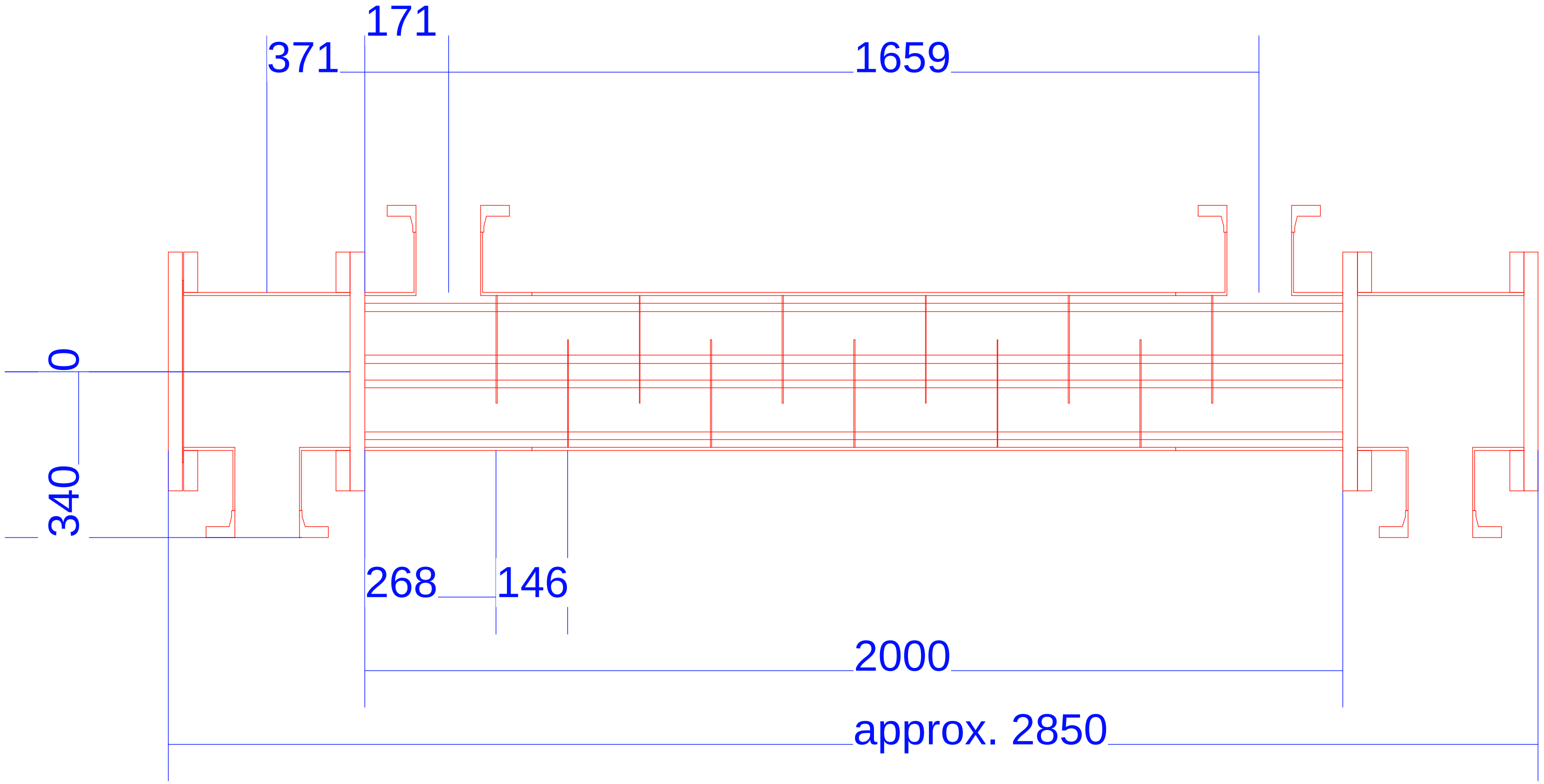


171
371
1659
0
340
268
146
2000
approx. 2850

Appearance

Input values:	1.23456	or	*1.23456*
Calculated values:	**1.23456**	or	***1.23456***
Estimated values:	1.23456	or	*1.23456*

In the tubes:				Around the tubes:			
Medium: Water				Medium: Water			
Mass flow	m_i	*20*	kg/s	Mass flow	m_a	**13.94**	kg/s
Volume flow	V_i	**0.02011**	m^3/s	Volume flow	V_a	***0.01434***	m^3/s
Stand.vol. flow	V_i		m^3/s	Stand.vol. flow	V_a		m^3/s
Pressure (in)	P	*500000*	Pa	Pressure (in)	P	*500000*	Pa
Inlet temp.	ϑe_i	*27*	°C	Inlet temp.	ϑe_a	*90*	°C
Outlet temp.	ϑa_i	*41*	°C	Outlet temp.	ϑa_a	*70*	°C
Average temp.	ϑm_i	**34**	°C	Average temp.	ϑm_a	**80**	°C
Density	ρ_i	*994.6*	kg/m^3	Density	ρ_a	*971.8*	kg/m^3
Spec.heat cap.	cp_i	*4177*	J/(kg·K)	Spec.heat cap.	cp_a	4195	J/(kg·K)
Thermal Cond.	λ_i	*0.6209*	W/(m·K)	Thermal Cond.	λ_a	*0.667*	W/(m·K)
Dyn. Viscosity	η_i	*0.7342*	mPa·s	Dyn. Viscosity	η_a	*0.3545*	mPa·s
Stand.-Density	ρ_i		kg/m^3	Stand.-Density	ρ_a		kg/m^3
Fouling resistance		0.00009	$m^2\cdot K/W$	Fouling resistance		0.00009	$m^2\cdot K/W$
For phase change:							
Density vapour	ρDi		kg/m^3	Density vapour	ρDa		kg/m^3
Latent heat	ΔHv	0	J/kg	Latent heat	ΔHv	0	J/kg
Vapour fraction	x_i	1	-	Vapour fraction	x_a	1	-
Heat duty	Q_i	**1169596**	W	Heat duty	Q_a	**-1169596**	W
				Heat loss	Q_v_a	0	W

