0.03	0.02
Tube length (m)	3.659	3.049	3.049	3.049
Tube pitch ratio	1.5	1.5	1.5	1.5
Tube layout		Triangul		
	Square	ar	Square	Square
Number of tube passes	1	1	1	1
Shell diameter (m)	0.889	0.94	0.94	0.991
Number of baffles	5	4	4	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC75:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.7	1.2	1.0	1.4
Shell-side velocity (m/s)	18.7	20.3	20.2	17.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,621.2	4,747.9	13,161.9	3,521.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,244.0	6,753.6	5,320.8	6,813.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,180.9	1,287.4	1,571.0	1,173.3
Tube-side pressure drop (Pa)	7,367.6	5,440.7	8,218.8	6,640.1
Shell-side pressure drop (Pa)	15,293.5	18,957.7	8,565.4	15,848.2

**Table SC76:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.5	1.0	1.1	1.4
Shell-side velocity (m/s)	10.7	10.1	10.1	11.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,309.3	4,282.0	9,577.8	3,751.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,889.8	3,961.4	3,404.5	4,039.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	976.2	1,099.9	1,286.5	1,046.7
Tube-side pressure drop (Pa)	5,408.1	4,814.6	6,111.4	8,019.3
Shell-side pressure drop (Pa)	13,637.6	12,630.8	5,981.7	15,392.3

**Table SC77:** Example 2: Design solutions with shell-side intensification models for minimizing *TAC*

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	18,311.5	14,230.0	14,306.9	NA	17,673.7	18,159.8
Heat transfer area (m <sup>2</sup> )	156.0	68.7	119.8		98.5	150.3
Tube area (m <sup>2</sup> )	156.0	68.7	119.8		98.5	150.3
Total number of tubes	424	419	391		291	523
Tube diameter (m)	0.032	0.022	0.032		0.03	0.025
Tube length (m)	3.659	2.439	3.049		3.659	3.659
Tube pit936.ch ratio	1.25	1.5	1.25		1.5	1.25
Tube layout	Triangular	Triangular	Square		Triangular	Square
Number of tube passes	4	1	2		1	1
Shell diameter (m)	0.94	0.737	0.94		0.838	0.838
Number of baffles	3	3	3		5	4
Number of external fins per unit length		210	\		210	\
Helical angle of helical baffle		\	30°		\	30°

**Table SC78:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	29.7	18.2	16.1	12.5	10.7	12.5
Shell-side velocity (m/s)	1.0	1.2	2.4	1.1	3.0	1.1
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,355.4	9,010.1	9,484.9	3,148.9	3,565.4	3,148.9
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,013.2	1,767.5	3,784.8	1,383.3	4,776.2	1,383.3
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,017.2	1,185.5	1,314.5	872.8	1,075.5	872.8
Tube-side pressure drop (Pa)	18,134.6	2,194.5	2,554.9	1,086.4	1,079.4	1,086.4
Shell-side pressure drop (Pa)	14,616.7	11,267.7	4,194.0	9,260.5	9,476.3	9,260.5

**Table SC79:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	45,391.0	44,442.4	42,128.9	46,647.8
Heat transfer area (m <sup>2</sup> )	117.8	104.8	64.7	114.7
Tube area (m <sup>2</sup> )	117.8	104.8	64.7	114.7
Total number of tubes	615	311	225	197
Tube diameter (m)	0.02	0.022	0.03	0.038
Tube length (m)	3.049	4.877	3.049	4.877
Tube pitch ratio	1.25	1.5	1.5	1.25
Tube layout	Square	Triangular	Triangular	Triangular
Number of tube passes	2	1	1	2
Shell diameter (m)	0.737	0.635	0.737	0.737
Number of baffles	4	7	4	6
Twisted-Tapes pitch (m)	\	\	\	0.103275
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC80:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	50,976.0	52,102.5	50,241.3	53,307.9
Heat transfer area (m <sup>2</sup> )	136.2	127.9	80.6	135.5
Tube area (m <sup>2</sup> )	136.2	127.9	80.6	135.5
Total number of tubes	474	445	478	786
Tube diameter (m)	0.03	0.025	0.022	0.018
Tube length (m)	3.049	3.659	2.439	3.049
Tube pitch ratio	1.33	1.5	1.5	1.33
Tube layout	Triangular	Square	Triangular	Square
Number of tube passes	4	2	1	1
Shell diameter (m)	0.991	0.94	0.787	0.787
Number of baffles	3	5	3	3
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.004
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC81:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.9	2.2	1.5	2.6
Shell-side velocity (m/s)	21.5	15.0	12.9	18.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,524.6	8,230.6	20,114.8	5,461.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,815.4	6,850.7	5,451.2	6,189.7
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,337.7	1,502.1	1,655.9	1,379.4
Tube-side pressure drop (Pa)	26,382.4	38,585.4	26,489.0	32,196.9
Shell-side pressure drop (Pa)	19,735.0	7,832.2	2,999.1	14,748.3

**Table SC82:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	2.8	2.3	1.5	2.4
Shell-side velocity (m/s)	10.3	10.1	12.1	13.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,943.8	7,197.1	15,986.0	6,159.8
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,893.0	3,587.2	3,520.5	3,886.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,171.9	1,232.0	1,366.5	1,183.6
Tube-side pressure drop (Pa)	29,268.1	35,586.0	19,364.5	31,224.1
Shell-side pressure drop (Pa)	19,387.7	8,875.7	11,757.5	15,952.1

**Table SC83:** Example 2: Design solutions with shell-side intensification models for minimizing  $C_A$ 

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	52,316.1	41,087.0	50,617.4	67,781.5	51,755.2	60,667.5
Heat transfer area (m <sup>2</sup> )	140.7	62.7	119.8	194.5	83.6	150.3
Tube area (m <sup>2</sup> )	140.7	62.7	119.8	194.5	83.6	150.3
Total number of tubes	408	176	391	1269	357	523
Tube diameter (m)	0.03	0.038	0.032	0.016	0.025	0.025
Tube length (m)	3.659	3.049	3.049	3.049	3.049	3.659
Tube pitch ratio	1.25	1.33	1.25	1.33	1.33	1.25
Tube layout	Triangular	Square	Square	Square	Triangular	Square
Number of tube passes	2	1	2	1	1	1
Shell diameter (m)	0.838	0.787	0.94	0.889	0.686	0.838
Number of baffles	4	3	3	3	4	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC84:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	17.9	12.1	16.1	13.5	15.7	10.7
Shell-side velocity (m/s)	1.4	1.2	2.4	1.1	1.7	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,223.4	7,269.1	9,484.9	3,975.7	3,139.3	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,496.0	2,495.1	3,784.8	2,171.8	2,574.3	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,121.1	1,327.8	1,314.5	824.0	1,012.8	1,075.5
Tube-side pressure drop (Pa)	4,048.0	610.2	2,554.9	2,745.7	1,745.7	1,079.4
Shell-side pressure drop (Pa)	32,446.2	35,306.9	4,194.0	34,623.7	39,416.0	9,476.3

**Table SC85:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	15,014.4	14,676.1	13,596.3	15,463.9
Heat transfer area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Tube area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Total number of tubes	400	590	282	467
Tube diameter (m)	0.022	0.022	0.032	0.025
Tube length (m)	4.877	3.049	2.439	3.659
Tube pitch ratio	1.33	1.5	1.25	1.25
Tube layout	Square	Square	Square	Triangular
Number of tube passes	1	1	1	1
Shell diameter (m)	0.686	0.94	0.787	0.737
Number of baffles	7	9	3	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC86:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	16,758.5	16,167.7	16,010.5	17,248.0
Heat transfer area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Tube area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Total number of tubes	788	681	317	794
Tube diameter (m)	0.018	0.022	0.03	0.02
Tube length (m)	3.659	3.049	3.049	3.049
Tube pitch ratio	1.5	1.5	1.5	1.5
Tube layout		Triangul		
	Square	ar	Square	Square
Number of tube passes	1	1	1	1
Shell diameter (m)	0.889	0.94	0.94	0.991
Number of baffles	5	4	4	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC87:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.7	1.2	1.0	1.4
Shell-side velocity (m/s)	18.7	20.3	20.2	17.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,621.2	4,747.9	13,161.9	3,521.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,244.0	6,753.6	5,320.8	6,813.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,180.9	1,287.4	1,571.0	1,173.3
Tube-side pressure drop (Pa)	7,367.6	5,440.7	8,218.8	6,640.1
Shell-side pressure drop (Pa)	15,293.5	18,957.7	8,565.4	15,848.2

