



SIMULATION OF THE SEAWATER HEAT EXCHANGER WITH HELICAL BAFFLES

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Background

Simulation Methods

- Property Calculation Method
- Algorithm Design
- Flow and Heat Transfer Model
- User Interface
- Conclusions



Background

The seawater heat exchangers with helical baffles have been widely applied in natural gas liquefaction plants.

Characteristics:

- Helical baffles
- Spiral flow in shell side
- Mixed refrigerant in shell side
- Seawater in tube side



Advantages:

- Good performance in shell side
- Small pressure drop in shell side
- Less possibility for scaling
- Smaller bundle vibration





Background

Designed with reference to traditional methods.

External Structure



Inner Structure

- Heterogeneous condensation
- complex flowing & heat exchanging properties
- lack of mature design experience

Problems





Specific factors ignored in traditional methods

- Heat transfer and mass transfer in the shell-side
- Properties of refrigerants change along the shell.
- Seawater properties are different from pure water.
- The structure of helical baffles

Accurate design calculation method for the seawater heat exchangers with helical baffles is necessary .











Developmets of seawater property calculation: PSS-78 → EOS-80 → IAPWS-95 → IAPWS-2008 Accuracy: low → high Range: small → large

IAPWS-2008 is used in the simulation.Salinity: 0%-9%Temprature: 0℃-100℃



IAPW-2008 Model

TemperatuDensi	ty Cp]	Cherm. CV	iscosity
K kg/m3	J/l	g.K V	l/m.K P	a.s
274	999.84	4217.09	0.56263	0.00174
275	999.89	4213.95	0.56453	0.001682
276	999.91	4211.04	0.56643	0.0016271
277	999.92	4208.33	0.56834	0.001575
278	999.92	4205.83	0.57024	0.0015255
279	999.9	4203.51	0.57214	0.0014785
280	999.86	4201.35	0.57404	0.0014337
281	999.81	4199.35	0.57593	0.001391
282	999.75	4197.5	0.57783	0.0013504
283	999.67	4195.79	0.57972	0.0013116
284	999.58	4194.2	0.5816	0.0012746
285	999.47	4192.73	0.58348	0.0012393
286	999.35	4191.37	0.58534	0.0012055
287	999.22	4190.12	0.58721	0.0011731
288	999.08	4188.97	0.58906	0.0011421
289	998.92	4187.9	0.5909	0.0011125
290	998.76	4186.93	0.59273	0.001084
291	998.58	4186.03	0.59455	0.0010567
292	998.39	4185.21	0.59636	0.0010305
293	998.19	4184.47	0.59815	0.0010053
294	997.98	4183.79	0.59993	0.00098114
295	997.76	4183.17	0.60169	0.00095787
296	997.53	4182.61	0.60344	0.00093548

Look-up-table



Fast Property Calculation for Mixed Refrigerant

Methods:

- Traditional mix proportion
- Fitting calculation of the traditional mixture properties based on GERG-2008
- Extensions for other proportion



Test:

Precision: Max Error<2%</p>

Average Error<0.5%

Speed: 10⁴ times faster than GERG







Control units

Control units are divided according to the number of baffles(k).

Subcooling and superheated sections should be calculated separately.



Energy balance equations:

$$Q = \sum m_i \times (h_i - h_{i+1}) = UA\Delta T$$



Algorithm Design





Algorithm Design









Heat transfer equations

Heat transfer equations

$$Q_{\rm R,w} = K_{\rm R,w} F_{\rm R,w} (\Delta T_{\rm m})_{\rm R,w}$$

$$F_{\rm R,w} = n_{\rm tube} L_{\rm tube} f_{\rm o}$$

$$f_{o} = \pi d_{o}$$

$$(\Delta T_{\rm m})_{\rm R,w} = \frac{\Delta T_{\rm max} - \Delta T_{\rm min}}{\ln \frac{\Delta T_{\rm max}}{\Delta T_{\rm min}}} = \frac{(T_{\rm r,out} - T_{\rm w,in}) - (T_{\rm r,in} - T_{\rm w,out})}{\ln \frac{(T_{\rm r,out} - T_{\rm w,in})}{(T_{\rm r,in} - T_{\rm w,out})}}$$

$$K_{\rm R,w} = \frac{1}{\left(\frac{1}{\alpha_{\rm i}} + r_{\rm i}\right) \frac{f_{\rm o}}{f_{\rm i}}} + \frac{\delta_{\rm tube}}{\lambda_{\rm tube}} \frac{2f_{\rm o}}{(f_{\rm o} + f_{\rm i})} + \frac{1}{\alpha_{\rm o}}}$$



Tube-side heat transfer coefficient :

$$\alpha_{i} = \left[1395 + 23.26\left(\overline{T}_{w} - 273.15\right)\right] \frac{w^{0.8}}{d_{i}^{0.2}}$$

Shelll-side heat transfer coefficient :

Single phase
$$\alpha_o = 0.023 \times \frac{\lambda_M}{d} \times \text{Re}^{0.8} \times \text{Pr}^{0.3} \times Y_1 \times Y_2$$