Geometry:
Bare tubes
Installation position: horizontal

Segmental baffles

Outside shell diam.	Do	*0.3239*	m	Shell wall thickness	sa	***0.0071***	m
Inside shell diam.	Di	*0.3097*	m				
Bundle-shell distance		*0.01571*	m	Min. bundle-shell dist.		*0.012*	m
Outside tube diam.	do	*0.016*	m	Inside tube diam.	di	*0.012*	m
Tube pitch (crosswise)		*0.021*	m	Tube pitch(lengthwise)		*0.01819*	m
Pitch angle	Φ	***60***	°	Path width	b	*0.034*	m
Dist. between baffles		***0.1464***	m	Number of baffles/pass		*11*	-
Dist.tubesheet-1.baffle		***0.268***	m	Baffle diameter		***0.3067***	m
Baffle borehole		***0.0168***	m	Baffle cut		*29.3*	%
Sealing strips pairs		*0*	-				

Fins (in the tubes):

Number of fins/tube	-	Fin height		m
Fin thickness	m	Thickness at fin root		m
Helix angle	°			

Thermal conductivity tube material	λ	52	W /(m·K)
Fouling resistance	Rf	**0.00021**	$m^2\cdot K/W$
Number of passes (tube-side)	Z	*1*	-
Number of passes (shell-side)	Z	*1*	-
Number of serial exchangers		*1*	-

Evaluation:

		required			final	
Exchanger area	A	**14.52**	m^2	Aa	**15.18**	m^2
Bundle length	l	**1.913**	m	la	*2*	m

Results:

Number of tubes	N	*151*	-
Heat transfer coefficient (inside)	α_i	**7141**	W/(m²·K)
Heat transfer coefficient (outside)	α_a	**7872**	W/(m²·K)
FN Factor	FN	**0.9963**	-
Logarithmic mean temperature diff.	$\delta\vartheta$	**45.93**	K
Overall heat transfer coefficient	k	**1761**	W/(m²·K)
Allowable overheating for condensation	ϑü		K

In the tubes:

Velocity (tube)		***1.177***	m/s
Pressure drop	Δpi	**7649**	Pa
Mean wall temp.	ϑwi	***49.04***	°C
Inlet nozzle (ID)		*0.1317*	m
Outlet nozzle (ID)		*0.1317*	m
Velocity (Nozzle in)		**1.476**	m/s
Velocity (Nozzle out)		**1.476**	m/s

Around the tubes:

Velocity (shell)		**0.9633**	m/s
Velocity (window zone)		**1.203**	m/s
Pressure drop	Δpa	**19181**	Pa
Mean wall temp.	ϑwa	***69.77***	°C
Inlet nozzle (ID)		*0.1317*	m
Outlet nozzle (ID)		*0.1317*	m
Velocity (Nozzle in)		**1.053**	m/s
Velocity (Nozzle out)		**1.053**	m/s

Equations:

INSIDE:

$$Q_i = m_i \cdot cp_i \cdot (\vartheta a_i - \vartheta e_i) + m_i \cdot x_i \cdot \Delta Hv_i =$$

$$= 20 \cdot 4177 \; (41 - 27) + 20 \cdot 1 \cdot 0$$

$$= 1169596$$

OUTSIDE:

$$Q_a = m_a \cdot cp_a \cdot (\vartheta a_a - \vartheta e_a) + m_a \cdot x_a \cdot \Delta Hv_a$$

$$= 13.94 \cdot 4195 \; (70 - 90) + 13.94 \cdot 1 \cdot 0$$

$$= -1169596$$

Balance:

$$Q_i = -(Q_a - Q_v) \quad 1169596 = -(-1169596 - 0)$$

TRANSITION:

$$\frac{1}{k} = \frac{1}{\alpha_i} \cdot \frac{do}{di} + \frac{do \ln(do/di)}{2 \cdot \lambda} + \frac{1}{\alpha_a} + Rf$$

$$\frac{0.016}{7141 \cdot 0.012} + \frac{0.016 \ln(0.016 / 0.012)}{2 \cdot 52} + \frac{1}{7872} + 0.00021$$

$$k = 1761$$

$$Q_i = k \cdot A \cdot \delta\vartheta \cdot FN \quad 1169596 = 1761 \cdot 14.52 \cdot 45.93 \cdot 0.9963$$

Tube length	l	1.913	m		
Total area	A	**14.52**	m^2		
Design = D; Rating / Simulation = R		< R >	-		
Number of exchangers in series		*1*			
Final tube length	la	*2*	m		
Inside shell diameter	Di	*0.3097*	m	**309.7**	mm
Bundle diameter	Db	*0.2783*	m	**278.3**	mm
Bundle - shell distance	D	***0.01571***	m	**15.71**	mm
Bundle - shell minimum distance	Dm	*0.012*	m	**12**	mm
Baffle diameter	Dl	*0.3067*	m	**306.7**	mm
Height of the window in the baffles	H	***0.08986***	m	**89.86**	mm
Height of the window % of diameter		*29.3*	%		
Head diameter	Da		m		mm
Bolt-circle diameter	Dt		m		mm
Outside tube diameter	da	*0.016*	m	**16**	mm
Inside tube diameter	di	*0.012*	m	**12**	mm
Pitch crosswise to direction of flow	sq	*0.021*	m	**21**	mm
Pitch in direction of flow	sl	*0.01819*	m	**18.19**	mm
Tube pattern: aligned = a / staggered = s		< S >	-		
Adapt window height Yes = Y / No = N		< >	-		
Arrangement: around central tube = 0 staggered by 1/2 pitch = 1		< 0 >	-		
Number of tube-side passes		*1*	-		
Number of shell-side passes		*1*	-		
Type		< 0 >	-		
Tube lane width (horizontal)		*0.034*	m	**34**	mm
Tube lane width (vertical)			m		mm
Number of bolts on bolt-circle			-		
Rotation angle for bolt-hole pattern			°		

F3 graphics:

Number of tubes	n	*151*	-
Number of tubes in the windows	nF	*64*	-
Number of tubes in the cross flow zone	nS	*87*	-
Number of boundary tubes	RR	66	-
Number of tube rows in a window	nRF	*4*	-
Number of tube rows in the cross flow zone	nW	*7*	-
Number of tube rows in the end zone	nWE	*11*	-
Sum of the shortest connecting paths (centre)	Le	0.1017	m
Shortest connecting path (tube-tube)	e	0.005	m
Shortest connecting path (tube-shell)	e1	*0.02085*	m
Number of connecting paths	nV	*12*	-
Mean distance boundary tubes-envelope circle centre	rh	0.1189	m

Tubes per pass:

Pass

1	2	3	4	5	6	7	8
151	0	0	0	0	0	0	0

Baffles:

Number of baffles	N	**11**			
Distance between baffles	S1	*0.1464*	m	**146.4**	mm
Distance between head and baffle	S2	*0.268*	m	**268**	mm

Design criteria:

Maximum bundle length	m
Maximum ratio l/Db	
Minimum ratio l/Db	

Lauterbach Verfahrenstechnik
Properties of water

WTS_print_example.atl

04-24-03

AltNr.: 1

		State 1:			**State 2:**	
Calculation for saturation? (Yes = Y / No = N)		< N >			< N >	
Temperature	t_1	34	°C	t_2	49.04	°C
Pressure	p_1	500000	Pa	p_2	500000	Pa

Properties of liquid water or superheated steam:

		State 1 liquid			State 2 liquid	
Specific enthalpy	h	**142824**	J/kg	h	**205682**	J/kg
Specific entropy	s	**491.1**	J/(kg·K)	s	**690.9**	J/(kg·K)
Density	ρ	**994.6**	kg/m³	ρ	**988.7**	kg/m³
Specific heat capacity	cp	**4177**	J/(kg·K)	cp	**4180**	J/(kg·K)
Dynamic viscosity	η	**0.7342**	mPa·s	η	**0.556**	mPa·s
Thermal conductivity	λ	**0.6209**	W/(m·K)	λ	**0.6396**	W/(m·K)
Surface tension	σ	**70.57**	mN/m	σ	**68.11**	mN/m
Kinematic viscosity	ν	**7.382E-7**	m²/s	ν	**5.624E-7**	m²/s
Prandtl number	Pr	**4.939**	-	Pr	**3.633**	-

Properties of vapour fraction of wet steam:

		State 1			State 2	
Specific enthalpy	h		J/kg	h		J/kg
Specific entropy	s		J/(kg·K)	s		J/(kg·K)
Density	ρ		kg/m³	ρ		kg/m³
Specific heat capacity	cp		J/(kg·K)	cp		J/(kg·K)
Dynamic viscosity	η		mPa·s	η		mPa·s
Thermal conductivity	λ		W/(m·K)	λ		W/(m·K)
Kinematic viscosity	ν		m²/s	ν		m²/s
Prandtl number	Pr		-	Pr		-
Heat of evaporation	Δhv		J/kg	Δhv		J/kg
Entropy of evaporation	Δsv		J/(kg·K)	Δsv		J/(kg·K)
Fraction vaporized	x		-	x		-
Enthalpy of wet steam	hx		J/kg	hx		J/kg
Entropy of wet steam	sx		J/(kg·K)	sx		J/(kg·K)

		State 1:			**State 2:**	
Calculation for saturation? (Yes = Y / No = N)		< N >			< N >	
Temperature	t_1	80	°C	t_2	69.76	°C
Pressure	p_1	500000	Pa	p_2	500000	Pa

Properties of liquid water or superheated steam:

	State 1 liquid			State 2 liquid		
Specific enthalpy	h	**335276**	J/kg	h	**292360**	J/kg
Specific entropy	s	**1075**	J/(kg·K)	s	**951.6**	J/(kg·K)
Density	ρ	**971.8**	kg/m³	ρ	**978**	kg/m³
Specific heat capacity	cp	**4196**	J/(kg·K)	cp	**4189**	J/(kg·K)
Dynamic viscosity	η	**0.3545**	mPa·s	η	**0.4054**	mPa·s
Thermal conductivity	λ	**0.667**	W/(m·K)	λ	**0.6595**	W/(m·K)
Surface tension	σ	**62.68**	mN/m	σ	**64.53**	mN/m
Kinematic viscosity	ν	**3.647E-7**	m²/s	ν	**4.145E-7**	m²/s
Prandtl number	Pr	**2.23**	-	Pr	**2.575**	-

Properties of vapour fraction of wet steam:

	State 1			State 2		
Specific enthalpy	h		J/kg	h		J/kg
Specific entropy	s		J/(kg·K)	s		J/(kg·K)
Density	ρ		kg/m³	ρ		kg/m³
Specific heat capacity	cp		J/(kg·K)	cp		J/(kg·K)
Dynamic viscosity	η		mPa·s	η		mPa·s
Thermal conductivity	λ		W/(m·K)	λ		W/(m·K)
Kinematic viscosity	ν		m²/s	ν		m²/s
Prandtl number	Pr		-	Pr		-
Heat of evaporation	Δhv		J/kg	Δhv		J/kg
Entropy of evaporation	Δsv		J/(kg·K)	Δsv		J/(kg·K)
Fraction vaporized	x		-	x		-
Enthalpy of wet steam	hx		J/kg	hx		J/kg
Entropy of wet steam	sx		J/(kg·K)	sx		J/(kg·K)

Temperature (inlet)	ϑ_e		°C
Temperature (outlet)	ϑ_a		°C
Dynamic viscosity	η	*0.7342*	mPa·s
Density	ρ	*994.6*	kg/m³
Thermal conductivity	λ	*0.6209*	W/(m·K)
Specific heat capacity	cp	**4177**	J/(kg·K)
Prandtl number	Pr	4.939	-
Prandtl number (wall)	PrW	3.633	-
Fluid: liquid <0> or gas <1>		< 0	>
Calculation of non-circular pipes: Yes = 1		< 0	>
Pipe length	l	*2*	m
Inside diameter	di	**0.01199**	m
Cross sectional area	f	**0.000113**	m²
Perimeter	u	**0.03768**	m
⇒ Hydraulic diameter	dh =	*0.012*	m
Total mass flow	Mg		kg/s
Number of pipes with parallel flow	Z		-
⇒ Mass flow per pipe	M =	**0.1323**	kg/s
⇒ Velocity	w =	*1.177*	m/s
⇒ Reynolds number	Re =	**19141**	-

Balance: Q = Mg · cp · (ϑ_a - ϑ_e) = W

Results: Constant wall temperature

$$Re = \frac{w \cdot dh \cdot \rho}{\eta / 1000} = \frac{1.177 \cdot 0.012 \cdot 994.6}{0.7342 / 1000} = 19141$$

Nu_m_ϑ = (laminar non-disturbed flow Re < 2300) [6]
Nu_m_ϑ = (laminar entrance flow Re < 2300) [12]
Nu_m_T = **133.4** (turbulent flow Re > 10000) [26]
Nu_m = (transition zone 2300 ≤ Re ≤ 10000) [29]