**Table SC88:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.5	1.0	1.1	1.4
Shell-side velocity (m/s)	10.7	10.1	10.1	11.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,309.3	4,282.0	9,577.8	3,751.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,889.8	3,961.4	3,404.5	4,039.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	976.2	1,099.9	1,286.5	1,046.7
Tube-side pressure drop (Pa)	5,408.1	4,814.6	6,111.4	8,019.3
Shell-side pressure drop (Pa)	13,637.6	12,630.8	5,981.7	15,392.3

**Table SC89:** Example 2: Design solutions with shell-side intensification models for minimizing  $TAC$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	18,311.5	14,230.0	14,306.9	25,757.4	17,673.7	18,159.8
Heat transfer area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Tube area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Total number of tubes	424	419	391	1269	291	523
Tube diameter (m)	0.032	0.022	0.032	0.016	0.03	0.025
Tube length (m)	3.659	2.439	3.049	3.049	3.659	3.659
Tube pitch ratio	1.25	1.5	1.25	1.33	1.5	1.25
Tube layout	Triangular	Triangular	Square	Square	Triangular	Square
Number of tube passes	4	1	2	1	1	1
Shell diameter (m)	0.940	0.737	0.94	0.889	0.838	0.838
Number of baffles	3	3	3	3	5	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC90:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	29.7	18.2	16.1	13.5	12.5	10.7
Shell-side velocity (m/s)	1.0	1.2	2.4	1.1	1.1	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,355.4	9,010.1	9,484.9	3,975.7	3,148.9	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,013.2	1,767.5	3,784.8	2,171.8	1,383.3	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,017.2	1,185.5	1,314.5	824.0	872.8	1,075.5
Tube-side pressure drop (Pa)	18,134.6	2,194.5	2,554.9	2,745.7	1,086.4	1,079.4
Shell-side pressure drop (Pa)	14,616.7	11,267.7	4,194.0	34,623.7	9,260.5	9,476.3

**Table SC91:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing  $C_A$

	HS	HS-CI	HS-IF	HS-TI
Capital cost (\$)	45,391.0	43,975.7	41,500.4	45,530.2
Heat transfer area (m <sup>2</sup> )	117.8	103.5	63.5	111.3
Tube area (m <sup>2</sup> )	117.8	103.5	63.5	111.3
Total number of tubes	615	360	184	484
Tube diameter (m)	0.02	0.025	0.03	0.02
Tube length (m)	3.049	3.659	3.659	3.659
Tube pitch ratio	1.25	1.5	1.33	1.33
Tube layout	Square	Triangular	Triangular	Square
Number of tube passes	2	2	1	1
Shell diameter (m)	0.737	0.787	0.591	0.686
Number of baffles	4	4	6	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.056402	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC92:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing  $C_A$

	VS	VS-CI	VS-IF	VS-TI
Capital cost (\$)	50,976.0	50,249.9	47,314.9	52,167.7
Heat transfer area (m <sup>2</sup> )	136.2	122.2	74.8	131.9
Tube area (m <sup>2</sup> )	136.2	122.2	74.8	131.9
Total number of tubes	474	580	542	459
Tube diameter (m)	0.03	0.022	0.018	0.025
Tube length (m)	3.049	3.049	2.439	3.659
Tube pitch ratio	1.33	1.33	1.5	1.5
Tube layout	Triangular	Square	Triangular	Triangular
Number of tube passes	4	2	1	2
Shell diameter (m)	0.991	0.838	0.686	0.889
Number of baffles	3	3	3	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.044179	\	\
Coiled-Wire diameter (m)	\	0.001951	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC93:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	2.9	2.9	1.8	2.8
Shell-side velocity (m/s)	21.5	10.1	25.3	18.6
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	5,524.6	9,288.3	23,996.1	6,803.8
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	6,815.4	6,430.7	5,539.7	6,867.9
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,337.7	1,535.7	1,690.1	1,420.6
Tube-side pressure drop (Pa)	26,382.4	58,895.2	46,030.0	40,221.0
Shell-side pressure drop (Pa)	19,735.0	2,537.4	19,213.2	12,837.3

**Table SC94:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	2.8	2.4	2.1	2.8
Shell-side velocity (m/s)	10.3	12.2	13.9	10.7
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	4,943.8	8,973.0	21,729.4	6,216.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,893.0	3,755.0	3,433.6	3,624.4
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,171.9	1,292.3	1,371.3	1,197.8
Tube-side pressure drop (Pa)	29,268.1	58,899.3	59,565.5	46,040.7
Shell-side pressure drop (Pa)	19,387.7	16,488.2	16,641.0	13,723.7

**Table SC95:** Example 2: Design solutions with shell-side intensification models for minimizing  $C_A$

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Capital cost (\$)	50,252.0	39,962.6	50,617.4	66,505.9	50,764.7	60,667.5
Heat transfer area (m <sup>2</sup> )	133.8	60.5	119.8	189.9	81.6	150.3
Tube area (m <sup>2</sup> )	133.8	60.5	119.8	189.9	81.6	150.3
Total number of tubes	873	170	391	751	396	523
Tube diameter (m)	0.016	0.038	0.032	0.022	0.022	0.025
Tube length (m)	3.049	3.049	3.049	3.659	3.049	3.659
Tube pitch ratio	1.33	1.25	1.25	1.33	1.33	1.25
Tube layout	Triangular	Triangular	Square	Square	Triangular	Square
Number of tube passes	1	2	2	1	1	1
Shell diameter (m)	0.686	0.686	0.94	0.94	0.635	0.838
Number of baffles	4	4	3	5	4	4
Number of external fins per unit length	\	210	\		210	\
Helical angle of helical baffle	\	\	30°		\	30°

**Table SC96:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	19.6	25.1	16.1	10.1	19.2	10.7
Shell-side velocity (m/s)	1.7	2.1	2.4	1.2	1.8	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	12,396.9	7,185.5	9,484.9	3,821.0	3,086.9	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,209.2	2,812.2	3,784.8	2,063.2	2,936.2	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,194.8	1,367.9	1,314.5	834.7	1,014.1	1,075.5
Tube-side pressure drop (Pa)	5,231.1	4,425.5	2,554.9	1,198.0	3,027.5	1,079.4
Shell-side pressure drop (Pa)	54,765.6	49,002.6	4,194.0	52,506.1	52,959.3	9,476.3

**Table SC97:** Example 2: Design solutions with tube-side intensification and horizontal models for minimizing *TAC*

	HS	HS-CI	HS-IF	HS-TI
TAC(\$/yr)	15,014.4	14,676.1	13,596.3	15,463.9
Heat transfer area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Tube area (m <sup>2</sup> )	134.8	124.3	69.1	134.2
Total number of tubes	400	590	282	467
Tube diameter (m)	0.022	0.022	0.032	0.025
Tube length (m)	4.877	3.049	2.439	3.659
Tube pitch ratio	1.33	1.5	1.25	1.25
Tube layout	Square	Square	Square	Triangular
Number of tube passes	1	1	1	1
Shell diameter (m)	0.686	0.94	0.787	0.737
Number of baffles	7	9	3	4
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000459	\

**Table SC98:** Example 2: Design solutions with tube-side intensification and vertical models for minimizing *TAC*

	VS	VS-CI	VS-IF	VS-TI
TAC(\$/yr)	16,758.5	16,167.7	16,010.5	17,248.0
Heat transfer area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Tube area (m <sup>2</sup> )	163.0	143.5	91.1	152.1
Total number of tubes	788	681	317	794
Tube diameter (m)	0.018	0.022	0.03	0.02
Tube length (m)	3.659	3.049	3.049	3.049
Tube pitch ratio	1.5	1.5	1.5	1.5
Tube layout	Square	Triangular	Square	Square
Number of tube passes	1	1	1	1
Shell diameter (m)	0.889	0.94	0.94	0.991
Number of baffles	5	4	4	5
Twisted-Tapes pitch (m)	\	\	\	0.074700
Twisted-Tapes thickness (m)	\	\	\	0.002
Coiled-Wire helical pitch (m)	\	0.031955	\	\
Coiled-Wire diameter (m)	\	0.001411	\	\
Number of internal fins per unit length	\	\	50	\
Helical angle of internal fins	\	\	35°	\
Height of internal fins (m)	\	\	0.000332	\

**Table SC99:** Example 2: Other results for horizontal configuration

	HS	HS-CI	HS-IF	HS-TI
Tube-side velocity (m/s)	1.7	1.2	1.0	1.4
Shell-side velocity (m/s)	18.7	20.3	20.2	17.9
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,621.2	4,747.9	13,161.9	3,521.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	7,244.0	6,753.6	5,320.8	6,813.5
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,180.9	1,287.4	1,571.0	1,173.3
Tube-side pressure drop (Pa)	7,367.6	5,440.7	8,218.8	6,640.1
Shell-side pressure drop (Pa)	15,293.5	18,957.7	8,565.4	15,848.2