Two-phase
$$\alpha_{o} = 10^{-0.25} \times 0.655 \times \left[\frac{\rho_{R, \text{sat}, l} \left(\rho_{R, \text{sat}, l} - \rho_{R, \text{sat}, g} \right) g \lambda_{R, \text{sat}, l}^{3} h_{\text{lg}}}{\mu_{R, \text{sat}, l} q d_{0}} \right]^{/3} \times Y_{1} \times Y_{2}^{'}$$

<u>_1/</u>



Pressure Drop Calculation

Tube-side pressure drop:

$$\Delta P_{i} = (\Delta P_{L} + \Delta P_{r})F_{t}N_{p} + \Delta P_{n}$$

$$\Delta P_{L} = \lambda \frac{l}{d} \left(\frac{\rho u^{2}}{2}\right) \qquad \Delta P_{r} = 3 \left(\frac{\rho u^{2}}{2}\right) \qquad \Delta P_{n} = 1.5 \left(\frac{\rho u^{2}}{2}\right) \qquad \left\{ \begin{array}{c} \lambda = \frac{64}{\text{Re}} & \text{Re} < 2000 \\ \lambda = \frac{0.3164}{\text{Re}^{0.25}} & \text{Re} > 2000 \end{array} \right\}$$

Shell-side pressure drop:

$$\Delta P = \Delta P_{ideal} \cdot Z_1 \cdot Z_2 \cdot Z_3 \cdot Z_4$$
$$\Delta P_{ideal} = 2f_{shell}\rho u^2 \frac{D_s}{D_e}$$

Two-phase multiplier for two-phase fluid:

$$\Delta P_{tp} = \Delta P \times \varphi_{L}^{2}$$
$$\varphi_{L}^{2} = 1 + \frac{C}{X_{tt}} + \frac{1}{X_{tt}^{2}}$$

 $C = 0.11 \ln(X_{tt} \cdot G) + 3.2$







Software framework





Main interface

> Input

Calculation Mode Refrigerant Thermal parameters Structural parameters Main components Additional conditions

> Output

Input Overview Warning messages Results (table) Results (chart)

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设计计算		πραι/ουιραι	2013/8/15	



Refrigerant Properties





Structural parameters





Results (table)

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保存结果 Ctrl+R			5	Inlet Refrigera	nt Temprature	С	
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守山泊未	- 开心会 ····		8	Inlet Refrigera	nt Pressure	Pa	
打印结果	制役剂		9	Outlet Refriger	rant Pressure	Pa	
NB-11	制冷剂入口温度	C	10	Inlet Water Te Outlet Water T	mperature Cemperature	C	
退田		-	12	Mass Flow Ra	te of Water	kg/s	
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	制冷刻后量流量	ka/s	14	Outlet Refriger	rant Enthalpy	J/kg Wotto	4(
口, 1 执力会物	市がそうがは主がに主	K9/3	15	Heating Capac	лу	watts	0
	制冷剂入口压力	Pa	17		Part	II : Design Input	
15% 热力参数	制态到出口压力	Do	18	Number of Pas	sses of Water Side		
□ 🕄 结构参数	制々刑山山江ノ	Fa	19	Arrangement of Wall Thickness	of Flow Pass	mm	_
	水的入口温度	C	21	Type of Tube	Arrangement		Tria
B	北的山口泪奔	<u>^</u>	22	Type of Tube			Sn
- 25. 売	水的田口温度	L	23	Inner Diameter	r of Tube	mm	
- 100 管束布局	水的质量流量	kg/s	25	Tube Material			
	制冷剂入口焓	J/kg	26	Water Side Ca Ref. Side Calib	libration Factor oration Factor		
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	管排布			īΕΞ	Part II : Che Refrigerant	ck Input R22	
	管型			翅	Inlet Referant Temperature Inlet Referant Pressure Mass Flow Rate of Referant	C 124.906 bar 23.749 kg/s 0.209	
	管内径	mm		:	Inlet Water Temperature Mass Flow Rate of Water	C 55 kg/s 10	
4果(表格)	管外径	mm		1	Inlet Rofrigerant Temprature Inlet Rofrigerant Pressure Inlet Rofrigerant Sat. Temp.	C 55.229 Pa 2374900 C 58.991	
4. 结果 (图表)	翅片高	mm			Outlet Refrigerant Temprature Outlet Refrigerant Pressure Outlet Refrigerant Sat. Temp.	C 124.906 Pa 2374900 C 38.991	
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· [八江江智	r	20	10/10/4	4	Water Pressure Drop Heating Capacity(Total)	Pa 23844.264 Watts 44263.938	
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- 1) A segmentation parameters model is developed, which could reflect heat transfer and mass transfer in the shell side
- 2) The IAPWS-2008 method is used for the seawater properties and a fast property calculation is built for the shell side.
- 3) Considering the influence of the helical baffle structure, the modified two-phase heat transfer and pressure drop correlations are developed.
- 4) A design software framework is set up and a friendly graphic user interface is developed.
- 5) The method can be used to study the influence of heat exchanger structures and to guide for the seawater heat exchanger design.





Thank you!