Factor K:

Liquids: $K = (Pr/PrW)^{0.11} = 1.034$

Gases: $K = (T/Tw)^{n} =$ for n = 0

Nu = Nu_m(_ϑ,T) · K = **138** [40,41]

$$\Rightarrow \alpha = \frac{Nu \cdot \lambda}{dh} = \frac{138 \cdot 0.6209}{0.012} = 7141 \quad W/(m^2 \cdot K)$$

Heat transfer: $Q = \alpha \cdot A \cdot \Delta\vartheta_{log}$

$= 7141 \cdot \cdot$

⇒ Wall temperature ϑ_W = *49.04* °C

Calculations:

Laminar flow: Re < 2300

Laminar non-disturbed flow:

$$HW = Re \cdot Pr \cdot dh/l = \mathbf{567.2}$$

$$Nu\_m\_\vartheta\_2 = 1.615 \cdot HW^{1/3} = \qquad [5]$$

$$Nu\_m\_\vartheta = \left[3.66^{3} + 0.7^{3} + \left[Nu\_m\_\vartheta\_2 - 0.7 \right]^{3} \right]^{1/3} =$$
$$= \left[3.66^{3} + 0.7^{3} + \left[\qquad - 0.7 \right]^{3} \right]^{1/3} = \qquad [6]$$

Laminar entrance flow:

$$Nu\_m\_\vartheta\_3 = \left[\frac{2}{1 + 22\ Pr} \right]^{1/6} \cdot \sqrt{HW} =$$
$$= \left[\frac{2}{1 + 22 \cdot 4.939} \right]^{1/6} \cdot \sqrt{\mathbf{567.2}} = \qquad [11]$$

$$Nu\_m\_\vartheta = \left[3.66^{3} + 0.7^{3} + \left[Nu\_m\_\vartheta\_2 - 0.7 \right]^{3} + Nu\_m\_\vartheta\_3^{3} \right]^{1/3} =$$
$$= \left[3.66^{3} + 0.7^{3} + \left[\qquad - 0.7 \right]^{3} + \quad ^{3} \right]^{1/3} = \qquad [12]$$

Turbulent flow: Re > 10000

$$\xi = [1.8 \cdot \log Re - 1.5]^{-2} = [\ 1.8 \cdot \log \mathbf{19141} \quad - 1.5\ ]^{-2} = \mathbf{0.02595} \qquad [27]$$

$$Nu\_m\_T = \frac{\xi/8 \cdot Re \cdot Pr}{1 + 12.7 \cdot \sqrt{\xi/8} \cdot (Pr^{2/3} - 1)} \cdot \left[1 + \left[\frac{dh}{l} \right]^{2/3} \right] = \qquad [26]$$

$$= \frac{\mathbf{0.02595}\ /8 \cdot \mathbf{19141} \cdot 4.939}{1 + 12.7 \cdot \sqrt{\mathbf{0.02595}\ /8} \cdot (\ 4.939^{2/3} - 1)} \cdot \left[1 + \left[\frac{0.012}{2} \right]^{2/3} \right] =$$

$$Nu\_m\_T = \mathbf{133.4}$$

Transition zone: $2300 \leq Re \leq 10000$

$$Nu\_m\_\vartheta\_2\_2300 = 1.615 \cdot (2300 \cdot Pr \cdot dh/l)^{1/3} = \mathbf{6.597} \qquad [32]$$

$$Nu\_m\_\vartheta\_3\_2300 = \left[\frac{2}{1 + 22\ Pr} \right]^{1/6} \cdot \sqrt{2300 \cdot Pr \cdot dh/l} = \mathbf{4.236} \qquad [33]$$

$$Nu\_m\_L\_2300 = \left[49.371 + \left[Nu\_m\_\vartheta\_2\_2300 - 0.7 \right]^3 + Nu\_m\_\vartheta\_3\_2300^3 \right]^{1/3} =$$

$$Nu\_m\_L\_2300 = \mathbf{6.913} \qquad [31]$$

$$Nu\_m\_T\_10000 = \frac{(0.0308/8) \cdot 10000 \cdot Pr}{1 + 12.7 \cdot \sqrt{0.0308/8} \cdot (Pr^{2/3} - 1)} \cdot \left[1 + \left[\frac{dh}{l} \right]^{2/3} \right] =$$

$$[37]$$

$$Nu\_m\_T\_10000 = \mathbf{78.62}$$

$$\gamma = \frac{Re - 2300}{10000 - 2300} = \frac{\mathbf{19141} - 2300}{10000 - 2300} = \qquad [30]$$

$$Nu\_m = (1 - \gamma) \cdot Nu\_m\_L\_2300 + \gamma \cdot Nu\_m\_T\_10000 = \qquad [29]$$

Inside diameter of the shell	D_i	*0.3097*	m
Diameter of the baffle	D_1	*0.3067*	m
Diameter of the tube bundle	D_B	*0.2783*	m
Height of the opening of the baffle	H	*0.08986*	m
Distance between the baffles	S	*0.1464*	m
Number of tubes including the existing dead and support tubes	n	151	-
Number of tubes in the top and bottom plate opening (window)	n_F	*64*	-
Outside diameter of the tubes	d_a	*0.016*	m
Diameter of the bore-holes for the tubes in the baffle	d_B	*0.0168*	m
Tube pitch crosswise to direction of flow	s_1	*0.021*	m
Tube pitch in direction of flow	s_2	*0.01819*	m
Number of sealing strip pairs	n_S	*0*	-
Main resistances in the cross-flow zone	n_W	*7*	-
Number of connection lines	n_V	*12*	-
Number of shell-side passes (1 or 2)	ND	*1*	-
Volume flow	V	*0.01434*	m^3/s
Inlet temperature	ϑ_E	*90*	°C
Outlet temperature	ϑ_A	*70*	°C
Wall temperature	ϑ_W	*69.77*	°C
Fluid: liquid <0> or vaporous <1>		<0 >	
Prandtl number	Pr	2.23	-
Prandtl number at wall temperature	Pr_W	2.575	-
Kinematic viscosity	ν	3.647E-7	m^2/s
Thermal conductivity	λ	*0.667*	W/(m·K)

Results:

f_W ≡ **0.5458** $Nu_{0,AW}$ ≡ **328.1** α ≡ **8571** $W/(m^2 \cdot K)$

Calculation of $Nu_{0,Bundle}$:

$\psi \equiv$ **0.4016** $\quad Re_{\psi,1} \equiv$ **54275**

$$Nu_{1,lam} = 0.664 \cdot \sqrt{Re_{\psi,1}} \cdot \sqrt[3]{Pr} \Leftrightarrow$$

$$\mathbf{202.1} = 0.664 \cdot \sqrt{\mathbf{54275}} \cdot \sqrt[3]{2.23}$$

$$Nu_{1,turb} = \frac{0.037 \cdot Re_{\psi,1}^{0.8} \cdot Pr}{1 + 2.443 \cdot Re_{\psi,1}^{-0.1} \cdot (Pr^{(2/3)} - 1)} \Leftrightarrow$$

$$\mathbf{320.2} = \frac{0.037 \cdot \mathbf{54275}^{0.8} \cdot 2.23}{1 + 2.443 \cdot \mathbf{54275}^{-0.1} \cdot (2.23^{(2/3)} - 1)}$$

$$Nu_{1,0} = 0.3 + \sqrt{Nu^2_{1,lam} + Nu^2_{1,turb}} \Leftrightarrow$$

$$\mathbf{378.9} = 0.3 + \sqrt{\mathbf{202.1}^2 + \mathbf{320.2}^2}$$

$$Nu_{0,Bundle} = f_A \cdot Nu_{1,0} \Leftrightarrow \mathbf{601.1} = \mathbf{1.587} \cdot \mathbf{378.9}$$

Calculation of f_G :

$$R_G = n_F / (n / ND) \Leftrightarrow \mathbf{0.4238} = 64 / (151 / 1)$$

$$f_G = 1 - R_G + 0.524 R_G^{0.32} \Leftrightarrow$$

$$\mathbf{0.9743} = 1 - \mathbf{0.4238} + 0.524 \cdot \mathbf{0.4238}^{0.32}$$

Calculation of f_L:

$e \equiv$ **0.005** $e_1 \equiv$ *0.02085* $L_E(e ; e_1) \equiv$ **0.1017**

$n = 151$ $n_F = 64$ $d_B = 0.0168$ $d_a = 0.016$

$$A_{SRU} = \left[\frac{n}{ND} - \frac{n_F}{2}\right] \frac{\pi (d_B^2 - d_a^2)}{4} \equiv \mathbf{0.002452}$$

$\gamma = 2 \arccos(1 - 2 \cdot H/D_1) \equiv$ **131.1** $= 2 \arccos(1 - 2 \cdot 0.08986 / 0.3067)$

$$A_{SMU} = \frac{\pi}{4} \cdot (D_i^2 - D_1^2) \cdot \frac{(360 - \gamma)}{360 \cdot ND} \Leftrightarrow$$

0.000924 $= \pi/4 \cdot (0.3097^2 - 0.3067^2) \cdot (360 -$ **131.1** $) / 360 / 1$

$A_{SG} = A_{SRU} + A_{SMU} \Leftrightarrow$ **0.003376** = **0.002452** + **0.000924**

$A_E = S \cdot L_E \Leftrightarrow$ **0.01489** = *0.1464* · **0.1017**

$R_L = A_{SG} / A_E \Leftrightarrow$ **0.2267** = **0.003376** / **0.01489**

$$f_L = 0.4 \frac{A_{SRU}}{A_{SG}} + \left[1 - 0.4 \frac{A_{SRU}}{A_{SG}}\right] \exp(-1.5\ R_L) \Leftrightarrow$$

$$\mathbf{0.7955} = 0.4 \frac{0.002452}{0.003376} + \left[1 - 0.4 \frac{0.002452}{0.003376}\right] \exp(-1.5 \cdot 0.2267)$$

Calculation of f_B:

$A_B = S\ (D_i - D_B - e) \equiv$ **0.003867** for $e < (D_i - D_B)$ $A_B = 0$ else

$R_B = A_B / A_E \Leftrightarrow$ **0.2597** = **0.003867** / **0.01489**

$$f_B = \exp\left[- ß \cdot R_B \left[1 - \sqrt[3]{2\ n_S / n_W}\right]\right] \quad \text{for } n_S \le n_W / 2$$

$$\mathbf{0.7043} = \exp\left[- ß \cdot 0.2597 \left[1 - \sqrt[3]{2 \cdot 0 / 7}\right]\right]$$

$f_B = 1$ for $n_S > n_W / 2$

$f_W = f_G \cdot f_L \cdot f_B \Leftrightarrow$ **0.5458** = **0.9743** · **0.7955** · **0.7043**

$Nu_{0,AW} = f_W \cdot Nu_{0,Bundle} \Leftrightarrow$ **328.1** = **0.5458** · **601.1**

$$\alpha = \frac{Nu_{0,AW} \cdot \lambda}{\pi/2 \cdot d_a} K \Leftrightarrow \mathbf{8571} = \frac{328.1 \cdot 0.667}{\pi/2 \cdot 0.016} \cdot 0.9843$$

Real logarithmic temperature difference for different heat exchanger types

Shell and tube heat exchanger

In the tubes:				**Around the tubes:**			
Mass flow	m_i	20	kg/s	Mass flow	m_a	13.94	kg/s
Spec.heat cap.	cp_i	4177	J/(kg·K)	Spec.heat cap.	cp_a	4195	J/(kg·K)
Inlet temp.	ϑe_i	27	°C	Inlet temp.	ϑe_a	90	°C
Outlet temp.	ϑa_i	**41.46**	°C	Outlet temp.	ϑa_a	**69.34**	°C

Overall heat transfer coefficient	k	1761	W/(m²·K)
Heat transfer area	A	15.18	m²
Number of tube-side passes	N_T	1	-
Number of shell-side passes	N_S	1	-
Number of exchangers (serial)	Z	1	-
Number of baffles per exchanger	N_B	11	-

Logarithmic temperature difference (counterflow)	dϑ =	**45.37**	K
Correction factor	FN =	**0.9963**	-
⇒ Real logarithmic temperature difference	$d\vartheta_m$ =	**45.2**	K

General formulation

Outside diameter of the tubes	da	16	mm
Wall thickness of the tubes	s	**2**	mm
Inside tube diameter	di =	12	mm
Cross-sectional area of the tubes	A =	**87.92**	mm²
Second moment of area of the tubes	J =	**2195**	mm^4
Modulus of elasticity	E	200000	N/mm²
Effective density	ρ	7850	kg/m³
Final span	L	268	mm