**Table SC100:** Example 2: Other results for vertical configuration

	VS	VS-CI	VS-IF	VS-TI
Tube-side velocity (m/s)	1.5	1.0	1.1	1.4
Shell-side velocity (m/s)	10.7	10.1	10.1	11.5
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,309.3	4,282.0	9,577.8	3,751.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	3,889.8	3,961.4	3,404.5	4,039.0
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	976.2	1,099.9	1,286.5	1,046.7
Tube-side pressure drop (Pa)	5,408.1	4,814.6	6,111.4	8,019.3
Shell-side pressure drop (Pa)	13,637.6	12,630.8	5,981.7	15,392.3

**Table SC101:** Example 2: Design solutions with shell-side intensification models for minimizing *TAC*

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
TAC(\$/yr)	18,311.5	14,230.0	14,306.9	25757.4	17673.7	18159.8
Heat transfer area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Tube area (m <sup>2</sup> )	156.0	68.7	119.8	194.5	98.5	150.3
Total number of tubes	424	419	391	1269	291	523
Tube diameter (m)	0.032	0.022	0.032	0.016	0.03	0.025
Tube length (m)	3.659	2.439	3.049	3.049	3.659	3.659
Tube pit936.ch ratio	1.25	1.5	1.25	1.33	1.5	1.25
Tube layout	Triangular	Triangular	Square	Square	Triangular	Square
Number of tube passes	4	1	2	1	1	1
Shell diameter (m)	0.94	0.737	0.94	0.889	0.838	0.838
Number of baffles	3	3	3	3	5	4
Number of external fins per unit length	\	210	\	\	210	\
Helical angle of helical baffle	\	\	30°	\	\	30°

**Table SC102:** Example 2: Other results for the above design solutions

	HT	HT-EF	HT-HB	VT	VT-EF	VT-HB
Tube-side velocity (m/s)	29.7	18.2	16.1	13.5	12.5	10.7
Shell-side velocity (m/s)	1.0	1.2	2.4	1.1	1.1	3.0
Tube-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	10,355.4	9,010.1	9,484.9	3,975.7	3,148.9	3,565.4
Shell-side heat transfer coefficient (W/(m <sup>2</sup> ·K))	2,013.2	1,767.5	3,784.8	2,171.8	1,383.3	4,776.2
Overall heat transfer coefficient (W/(m <sup>2</sup> ·K))	1,017.2	1,185.5	1,314.5	824.0	872.8	1,075.5
Tube-side pressure drop (Pa)	18,134.6	2,194.5	2,554.9	2,745.7	1,086.4	1,079.4
Shell-side pressure drop (Pa)	14,616.7	11,267.7	4,194.0	34,623.7	9,260.5	9,476.3

## *References*

Pereira I. P. S., M. J. Bagajewicz, A. L. H. Costa, 2021. Global optimization of the design of horizontal shell and tube condensers. *Chemical Engineering Science*, 236, 116474.

## Part D

We show the results for different pressure limits.

**Table SD1:** Optimization results with different pressure limit for Example 1

Type	20kPa limit			40kPa limit			60kPa limit		
	A (Min $C_A$ )	A (Min $TAC$ )	TAC	A (Min $C_A$ )	A (Min $TAC$ )	TAC	A (Min $C_A$ )	A (Min $TAC$ )	TAC
HS	104.2	109.2	11,727	103.1	109.2	11,727	99.3	109.2	11,727
HS-CI	101.2	105.9	12,238	100.3	105.9	12,238	97.1	105.9	12,238
HS-IF	72.1	72.1	13,150	69.3	72.1	13,150	67.7	72.1	13,150
HS-TI	104.5	109.2	13,018	102.0	109.2	13,018	100.3	109.2	13,018
HT		NA		93.2	93.2	12,269	91.7	93.2	12,269
HT-EF	51.0	55.9	10,608	51.0	55.9	10,608	51.0	55.9	10,608
HT-HB	88.0	92.3	10,976	86.7	92.3	10,976	86.7	92.3	10,976
VS	148.9	152.8	15,350	148.9	152.8	15,350	147.0	152.8	15,350
VS-CI	144.2	150.4	16,495	144.2	150.4	16,495	143.3	150.4	16,495
VS-IF	108.1	108.1	18,310	107.7	108.1	18,310	102.3	108.1	18,310
VS-TI		NA		147.0	147.9	17,427	144.2	147.9	17,427
VT		NA			NA			NA	
VT-EF	105.6	105.6	17,952	101.6	105.6	17,952	101.0	105.6	17,952
VT-HB	184.4	186.4	19,160	184.2	186.4	19,160	184.2	186.4	19,160
Best $C_A$		HT-EF			HT-EF			HT-EF	
Best TAC		HT-EF			HT-EF			HT-EF	

**Table SD2:** Optimization results with different pressure limit for Example 2

Type	20kPa limit			40kPa limit			60kPa limit		
	A (Min $C_A$ )	A (Min $TAC$ )	TAC	A (Min $C_A$ )	A (Min $TAC$ )	TAC	A (Min $C_A$ )	A (Min $TAC$ )	TAC
HS	124.5	134.8	15,014	117.8	134.8	15,014	117.8	134.8	15,014
HS-CI	112.1	124.3	14,676	104.8	124.3	14,676	103.5	124.3	14,676
HS-IF	66.0	69.1	13,596	64.7	69.1	13,596	63.5	69.1	13,596
HS-TI	118.6	134.2	15,464	114.7	134.2	15,464	111.3	134.2	15,464
HT	152.5	156.0	18,312	140.7	156.0	18,312	133.8	156.0	18,312
HT-EF	66.5	68.7	14,230	62.7	68.7	14,230	60.5	68.7	14,230
HT-HB	119.8	119.8	14,307	119.8	119.8	14,307	119.8	119.8	14,307
VS	147.9	163.0	16,758	136.2	163.0	16,758	136.2	163.0	16,759
VS-CI	135.5	143.5	16,168	127.9	143.5	16,168	122.2	143.5	16,168
VS-IF	80.6	91.1	16,010	80.6	91.1	16,010	74.8	91.1	16,011
VS-TI	141.2	152.1	17,248	135.5	152.1	17,248	131.9	152.1	17,248
VT		NA		194.5	194.5	25,757	189.9	194.5	25,757
VT-EF	90.1	98.5	17,674	83.6	98.5	17,674	81.6	98.5	17,674
VT-HB	150.3	150.3	18,160	150.3	150.3	18,160	150.3	150.3	18,160
Best $C_A$		HS-IF			HT-EF			HT-EF	
Best TAC		HS-IF			HS-IF			HS-IF	

## Part E

The active candidates after Set Trimming by individual running are in Tables SE1 and SE2.

**Table SE1:** Number of active candidates by individual running after the trim related to each

constraint for Example 1

HS	HS-CI	HS-IF	HS-TI
Constraint	Number of active candidates	Constraint	Number of active candidates
start	403,200	start	3,628,800
min $L/d_s$	288,000	min $L/d_s$	2,592,000
max $L/d_s$	288,000	max $L/d_s$	2,592,000
min $lbc/d_s$	273,600	min $PCI/d_{t,i}$	1,814,400
max $lbc/d_s$	207,600	min $PCI/d_t$	1,468,800
min $v_s$	203,440	min $\alpha_{CI}$	1,468,800
max $v_s$	75,520	min $\alpha_{CI}$	1,036,800
min $v_t$	47,242	min $lbc/d_s$	984,960
max $v_t$	33,285	max $lbc/d_s$	747,360
min $Re_s$	33,285	min $v_s$	732,384
min $Re_t$	33,285	max $v_s$	271,872
max $\Delta p_t$	30,392	min $v_t$	176,256
max $\Delta p_s$	24,832	max $v_t$	119,961
min $A$	11,319	min $Re_s$	119,961
		min $Re_t$	119,961
		max $\Delta p_t$	74,361
		max $\Delta p_s$	57,564
		min $A$	34,356
		start	4,838,400
		min $L/d_s$	3,456,000
		max $L/d_s$	3,456,000
		min $lbc/d_s$	3,283,200
		max $lbc/d_s$	2,491,200
		min $v_s$	2,441,280
		max $v_s$	906,240
		min $e_{IF}/d_{t,i}$	845,824
		min $e_{IF}/d_{t,i}$	664,576
		min $v_t$	410,248
		max $v_t$	294,008
		min $Re_t$	294,008
		max $\Delta p_t$	169,481
		min $Re_s$	169,481
		max $\Delta p_s$	141,723
		min $A$	31,690
		start	3,628,800
		min $L/d_s$	2,592,000
		max $L/d_s$	2,592,000
		min $lbc/d_s$	2,462,400
		max $lbc/d_s$	1,868,400
		min $v_s$	1,830,960
		max $v_s$	679,680
		min $y$	498,432
		max $y$	294,528
		min $v_t$	183,054
		max $v_t$	131,193
		min $v_{t, TI}$	131,193
		max $v_{t, TI}$	100,431
		min $Re_s$	100,431
		min $Re_t$	100,431
		min $Re_{t, TI}$	100,431
		max $\Delta p_t$	67,918
		max $\Delta p_s$	58,967
		min $A$	25,110

**Table SE1 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 1

VS		VS-CI		VS-IF		VS-TI	
Constrain t	Number of active candidate s	Constraint	Number of active candidate s	Constrain t	Number of active candidate s	Constrain t	Number of active candidate s
start	403,200	start	3,628,800	start	4,838,400	start	3,628,800
min $L/d_s$	288,000	min $L/d_s$	2,592,000	min $L/d_s$	3,456,000	min $L/d_s$	2,592,000
max $L/d_s$	288,000	max $L/d_s$	2,592,000	max $L/d_s$	3,456,000	max $L/d_s$	2,592,000
min $lbc/d_s$	273,600	min $P_{CI}/d_{t,i}$	1,814,400	min $lbc/d_s$	3,283,200	min $lbc/d_s$	2,462,400
max $lbc/d_s$	207,600	min $P_{CI}/d_t$	1,468,800	max $lbc/d_s$	2,491,200	max $lbc/d_s$	1,868,400
min $v_s$	203,440	min $\alpha_{CI}$	1,468,800	min $v_s$	2,441,280	min $v_s$	1,830,960
max $v_s$	75,520	min $\alpha_{CI}$	1,036,800	max $v_s$	906,240	max $v_s$	679,680
min $v_t$	47,242	min $lbc/d_s$	984,960	min $e_{IF}/d_{t,i}$	845,824	min $y$	498,432
max $v_t$	33,285	max $lbc/d_s$	747,360	min $e_{IF}/d_{t,i}$	664,576	max $y$	294,528
min $Re_s$	33,285	min $v_s$	732,384	min $v_t$	410,248	min $v_t$	183,054
min $Re_t$	33,285	max $v_s$	271,872	max $v_t$	294,008	max $v_t$	131,193
max $\Delta p_t$	30,392	min $v_t$	176,256	min $Re_s$	294,008	min $v_{t, TI}$	131,193
max $\Delta p_s$	12,204	max $v_t$	119,961	min $Re_t$	294,008	max $v_{t, TI}$	100,431
min $A$	1,853	min $Re_s$	119,961	max $\Delta p_t$	169,481	min $Re_s$	100,431
		min $Re_t$	119,961	max $\Delta p_s$	69,995	min $Re_t$	100,431
		max $\Delta p_t$	74,361	min $A$	4,753	min $Re_{t, TI}$	100,431
		max $\Delta p_s$	23,580			max $\Delta p_t$	67,918
		min $A$	6,020			max $\Delta p_s$	27,736
						min $A$	3,270

**Table SE1 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 1

Constraint	HT	Constraint	HT-EF	Constraint	HT-HB
	Number of active candidates		Number of active candidates		Number of active candidates
start	403,200	start	1,209,600	start	1,612,800
min $L/d_s$	288,000	min $L/d_s$	864,000	min $L/d_s$	1,152,000
max $L/d_s$	288,000	max $L/d_s$	864,000	max $L/d_s$	1,152,000
min $lbc/d_s$	273,600	min $lbc/d_s$	820,800	min $lbc/d_s$	1,094,400
max $lbc/d_s$	207,600	max $lbc/d_s$	622,800	max $lbc/d_s$	830,400
min $v_s$	140,720	min $v_{s,EF}$	419,816	min $lbc_{HB}/d_s$	830,400
max $v_s$	118,480	max $v_{s,EF}$	356,408	max $lbc_{HB}/d_s$	415,200
min $v_t$	114,611	min $v_t$	345,021	min $v_s$	344,136
max $v_t$	29,984	max $v_t$	89,816	max $v_s$	258,120
min $Re_s$	29,984	min $Re_s$	81,817	min $v_t$	247,414
min $Re_t$	29,984	min $Re_t$	81,817	max $v_t$	75,175
max $\Delta p_t$	29,984	max $\Delta p_t$	81,817	min $Re_s$	70,525
max $\Delta p_s$	17,847	max $\Delta p_s$	57,865	min $Re_t$	70,525
min $A$	5,981	min $A$	32,593	max $\Delta p_t$	70,525
				max $\Delta p_s$	54,512
				min $A$	31,337

**Table SE1 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 1

Constraint	VT	Constraint	VT-EF	Constraint	VT-HB
	Number of active candidates		Number of active candidates		Number of active candidates
start	100,800	start	302,400	start	403,200
min $L/d_s$	72,000	min $L/d_s$	216,000	min $L/d_s$	288,000
max $L/d_s$	72,000	max $L/d_s$	216,000	max $L/d_s$	288,000
min $lbc/d_s$	68,400	min $lbc/d_s$	205,200	min $lbc/d_s$	273,600
max $lbc/d_s$	51,900	max $lbc/d_s$	155,700	max $lbc/d_s$	207,600
min $v_s$	35,180	min $v_{s,EF}$	104,954	min $lbc_{HB}/d_s$	207,600
max $v_s$	29,620	max $v_{s,EF}$	89,102	max $lbc_{HB}/d_s$	103,800
min $v_t$	25,751	min $v_t$	77,715	min $v_s$	86,034
max $v_t$	19,250	max $v_t$	57,969	max $v_s$	64,530
min $Re_s$	19,250	min $Re_s$	53,113	min $v_t$	53,824
min $Re_t$	19,250	min $Re_t$	53,113	max $v_t$	45,605
max $\Delta p_t$	19,250	max $\Delta p_t$	21,777	min $Re_s$	43,292
max $\Delta p_s$	7,207	max $\Delta p_s$	12,138	min $Re_t$	43,292
min $A$	23	min $A$	2,823	max $\Delta p_t$	18,317
				max $\Delta p_s$	18,177
				min $A$	2,690

**Table SE2:** Number of active candidates by individual running after the trim related to each constraint for Example 2

HS		HS-CI		HS-IF		HS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	403,200	start	3,628,800	start	4,838,400	start	3,628,800
min $L/d_s$	288,000	min $L/d_s$	2,592,000	min $L/d_s$	3,456,000	min $L/d_s$	2,592,000
max $L/d_s$	288,000	max $L/d_s$	2,592,000	max $L/d_s$	3,456,000	max $L/d_s$	2,592,000
min $lbc/d_s$	273,60	min $P_{CI}/d_{t,i}$	1,814,400	min $lbc/d_s$	3,283,200	min $lbc/d_s$	2,462,400
max $lbc/d_s$	207,600	min $P_{CI}/d_t$	1,468,800	max $lbc/d_s$	2,491,200	max $lbc/d_s$	1,868,400
min $v_s$	204,320	min $\alpha_{CI}$	1,468,800	min $v_s$	2,451,840	min $v_s$	1,838,880
max $v_s$	71,280	min $\alpha_{CI}$	1,036,800	max $v_s$	855,360	max $v_s$	641,520
min $v_t$	64,733	min $lbc/d_s$	984,960	min $e_{IF}/d_{t,i}$	798,336	min $y$	470,448
max $v_t$	23,964	max $lbc/d_s$	747,360	min $e_{IF}/d_{t,i}$	627,264	max $y$	277,992
min $Re_s$	23,964	min $v_s$	735,552	min $v_t$	566,700	min $v_t$	252,399
min $Re_t$	23,964	max $v_s$	256,608	max $v_t$	212,632	max $v_t$	94,086
max $\Delta p_t$	23,964	min $v_t$	238,422	min $Re_t$	212,632	min $v_{t,TI}$	94,086
max $\Delta p_s$	11,953	max $v_t$	84,924	max $\Delta p_t$	173,253	max $v_{t,TI}$	94,086
min $A$	3,780	min $Re_s$	84,924	min $Re_s$	173,253	min $Re_s$	71,447
		min $Re_t$	84,924	max $\Delta p_s$	93,364	min $Re_t$	71,447
		max $\Delta p_t$	76,538	min $A$	37,537	min $Re_{t,TI}$	71,447
		max $\Delta p_s$	29,409			max $\Delta p_t$	70,855
		min $A$	18,731			max $\Delta p_s$	34,760
						min $A$	15,296