Support:	jointed on both sides	C = 3.14
	jointed - fixed	C = 3.93
	fixed on both sides	C = 4.73

Factor for support	C	3.93	-
Factor for additional forces	Cf	1	-
Natural frequency of the tubes	fR =	**863.2**	1/s
Safety factor	S	1.5	-
Allowable exciting frequency	fz =	**575.5**	1/s

Pitch (crosswise)	t	21	mm
Pitch (lengthwise)	l	18.19	mm
Transverse pitch ratio	t/da =	**1.313**	-
Longitudinal pitch ratio	l/da =	**1.137**	-
1: Strouhal number staggered (bare tubes)	SSt1 =	**0.2338**	-
2: Strouhal number staggered (fin-tubes)	SSt2 =		-
3: Strouhal number aligned	SSt3 =		-
Selected arrangement (1-3)		1	-
→ Strouhal number of the bundle	SSt	**0.2338**	-
Velocity in the narrowest cross section	we	1.053	m/s
Exciting frequency of the flow	ferr =	**15.38**	1/s
Allowable exciting frequency	fz =	**575.5**	1/s

Equations

$di = da - 2 * s \Leftrightarrow 12 = 16 - 2 * \mathbf{2}$

$A = \pi/4 * (da^2 - di^2) \Leftrightarrow \mathbf{87.92} = .785 * (16^2 - 12^2)$

$J = \pi/64 * (da^4 - di^4) \Leftrightarrow \mathbf{2195} = .049 * (16^4 - 12^4)$

$$fR = \frac{10^6}{2*\pi} * \left[\frac{C}{L}\right]^2 * \sqrt{\frac{E * J}{\rho * A}} * Cf \Leftrightarrow$$

$$\mathbf{863.2} = \frac{10^6}{6.283} * \left[\frac{3.93}{268}\right]^2 * \sqrt{\frac{200000 * \mathbf{2195}}{7850 * \mathbf{87.92}}} * 1$$

$fz = fR / S \Leftrightarrow \mathbf{575.5} = \mathbf{863.2} / 1.5$

$$ferr = \frac{SSt * we}{da/1000} \Leftrightarrow \mathbf{15.38} = \frac{\mathbf{0.2338} * 1.053}{16 / 1000}$$

Properties		Fluid		Wall	
Temperature (Inlet)	ϑ	*27*	°C		
Temperature (Outlet)	ϑ^{e}	*41*	°C		
Temperature	ϑ^{a}	**34**	°C	*49.04*	°C
Pressure (Inlet)	P	*500000*	Pa		
Density	ρ^{e}	*994.6*	kg/m³	993.6	kg/m³
Specific heat capacity	cp	*4177*	J/(kg·K)		
Thermal conductivity	λ	*0.6209*	W/(m·K)		
Dynamic viscosity	η	*0.7342*	mPa·s	*0.556*	mPa·s
Fluid: liquid = 0, gas = 1		*0*			

Acceleration due to gravity	g	9.81	m/s²
Type (straight tube=1; U-tube=2)		1	
Inside diameter of inlet nozzle	DTNI	*0.1317*	m
Inside diameter of outlet nozzle	DTNO	*0.1317*	m
Number of passes	NTP	*1*	-
Number of tubes per pass	N	*151*	-
Length of one tube	L	*2*	m
Inside tube diameter	DI	*0.012*	m
Outside tube diameter	DO	*0.016*	m
Tube wall thickness	t =	**0.002**	m

Mass flow	W	*20*	kg/s
Mean velocity (inlet nozzle)	Vn_i =	**1.476**	m/s
Mean velocity (outlet nozzle)	Vn_o =	**1.476**	m/s
Mean velocity (tube)	Vt =	**1.177**	m/s
Reynolds-Number	Re =	**19137**	-
Prandtl-Number	Pr =	**4.939**	-
Grashof-Number	Gr =	**31111**	-

Pressure loss factor	Ke =	**0.9**	-
Friction coefficient	$\xi$is =	**0.0077**	-
Correction factor (viscosity)	Φ =	**0.961**	-
Correction factor (convection)	ψ =	**1**	-
Friction factor ($\xi$is · Φ · ψ)	ξ =	**0.007399**	-
Pressure loss (inlet nozzle)	ΔPn_i =	**974.4**	Pa
Pressure loss (outlet nozzle)	ΔPn_o =	**974.4**	Pa
Pressure loss (inlet ; outlet and baffle)	ΔPe =	**620.3**	Pa
Pressure loss (friction)	ΔPt =	**3400**	Pa
Fouling factor	Ft =	**1.494**	-
Total pressure loss (ΔPn + ΔPe + Ft·ΔPt)	ΔP =	**7649**	Pa

Equations

$$t = 1/2 \cdot (DO - DI) \Leftrightarrow 0.002 = 1/2 \cdot (0.016 - 0.012)$$

$$Vn_i = \frac{1.273 \cdot W}{DTNI^2 \cdot \rho} \Leftrightarrow 1.476 = \frac{1.273 \cdot 20}{0.1317^2 \cdot 994.6}$$

$$Vn_o = \frac{1.273 \cdot W}{DTNO^2 \cdot \rho} \Leftrightarrow 1.476 = \frac{1.273 \cdot 20}{0.1317^2 \cdot 994.6}$$

$$Vt = \frac{1.273 \cdot W}{DI^2 \cdot N \cdot \rho} \Leftrightarrow 1.177 = \frac{1.273 \cdot 20}{0.012^2 \cdot 151 \cdot 994.6}$$

$$Re = \frac{Vt \cdot DI \cdot \rho}{\eta/1000} \Leftrightarrow 19137 = \frac{1.177 \cdot 0.012 \cdot 994.6}{0.000734}$$

$$Pr = \eta/1000 \cdot Cp / \lambda \Leftrightarrow 4.939 = 0.000734 \cdot 4177 / 0.6209$$

$$Gr = \frac{g \cdot DI^3}{(\eta/1000 / \rho)^2} \cdot \frac{|\rho - \rho W|}{\rho} \Leftrightarrow$$

$$31111 = \frac{9.81 \cdot 0.012^3}{(0.000734 / 994.6)^2} \cdot \frac{|994.6 - 993.6|}{994.6}$$