**Table SE2 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 2

	VS	VS-CI	VS-IF	VS-TI			
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates		
start	403,200	start	3,628,800	start	4,838,400	start	3,628,800
min $L/d_s$	288,000	min $L/d_s$	2,592,000	min $L/d_s$	3,456,000	min $L/d_s$	2,592,000
max $L/d_s$	288,000	max $L/d_s$	2,592,000	max $L/d_s$	3,456,000	max $L/d_s$	2,592,000
min $lbc/d_s$	273,600	min $PCI/d_{t,i}$	1,814,400	min $lbc/d_s$	3,283,200	min $lbc/d_s$	2,462,400
max $lbc/d_s$	207,600	min $PCI/d_t$	1,468,800	max $lbc/d_s$	2,491,200	max $lbc/d_s$	1,868,400
min $v_s$	204,320	min $\alpha_{CI}$	1,468,800	min $v_s$	2,451,840	min $v_s$	1,838,880
max $v_s$	71,280	min $\alpha_{CI}$	1,036,800	max $v_s$	855,360	max $v_s$	641,520
min $v_t$	64,733	min $lbc/d_s$	984,960	min $e_{IF}/d_{t,i}$	798,336	min $y$	470,448
max $v_t$	23,964	max $lbc/d_s$	747,360	min $e_{IF}/d_{t,i}$	627,264	max $y$	277,992
min $Re_s$	23,964	min $v_s$	735,552	min $v_t$	566,700	min $v_t$	252,399
min $Re_t$	23,964	max $v_s$	256,608	max $v_t$	212,632	max $v_t$	94,086
max $\Delta p_t$	23,964	min $v_t$	238,422	min $Re_s$	212,632	min $v_{t,TI}$	94,086
max $\Delta p_s$	2,799	max $v_t$	84,924	min $Re_t$	212,632	max $v_{t,TI}$	94,086
min $A$	230	min $Re_s$	84,924	max $\Delta p_t$	173,253	min $Re_s$	71,447
		min $Re_t$	84,924	max $\Delta p_s$	21,657	min $Re_t$	71,447
		max $\Delta p_t$	76,538	min $A$	5,058	min $Re_{t,TI}$	71,447
		max $\Delta p_s$	4,675			max $\Delta p_t$	70,855
		min $A$	1,603			max $\Delta p_s$	7,080
						min $A$	1,197

**Table SE2 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 2

HT		HT-EF		HT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	403,200	start	1,209,600	start	1,612,800
min $L/d_s$	288,000	min $L/d_s$	864,000	min $L/d_s$	1,152,000
max $L/d_s$	288,000	max $L/d_s$	864,000	max $L/d_s$	1,152,000
min $lbc/d_s$	273,600	min $lbc/d_s$	820,800	min $lbc/d_s$	1,094,400
max $lbc/d_s$	207,600	max $lbc/d_s$	622,800	max $lbc/d_s$	830,400
min $v_s$	202,320	min $v_{s,EF}$	607,696	min $lbc_{HB}/d_s$	830,400
max $v_s$	81,520	max $v_{s,EF}$	243,792	max $lbc_{HB}/d_s$	415,200
min $v_t$	76,049	min $v_t$	227,298	min $v_s$	415,200
max $v_t$	76,049	max $v_t$	79,379	max $v_s$	104,352
min $Re_s$	76,049	min $Re_s$	79,217	min $v_t$	94,638
min $Re_t$	76,049	min $Re_t$	79,217	max $v_t$	37,888
max $\Delta p_t$	25,158	max $\Delta p_t$	75,290	min $Re_s$	37,888
max $\Delta p_s$	17,401	max $\Delta p_s$	47,603	min $Re_t$	37,888
min $A$	4,854	min $A$	29,379	max $\Delta p_t$	35,901
				max $\Delta p_s$	22,542
				min $A$	14,186

**Table SE2 (continued):** Number of active candidates by individual running after the trim related to each constraint for Example 2

VT		VT-EF		VT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	100,800	start	302,400	start	403,200
min $L/d_s$	72,000	min $L/d_s$	216,000	min $L/d_s$	288,000
max $L/d_s$	72,000	max $L/d_s$	216,000	max $L/d_s$	288,000
min $lbc/d_s$	68,400	min $lbc/d_s$	205,200	min $lbc/d_s$	273,600
max $lbc/d_s$	51,900	max $lbc/d_s$	155,700	max $lbc/d_s$	207,600
min $v_s$	50,580	min $v_{s,EF}$	151,924	min $lbc_{HB}/d_s$	207,600
max $v_s$	20,380	max $v_{s,EF}$	60,948	max $lbc_{HB}/d_s$	103,800
min $v_t$	14,909	min $v_t$	44,454	min $v_s$	103,800
max $v_t$	13,663	max $v_t$	40,874	max $v_s$	26,088
min $Re_s$	13,663	min $Re_s$	40,821	min $v_t$	16,374
min $Re_t$	13,663	min $Re_t$	40,821	max $v_t$	16,374
max $\Delta p_t$	13,638	max $\Delta p_t$	33,372	min $Re_s$	16,374
max $\Delta p_s$	5,860	max $\Delta p_s$	18,783	min $Re_t$	16,374
min $A$	560	min $A$	9,520	max $\Delta p_t$	12,913
				max $\Delta p_s$	12,913
				min $A$	5,149

## Part F

The active candidates after Set Trimming by automatic running are in Tables SF1 and SF4.

**Table SF1:** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 1

	HS		HT		VS		VT
Constraint	Number of active candidates						
start	403,200	start	207,600	start	207,600	start	51,900
min $L/d_s$	288,000	max $C_A$	128,243	max $C_A$	119,932	max $C_A$	28,155
max $L/d_s$	288,000	min $v_s$	104,398	min $v_s$	119,236	min $v_s$	27,949
min $lbc/d_s$	273,600	max $v_s$	82,471	max $v_s$	25,788	max $v_s$	6,584
max $lbc/d_s$	207,600	min $v_t$	81,512	min $v_t$	18,879	min $v_t$	5,736
min $v_s$	203,440	max $v_t$	16,603	max $v_t$	10,553	max $v_t$	4,748
max $v_s$	75,520	min $Re_s$	16,603	min $Re_s$	10,553	min $Re_s$	4,748
min $v_t$	47,242	min $Re_t$	16,603	min $Re_t$	10,553	min $Re_t$	4,748
max $v_t$	33,285	max $\Delta p_t$	16,603	max $\Delta p_t$	10,553	max $\Delta p_t$	4,748
min $Re_s$	33,285	max $\Delta p_s$	12,042	max $\Delta p_s$	6,788	max $\Delta p_s$	3,221
min $Re_t$	33,285	min $A$	265	min $A$	0	min $A$	0
max $\Delta p_t$	30,392						
max $\Delta p_s$	24,832						
min $A$	11,319						
incumbent $C_A$	39,582	incumbent $C_A$	36,548	incumbent $C_A$	36,548	incumbent $C_A$	36,548

**Table SF1 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 1

HS-CI		HS-IF		HS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $C_A$	1,007,415	max $C_A$	930,804	max $C_A$	1,030,446
min $P_{CI}/d_{t,i}$	593,343	min $v_s$	928,908	min $v_s$	1,024,974
min $P_{CI}/d_t$	509,613	max $v_s$	137,244	max $v_s$	212,724
min $\alpha_{CI}$	509,613	min $e_{IF}/d_{t,i}$	103,396	min $y$	107,997
min $\alpha_{CI}$	322,929	min $e_{IF}/d_{t,i}$	96,528	max $y$	82,617
min $v_s$	322,671	min $v_t$	79,712	min $v_t$	65,193
max $v_s$	45,639	max $v_t$	33,712	max $v_t$	32,562
min $v_t$	39,735	min $Re_t$	33,712	min $v_{t,TI}$	32,562
max $v_t$	15,933	max $\Delta p_t$	27,163	max $v_{t,TI}$	32,562
min $Re_s$	15,933	min $Re_s$	27,163	min $Re_s$	24,549
min $Re_t$	15,933	max $\Delta p_s$	27,163	min $Re_t$	24,549
max $\Delta p_t$	15,257	min $A$	0	min $Re_{t,TI}$	24,549
max $\Delta p_s$	15,251			max $\Delta p_t$	24,023
min $A$	0			max $\Delta p_s$	24,023
				min $A$	0
incumbent $C_A$	36,548	incumbent $C_A$	36,548	incumbent $C_A$	36,548