Straight tubes:	one pass	Ke = 0.9	NTP = 1
	multiple passes	Ke = 1.6 · NTP	
U-tubes:	two passes	Ke = 0.9	
	four or more passes	Ke = 0.8 · NTP	Ke = 0.9

$$\xi is = \xi is(Re) = 0.0077 = \xi is(19137)$$
$$\Phi = \Phi(Re ; \eta/\eta W) = 0.961 = \Phi(19137 ; 1.32)$$
$$\psi = \psi(Re ; Gr \cdot Pr \cdot \eta/\eta W) = 1 = \psi(19137 ; 202902)$$

$$\Delta Pn_E = \rho_E \cdot Vn_E^2 / 2.224 = 974.4 = 994.6 \cdot 1.476^2 / 2.224$$
$$\Delta Pn_A = \rho_A \cdot Vn_A^2 / 2.224 = 974.4 = 994.6 \cdot 1.476^2 / 2.224$$

$$\Delta Pe = Ke \cdot \rho \cdot Vt^2 / 2.0 = 620.3 = 0.9 \cdot 994.6 \cdot 1.177^2 / 2.0$$

$$\Delta Pt = 2 \cdot \xi \cdot \frac{\rho \cdot Vt^2 \cdot NTP \cdot L}{DI} \Leftrightarrow$$

$$3400 = 2 \cdot 0.007399 \cdot \frac{994.6 \cdot 1.177^2 \cdot 1 \cdot 2}{0.012}$$

$$Ft = \left[\frac{DO - 2 \cdot t}{DO - 2.2 \cdot t - 0.00182 \cdot DO^{0.3}}\right]^5 \Leftrightarrow$$

$$1.494 = \left[\frac{0.016 - 2 \cdot 0.002}{0.016 - 2.2 \cdot 0.002 - 0.00182 \cdot 0.016^{0.3}}\right]^5$$

Geometric variables:

Tube bundle diameter	D_B	*0.2783*	m
Inside shell diameter	D_i	*0.3097*	m
Baffle diameter	D_l	*0.3067*	m
Outside pipe diameter	d_a	*0.016*	m
Bore diameter	d_B	*0.0168*	m
Inside nozzle diameter (inlet)	d_Si	*0.1317*	m
Inside nozzle diameter (outlet)	d_So	*0.1317*	m
Opening baffle	H	*0.08986*	m
Number of tubes in the bundle	n	151	-
Number of tubes in the upper and lower windows	n_F	*64*	-
Number of rows in the window zone	n_RF	*4*	-
Number of sealing strips	n_S	*0*	-
Number of baffles	n_U	*11*	-
Number of connection lines	n_V	*12*	-
Main resistances in the cross-flow zone	n_W	*7*	-
Main resistances in the end zone	n_WE	*11*	-
Distance between baffles	S	*0.1464*	m
Head-baffle distance	S_E	*0.268*	m
Distance between boundary tubes and shell	e_1	*0.02085*	m
Volume flow	V	*0.01434*	m^3/s
Tube division lengthwise	s_1	*0.01819*	m
Tube division crosswise	s_q	*0.021*	m
Pitch angle		*60*	°
Number of shell-side passes	ND	*1*	-

Properties of the media:

Fluid: liquid = 0 or gas = 1		*0*	
Inlet pressure	P_E	*500000*	Pa
Inlet temperature	ϑ_E	*90*	°C
Outlet temperature	ϑ_A	*70*	°C
Mean temperature	ϑ	**80**	°C
Density	ρ	*971.8*	kg/m^3
Dynamic viscosity	η	*0.3545*	mPa·s
Wall temperature	ϑ_W	*69.77*	°C
Dynamic viscosity (at ϑ_W)	η_W	*0.4054*	mPa·s

Friction loss on the shellside of the heat exchanger:

$$
\begin{aligned}
\Delta p = \;& (n\_U - 1) \cdot \Delta p\_Q \cdot ND &&= (11 - 1) \cdot 230 \cdot 1 \\
&+ 2 \cdot \Delta p\_Q\_E &&= 2 \cdot 251 \\
&+ n\_U \cdot \Delta p\_F \cdot ND &&= 11 \cdot 1391 \cdot 1 \\
&+ \Delta p\_S &&= 1077
\end{aligned}
$$

Δp = **19181** Pa

Results:

a =	**1.313**	-	b =	**1.137**	-	c =	**1.312**	-
e =	**0.005**	m						

Cross-flow zone:

L_E =	**0.1017**	m	A_E =	**0.01489**	m²	w_e =	**0.9633**	m/s
f_a_l_f =	**194.9**	-	f_a_t_f =	**0.6867**	-	Xi_l =	**0.004612**	-
Re =	**42257**	-	f_a_t_v =	**5.259**	-	Xi_t =	**0.3668**	-
f_z_t =	**1.019**	-	Xi =	**0.3784**	-	Δp_Q_0 =	**1194**	Pa
A_SRU =	**0.002452**	m²	γ =	**131.1**	°	A_SMU =	**0.000924**	m²
A_SG =	**0.003376**	m²	R_M =	**0.2736**	-	R_L =	**0.2267**	-
r =	**0.609**	-	f_L =	**0.5035**	-	R_S =	**0**	-
ß =	3.7	-	A_B =	**0.003867**	-	R_B =	**0.2597**	-
f_B =	**0.3825**	-	F_z_l =	**1.005**	-	f_a_l_v =	**194.9**	-
Δp_Q =	**230**	Pa						

End zone:

Re_E =	**23084**	-	A_E_E =	**0.02726**	-	w_e_E =	**0.5262**	m/s
Δp_QE_0 =	**656**	Pa	Δp_QE =	**251**	Pa			

Window zone:

A_FG =	**0.01836**	-	A_FR =	**0.006434**	-	A_F =	**0.01192**	-
w_p =	**1.203**	m/s	w_z =	**1.076**	m/s	n_WF =	**3.953**	-
d_g =	**0.0243**	-	U_F =	**1.963**	-			
Δp_F_l =	**1137**	Pa	Δp_F_t =	**2461**	Pa			
Δp_F =	**1391**	Pa						

Shell nozzles:

w_S_i =	**1.053**	m/s	Δp_S_i =	**538.6**	Pa
w_S_o =	**1.053**	m/s	Δp_S_o =	**538.6**	Pa
Δp_S =	**1077**	Pa			