**Table SF1 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 1

VS-CI		VS-IF		VS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $C_A$	1,007,415	max $C_A$	930,804	max $C_A$	1,030,446
min $P_{CI}/d_{t,i}$	593,343	min $v_s$	928,908	min $v_s$	1,024,974
min $P_{CI}/d_t$	509,613	max $v_s$	137,244	max $v_s$	212,724
min $\alpha_{CI}$	509,613	min $e_{IF}/d_{t,i}$	103,396	min $y$	107,997
min $\alpha_{CI}$	322,929	min $e_{IF}/d_{t,i}$	96,528	max $y$	82,617
min $v_s$	322,671	min $v_t$	79,712	min $v_t$	65,193
max $v_s$	45,639	max $v_t$	33,712	max $v_t$	32,562
min $v_t$	39,735	min $Re_t$	33,712	min $v_{t,TI}$	32,562
max $v_t$	15,933	max $\Delta p_t$	33,712	max $v_{t,TI}$	32,562
min $Re_s$	15,933	min $Re_s$	27,163	min $Re_s$	24,549
min $Re_t$	15,933	max $\Delta p_s$	22,414	min $Re_t$	24,549
max $\Delta p_t$	15,257	min $A$	0	min $Re_{t,TI}$	24,549
max $\Delta p_s$	8,313			max $\Delta p_t$	24,023
min $A$	0			max $\Delta p_s$	14,372
				min $A$	0
incumbent $C_A$	36,548	incumbent $C_A$	36,548	incumbent $C_A$	36,548

**Table SF1 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 1

HT-EF		HT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	622,800	start	830,400
max $C_A$	234,936	max $C_A$	418,052
min $v_{s,EF}$	209,526	min $lb_{CHB}/d_s$	418,052
max $v_{s,EF}$	153,486	max $lb_{CHB}/d_s$	209,026
min $v_t$	152,648	min $v_s$	198,454
max $v_t$	23,355	max $v_s$	122,689
min $Re_s$	23,224	min $v_t$	121,413
min $Re_t$	23,224	max $v_t$	26,439
max $\Delta p_t$	23,224	min $Re_s$	26,439
max $\Delta p_s$	18,790	min $Re_t$	26,439
min $A$	114	max $\Delta p_t$	26,439
		max $\Delta p_s$	16,140
		min $A$	0
incumbent $C_A$	34,842	incumbent $C_A$	34,842

**Table SF1 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 1

VT-EF		VT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	155,700	start	207,600
max $C_A$	48,129	max $C_A$	96,024
min $v_{s,EF}$	43,512	min $lb_{CHB}/d_s$	96,024
max $v_{s,EF}$	30,785	max $lb_{CHB}/d_s$	48,012
min $v_t$	30,102	min $v_s$	45,715
max $v_t$	17,363	max $v_s$	27,859
min $Re_s$	17,260	min $v_t$	26,583
min $Re_t$	17,260	max $v_t$	19,805
max $\Delta p_t$	3,636	min $Re_s$	19,805
max $\Delta p_s$	2,492	min $Re_t$	19,805
min $A$	0	max $\Delta p_t$	5,492
		max $\Delta p_s$	5,492
		min $A$	0
incumbent $C_A$	34,842	incumbent $C_A$	34,842

**Table SF2:** Number of active candidates by automatic running to minimize  $TAC$  after the trim

related to each constraint for Example 1

HS		HT		VS		VT	
Constraint	Number of active candidates						
start	403,200	start	207,600	start	207,600	start	51,900
min $L/d_s$	288,000	max $TAC$	66,481	max $TAC$	83,222	max $TAC$	11,173
max $L/d_s$	288,000	min $v_s$	41,883	min $v_s$	82,353	min $v_s$	6,047
min $lbc/d_s$	273,600	max $v_s$	40,788	max $v_s$	22,127	max $v_s$	5,993
max $lbc/d_s$	207,600	min $v_t$	40,368	min $v_t$	12,034	min $v_t$	5,812
min $v_s$	203,440	max $v_t$	7,525	max $v_t$	10,701	max $v_t$	3,485
max $v_s$	75,520	min $Re_s$	7,525	min $Re_s$	10,701	min $Re_s$	3,485
min $v_t$	47,242	min $Re_t$	7,525	min $Re_t$	10,701	min $Re_t$	3,485
max $v_t$	33,285	max $\Delta p_t$	7,525	max $\Delta p_t$	10,701	max $\Delta p_t$	3,485
min $Re_s$	33,285	max $\Delta p_s$	7,525	max $\Delta p_s$	6,780	max $\Delta p_s$	3,485
min $Re_t$	33,285	min $A$	0	min $A$	0	min $A$	0
max $\Delta p_t$	30,392						
max $\Delta p_s$	24,832						
min $A$	11,319						
incumbent		incumbent		incumbent		incumbent	
$TAC$	11,727	$TAC$	11,727	$TAC$	11,727	$TAC$	11,727

**Table SF2 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 1

HS-CI		HS-IF		HS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $TAC$	606,542	max $TAC$	681,624	max $TAC$	500,929
min $P_{CI}/d_{t,i}$	293,367	min $v_s$	679,271	min $v_s$	496,018
min $P_{CI}/d_t$	260,641	max $v_s$	113,058	max $v_s$	128,076
min $\alpha_{CI}$	260,641	min $e_{IF}/d_{t,i}$	81,686	min $y$	53,350
min $\alpha_{CI}$	146,373	min $e_{IF}/d_{t,i}$	68,898	max $y$	45,853
min $v_s$	146,063	min $v_t$	41,615	min $v_t$	17,550
max $v_s$	23,286	max $v_t$	25,595	max $v_t$	17,367
min $v_t$	12,596	min $Re_t$	25,595	min $v_{t,TI}$	17,367
max $v_t$	12,299	max $\Delta p_t$	25,595	max $v_{t,TI}$	17,367
min $Re_s$	12,299	min $Re_s$	25,595	min $Re_s$	16,640
min $Re_t$	12,299	max $\Delta p_s$	25,595	min $Re_t$	16,640
max $\Delta p_t$	12,299	min $A$	0	min $Re_{t,TI}$	16,640
max $\Delta p_s$	12,286			max $\Delta p_t$	16,640
min $A$	0			max $\Delta p_s$	16,637
				min $A$	0
incumbent $TAC$	11,727	incumbent $TAC$	11,727	incumbent $TAC$	11,727

**Table SF2 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 1

VS-CI		VS-IF		VS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $TAC$	606,542	max $TAC$	681,624	max $TAC$	500,929
min $P_{CI}/d_{t,i}$	293,367	min $v_s$	679,271	min $v_s$	496,018
min $P_{CI}/d_t$	260,641	max $v_s$	113,058	max $v_s$	128,076
min $\alpha_{CI}$	260,641	min $e_{IF}/d_{t,i}$	81,686	min $y$	53,350
min $\alpha_{CI}$	146,373	min $e_{IF}/d_{t,i}$	68,898	max $y$	45,853
min $v_s$	146,063	min $v_t$	41,615	min $v_t$	17,550
max $v_s$	23,286	max $v_t$	25,595	max $v_t$	17,367
min $v_t$	12,596	min $Re_t$	25,595	min $v_{t,TI}$	17,367
max $v_t$	12,299	max $\Delta p_t$	25,595	max $v_{t,TI}$	17,367
min $Re_s$	12,299	min $Re_s$	25,595	min $Re_s$	16,640
min $Re_t$	12,299	max $\Delta p_s$	19,914	min $Re_t$	16,640
max $\Delta p_t$	12,299	min $A$	0	min $Re_{t,TI}$	16,640
max $\Delta p_s$	6,939			max $\Delta p_t$	16,640
min $A$	0			max $\Delta p_s$	10,692
				min $A$	0
incumbent $TAC$	11,727	incumbent $TAC$	11,727	incumbent $TAC$	11,727

**Table SF2 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 1

HT-EF		HT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	622,800	start	830,400
max $TAC$	118,878	max $TAC$	442,386
min $v_{s,EF}$	87,182	min $lb_{CHB}/d_s$	442,386
max $v_{s,EF}$	80,055	max $lb_{CHB}/d_s$	216,130
min $v_t$	79,368	min $v_s$	200,787
max $v_t$	14,050	max $v_s$	134,027
min $Re_s$	14,048	min $v_t$	132,230
min $Re_t$	14,048	max $v_t$	30,353
max $\Delta p_t$	14,048	min $Re_s$	30,353
max $\Delta p_s$	14,048	min $Re_t$	30,353
min $A$	123	max $\Delta p_t$	30,353
		max $\Delta p_s$	18,589
		min $A$	0
incumbent $TAC$	10,609	incumbent $TAC$	10,609