TEMA type ael

	In the tubes			Around the tubes		
Medium	Water			Water		
Pressure (in)	p	*500000*	Pa	p	*500000*	Pa
Pressure stage		1600000	Pa		1600000	Pa
Inlet temperature	$\vartheta_{e,i}$	*27*	°C	$\vartheta_{e,a}$	*90*	°C
Outlet temperature	$\vartheta_{a,i}$	*41*	°C	$\vartheta_{a,a}$	*70*	°C
Mean temperature	$\vartheta_{m,i}$	**34**	°C	$\vartheta_{m,a}$	**80**	°C
Design temperature			°C			°C
Inlet nozzle:						
Flange connection n.w.*		125	mm		125	mm
Outside diameter		**0.1397**	m		**0.1397**	m
Nozzle wall thickness		0.004	m		0.004	m
Inside diameter		*0.1317*	m		*0.1317*	m
Outlet nozzle:						
Flange connection n.w.*		125	mm		125	mm
Outside diameter		**0.1397**	m		**0.1397**	m
Nozzle wall thickness		0.004	m		0.004	m
Inside diameter		*0.1317*	m		*0.1317*	m

* n.w. = nominal weidth

Geometry:

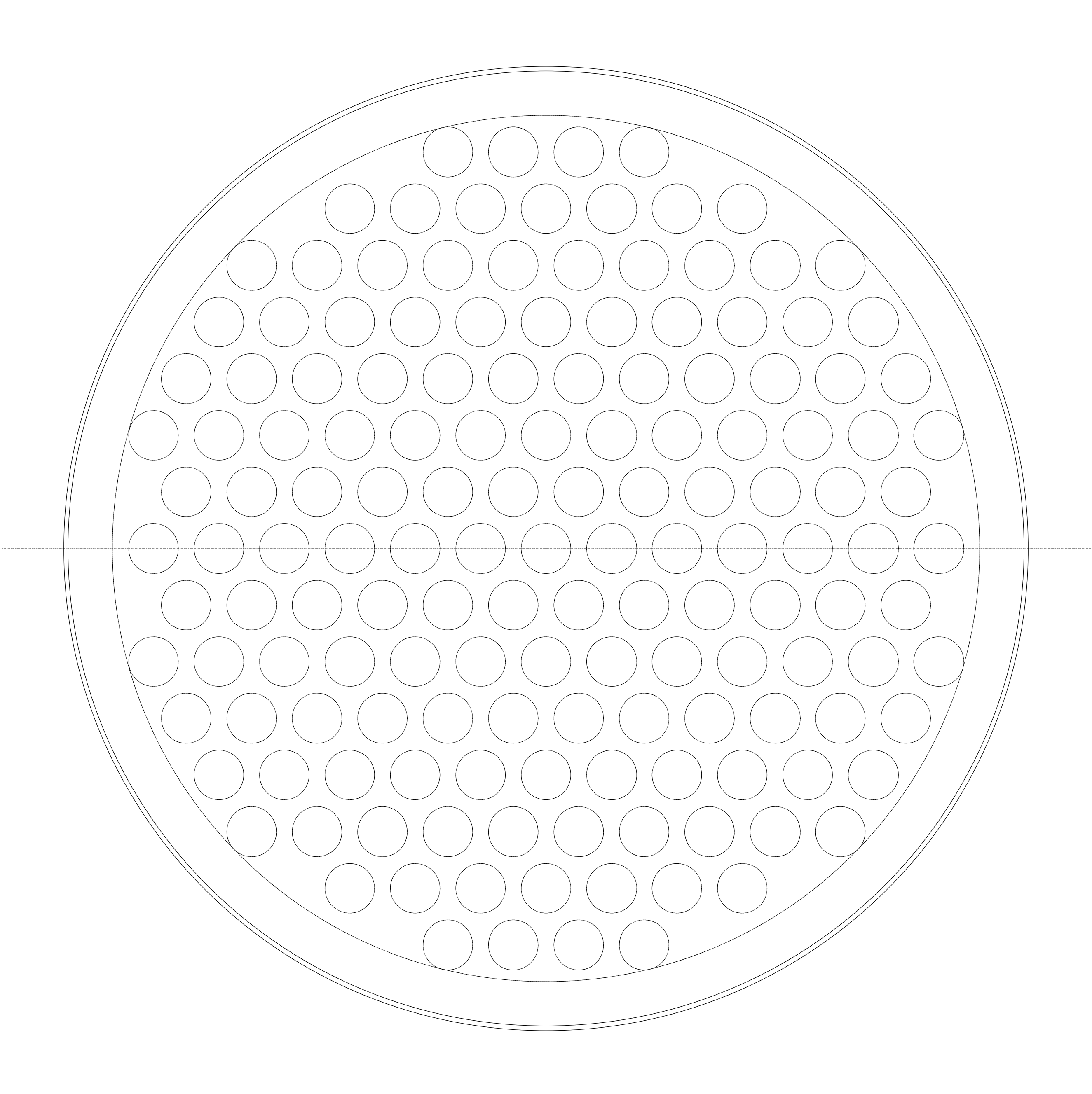
Outside shell diameter	Do	*0.3239*	m	Shell wall thickness	sa	*0.0071*	m
Inside shell diameter	Di	**0.3097**	m				
Bundle - shell distance		*0.01571*	m				
Outside tube diameter	do	*0.016*	m	Inside tube diameter	di	*0.012*	m
Tube pitch (crosswise)	sq	*0.021*	m	Tube pitch(lengthwise)	sl	*0.01819*	m
Pitch angle	Φ	**60**	°	Path width	b	*0.034*	m
Distance between baffles		*0.1464*	m	Number of baffles/pass		*11*	-
Dist.tubesheet-1st baffle		*0.268*	m	Baffle diameter		*0.3067*	m
Baffle borehole		*0.0168*	m	Baffle cut		*29.3*	%
Sealing strips pairs		*0*	-				

Number of passes (tube-side)	Z	*1*	-
Number of passes (shell-side)	Z	*1*	-
Final bundle length	l	*2*	m
Final shell length	l_a^a	**2**	m
Number of tubes	R	*151*	
Expansion joint diameter			m
Plate thickness (fixed plate)		0.03	m
Plate thickness (free plate)		0.03	m

Scale1:2

24.04.03
11:33:33

Example



Total number of tubes	151
Shell inside-diameter Di [mm]	309,7
Tube outside-diameter da [mm]	16
Transverse pitch sq [mm]	21
Longitudinal pitch sl [mm]	18,2
Number of tube-side passes	1
Number of shell-side passes	1
Baffle diameter Dl [mm]	306,7
Baffle window height [%]	29,3