**Table SF2 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 1

VT-EF		VT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	155,700	start	207,600
max $TAC$	20,707	max $TAC$	103,238
min $v_{s,EF}$	15,483	min $lb_{CHB}/d_s$	103,238
max $v_{s,EF}$	14,191	max $lb_{CHB}/d_s$	50,355
min $v_t$	13,767	min $v_s$	46,868
max $v_t$	8,742	max $v_s$	31,060
min $Re_s$	8,742	min $v_t$	29,263
min $Re_t$	8,742	max $v_t$	22,091
max $\Delta p_t$	894	min $Re_s$	22,091
max $\Delta p_s$	894	min $Re_t$	22,091
min $A$	0	max $\Delta p_t$	6,327
		max $\Delta p_s$	6,327
		min $A$	0
incumbent $TAC$	10,609	incumbent $TAC$	10,609

**Table SF3:** Number of active candidates by automatic running to minimize  $CA$  after the trim related to each constraint for Example 2

HS		HT		VS		VT	
Constraint	Number of active candidates						
start	403,200	start	207,600	start	207,600	start	51,900
min $L/d_s$	288,000	max $CA$	142,981	max $CA$	142,981	max $CA$	34,298
max $L/d_s$	288,000	min $v_s$	141,381	min $v_s$	141,997	min $v_s$	33,937
min $lbc/d_s$	273,600	max $v_s$	40,360	max $v_s$	33,623	max $v_s$	9,430
max $lbc/d_s$	207,600	min $v_t$	38,830	min $v_t$	31,696	min $v_t$	7,900
min $v_s$	204,320	max $v_t$	11,153	max $v_t$	9,918	max $v_t$	6,760
max $v_s$	71,280	min $Re_s$	11,153	min $Re_s$	9,918	min $Re_s$	6,760
min $v_t$	64,733	min $Re_t$	11,153	min $Re_t$	9,918	min $Re_t$	6,760
max $v_t$	23,964	max $\Delta p_t$	11,153	max $\Delta p_t$	9,918	max $\Delta p_t$	6,760
min $Re_s$	23,964	max $\Delta p_s$	10,000	max $\Delta p_s$	2,209	max $\Delta p_s$	4,060
min $Re_t$	23,964	min $A$	0	min $A$	0	min $A$	0
max $\Delta p_t$	23,964						
max $\Delta p_s$	11,953						
min $A$	3,780						
incumbent $CA$	45,391						

**Table SF3 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 2

HS-CI		HS-IF		HS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $CA$	1,158,642	max $CA$	1,987,116	max $CA$	1,142,883
min $P_{CI}/d_{t,i}$	702,669	min $v_s$	1,967,748	min $v_s$	1,136,844
min $P_{CI}/d_t$	599,520	max $v_s$	540,828	max $v_s$	239,472
min $a_{CI}$	599,520	min $e_{IF}/d_{t,i}$	483,804	min $y$	127,575
min $a_{CI}$	385,143	min $e_{IF}/d_{t,i}$	422,208	max $y$	96,459
min $v_s$	384,537	min $v_t$	395,748	min $v_t$	94,581
max $v_s$	60,291	max $v_t$	135,128	max $v_t$	26,133
min $v_t$	60,174	min $Re_t$	135,128	min $v_{t,TI}$	26,133
max $v_t$	12,828	max $\Delta p_t$	117,048	max $v_{t,TI}$	26,133
min $Re_s$	12,828	min $Re_s$	117,048	min $Re_s$	19,029
min $Re_t$	12,828	max $\Delta p_s$	75,395	min $Re_t$	19,029
max $\Delta p_t$	12,811	min $A$	29,143	min $Re_{t,TI}$	19,029
max $\Delta p_s$	8,258			max $\Delta p_t$	19,029
min $A$	2			max $\Delta p_s$	13,831
				min $A$	0
incumbent $CA$	42,761	incumbent $CA$	41,047	incumbent $CA$	41,047

**Table SF3 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 2

VS-CI		VS-IF		VS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $CA$	1,119,906	max $CA$	1,070,760	max $CA$	1,142,883
min $P_{CI}/d_{t,i}$	673,767	min $v_s$	1,068,300	min $v_s$	1,136,844
min $P_{CI}/d_t$	575,907	max $v_s$	161,604	max $v_s$	239,472
min $\alpha_{CI}$	575,907	min $e_{IF}/d_{t,i}$	124,028	min $y$	127,575
min $\alpha_{CI}$	368,490	min $e_{IF}/d_{t,i}$	114,948	max $y$	96,459
min $v_s$	368,490	min $v_t$	113,008	min $v_t$	94,581
max $v_s$	54,741	max $v_t$	27,028	max $v_t$	26,133
min $v_t$	54,729	min $Re_t$	27,028	min $v_{t,TI}$	26,133
max $v_t$	11,157	max $\Delta p_t$	27,028	max $v_{t,TI}$	26,133
min $Re_s$	11,157	min $Re_s$	25,475	min $Re_s$	19,029
min $Re_t$	11,157	max $\Delta p_s$	7,822	min $Re_t$	19,029
max $\Delta p_t$	11,150	min $A$	0	min $Re_{t,TI}$	19,029
max $\Delta p_s$	1,650			max $\Delta p_t$	19,029
min $A$	0			max $\Delta p_s$	3,779
				min $A$	0
incumbent $CA$	41,047	incumbent $CA$	41,047	incumbent $CA$	41,047

**Table SF3 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 2

HT-EF		HT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	622,800	start	830,400
max $CA$	269,996	max $CA$	457,412
min $v_{s,EF}$	269,163	min $lb_{CHB}/d_s$	457,412
max $v_{s,EF}$	49,393	max $lb_{CHB}/d_s$	228,706
min $v_t$	48,394	min $v_s$	228,706
max $v_t$	11,152	max $v_s$	22,145
min $Re_s$	11,152	min $v_t$	20,833
min $Re_t$	11,152	max $v_t$	7,092
max $\Delta p_t$	11,152	min $Re_s$	7,092
max $\Delta p_s$	9,713	min $Re_t$	7,092
min $A$	44	max $\Delta p_t$	7,092
		max $\Delta p_s$	2,233
		min $A$	0
incumbent $CA$	38,241	incumbent $CA$	38,241

**Table SF3 (continued):** Number of active candidates by automatic running to minimize  $C_A$  after the trim related to each constraint for Example 2

VT-EF		VT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	155,700	start	207,600
max $C_A$	55,491	max $C_A$	106,840
min $v_{s,EF}$	55,360	min $lb_{CHB}/d_s$	106,840
max $v_{s,EF}$	8,987	max $lb_{CHB}/d_s$	53,420
min $v_t$	8,224	min $v_s$	53,420
max $v_t$	6,391	max $v_s$	4,997
min $Re_s$	6,391	min $v_t$	3,685
min $Re_t$	6,391	max $v_t$	3,685
max $\Delta p_t$	3,422	min $Re_s$	3,685
max $\Delta p_s$	2,896	min $Re_t$	3,685
min $A$	0	max $\Delta p_t$	1,701
		max $\Delta p_s$	1,701
		min $A$	0
incumbent $C_A$	38,241	incumbent $C_A$	38,241

**Table SF4:** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 2

HS		HT		VS		VT	
Constraint	Number of active candidates						
start	403,200	start	207,600	start	207,600	start	51,900
min $L/d_s$	288,000	max $TAC$	20,213	max $TAC$	58,485	max $TAC$	2,303
max $L/d_s$	288,000	min $v_s$	18,145	min $v_s$	57,838	min $v_s$	1,911
min $lbc/d_s$	273,600	max $v_s$	15,765	max $v_s$	16,498	max $v_s$	1,816
max $lbc/d_s$	207,600	min $v_t$	15,161	min $v_t$	13,625	min $v_t$	1,563
min $v_s$	204,320	max $v_t$	4,336	max $v_t$	10,986	max $v_t$	1,350
max $v_s$	71,280	min $Re_s$	4,336	min $Re_s$	10,986	min $Re_s$	1,350
min $v_t$	64,733	min $Re_t$	4,336	min $Re_t$	10,986	min $Re_t$	1,350
max $v_t$	23,964	max $\Delta p_t$	4,336	max $\Delta p_t$	10,986	max $\Delta p_t$	1,350
min $Re_s$	23,964	max $\Delta p_s$	4,336	max $\Delta p_s$	2,311	max $\Delta p_s$	1,350
min $Re_t$	23,964	min $A$	0	min $A$	0	min $A$	0
max $\Delta p_t$	23,964						
max $\Delta p_s$	11,953						
min $A$	3,780						
incumbent $TAC$	15,014						

**Table SF4 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 2

HS-CI		HS-IF		HS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $TAC$	339,534	max $TAC$	666,778	max $TAC$	259,236
min $PCI/d_{t,i}$	150,027	min $v_s$	664,541	min $v_s$	256,501
min $PCI/d_t$	135,254	max $v_s$	114,247	max $v_s$	71,093
min $\alpha_{CI}$	135,254	min $e_{IF}/d_{t,i}$	91,952	min $y$	26,844
min $\alpha_{CI}$	67,993	min $e_{IF}/d_{t,i}$	69,800	max $y$	24,940
min $v_s$	67,669	min $v_t$	64,226	min $v_t$	20,218
max $v_s$	13,256	max $v_t$	28,214	max $v_t$	19,267
min $v_t$	11,990	min $Re_t$	28,214	min $v_{t,II}$	19,267
max $v_t$	11,538	max $\Delta p_t$	28,214	max $v_{t,II}$	19,267
min $Re_s$	11,538	min $Re_s$	28,214	min $Re_s$	17,312
min $Re_t$	11,538	max $\Delta p_s$	23,805	min $Re_t$	17,312
max $\Delta p_t$	11,538	min $A$	79	min $Re_{t,II}$	17,312
max $\Delta p_s$	7,250			max $\Delta p_t$	17,312
min $A$	44			max $\Delta p_s$	12,706
				min $A$	0
incumbent $TAC$	14,676	incumbent $TAC$	13,596	incumbent $TAC$	13,596

**Table SF4 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 2

VS-CI		VS-IF		VS-TI	
Constraint	Number of active candidates	Constraint	Number of active candidates	Constraint	Number of active candidates
start	1,868,400	start	2,491,200	start	1,868,400
max $TAC$	293,466	max $TAC$	603,353	max $TAC$	259,236
min $P_{CI}/d_{t,i}$	120,801	min $v_s$	601,643	min $v_s$	256,501
min $P_{CI}/d_t$	110,535	max $v_s$	95,108	max $v_s$	71,093
min $\alpha_{CI}$	110,535	min $e_{IF}/d_{t,i}$	75,261	min $y$	26,844
min $\alpha_{CI}$	53,266	min $e_{IF}/d_{t,i}$	57,357	max $y$	24,940
min $v_s$	53,081	min $v_t$	53,300	min $v_t$	20,218
max $v_s$	9,139	max $v_t$	22,737	max $v_t$	19,267
min $v_t$	8,502	min $Re_t$	22,737	min $v_{t,TI}$	19,267
max $v_t$	8,182	max $\Delta p_t$	22,737	max $v_{t,TI}$	19,267
min $Re_s$	8,182	min $Re_s$	22,737	min $Re_s$	17,312
min $Re_t$	8,182	max $\Delta p_s$	6,718	min $Re_t$	17,312
max $\Delta p_t$	8,182	min $A$	0	min $Re_{t,TI}$	17,312
max $\Delta p_s$	1,294			max $\Delta p_t$	17,312
min $A$	0			max $\Delta p_s$	3,493
				min $A$	0
incumbent $TAC$	13,596	incumbent $TAC$	13,596	incumbent $TAC$	13,596

**Table SF4 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 2

HT-EF		HT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	622,800	start	830,400
max $TAC$	18,319	max $TAC$	486,337
min $v_{s,EF}$	17,050	min $lb_{CHB}/d_s$	486,337
max $v_{s,EF}$	13,593	max $lb_{CHB}/d_s$	230,204
min $v_t$	13,095	min $v_s$	230,204
max $v_t$	3,804	max $v_s$	39,234
min $Re_s$	3,804	min $v_t$	36,555
min $Re_t$	3,804	max $v_t$	13,256
max $\Delta p_t$	3,804	min $Re_s$	13,256
max $\Delta p_s$	3,804	min $Re_t$	13,256
min $A$	0	max $\Delta p_t$	13,256
		max $\Delta p_s$	5,124
		min $A$	0
incumbent $TAC$	13,596	incumbent $TAC$	13,596

**Table SF4 (continued):** Number of active candidates by automatic running to minimize  $TAC$  after the trim related to each constraint for Example 2

VT-EF		VT-HB	
Constraint	Number of active candidates	Constraint	Number of active candidates
start	155,700	start	207,600
max $TAC$	4,085	max $TAC$	115,581
min $v_{s,EF}$	3,807	min $lb_{CHB}/d_s$	115,581
max $v_{s,EF}$	3,027	max $lb_{CHB}/d_s$	54,592
min $v_t$	2,529	min $v_s$	54,592
max $v_t$	2,337	max $v_s$	9,072
min $Re_s$	2,337	min $v_t$	6,393
min $Re_t$	2,337	max $v_t$	6,393
max $\Delta p_t$	811	min $Re_s$	6,393
max $\Delta p_s$	811	min $Re_t$	6,393
min $A$	0	max $\Delta p_t$	3,435
		max $\Delta p_s$	3,435
		min $A$	0
incumbent $TAC$	13,596	incumbent $TAC$	13,596

## Part G

The larger set of design variables is shown in Table SG1.

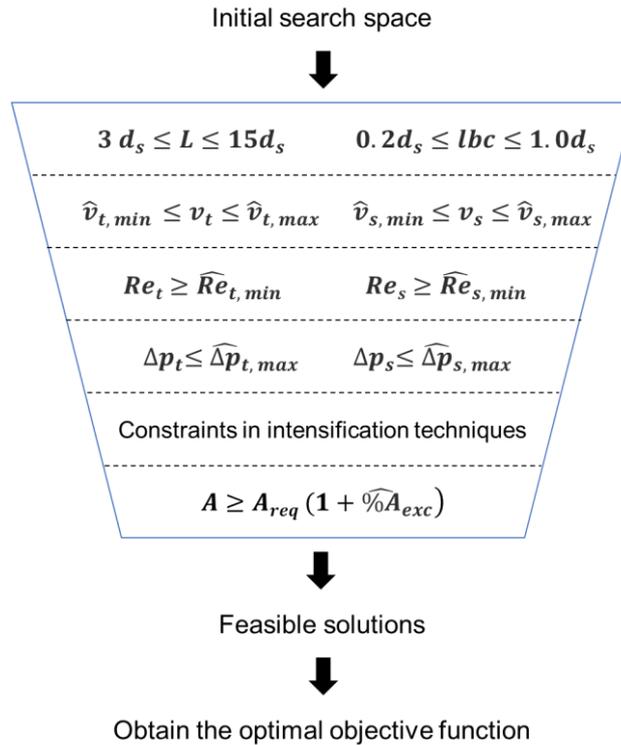
**Table SG1:** Larger design variables alternatives

<b>Variable</b>	<b>Values</b>
Outer tube diameter (m)	0.016, 0.018, 0.019, 0.020, 0.022, 0.025, 0.030, 0.032, 0.038, 0.040, 0.051, 0.070
Tube length (m)	1.219, 1.829, 2.439, 3.049, 3.659, 4.877, 6.098
Tube pitch ratio	1.25, 1.33, 1.50
Tube layout	1 = Square, 2 = Triangular
Number of tube passes	1, 2, 4, 6 (*)
Number of baffles	1, 2, ..., 20
Shell diameter (m)	0.438, 0.489, 0.540, 0.591, 0.635, 0.686, 0.737, 0.787, 0.838, 0.889, 0.940, 0.991, 1.067, 1.143, 1.219, 1.372, 1.524

## Part H

The premise of Set Trimming is that the variables in the optimization problem are discrete. For example, in the case of a condenser, the variables might include tube length, tube diameter, shell diameter, tube pitch, tube layout, etc., all of which are initially discrete variables. Set Trimming is based on creating a set, whose elements are combinations of all instances of the discrete values of the variables. Each element of this set is a candidate solution, which at this point can be feasible or infeasible. Set Trimming eliminates candidates that do not satisfy the inequality constraints. At each step, the function corresponding to each inequality is evaluated for all candidates and those candidates that do not satisfy the constraint are eliminated from the set.

The basic process of Set Trimming in our study is illustrated in Figure SH1. The condenser optimization is an Mixed-Integer Nonlinear Optimization Model (MINLON); no solver is required, neither one based on Metaheuristics (GA, PSO, SA, etc.), nor a Mixed-Integer Nonlinear Programming (MINLP) procedure. Everything is handled using set manipulations. In our case, we used Dynamic Sets, which is a tool available in GAMS.



**Figure SH1:** The basic process of Set Trimming

For a single condenser, the steps of Set Trimming are as follows:

**Step 1:** Place all variable combinations into a set to form the initial search space.

**Step 2:** Calculate process parameters, such as flow velocity, pressure drop, Reynolds number, etc. Apply inequalities to trim combinations that do not meet the requirements based on the calculated process parameters

**Step 3:** Obtain feasible solutions, calculate the values of the objective functions of all candidates, and select the globally optimal objective function.