SIMULATION OF THE SEAWATER HEAT EXCHANGER WITH HELICAL BAFFLES

Qingnan Huang

Shanghai Jiao Tong University, China

Outlines

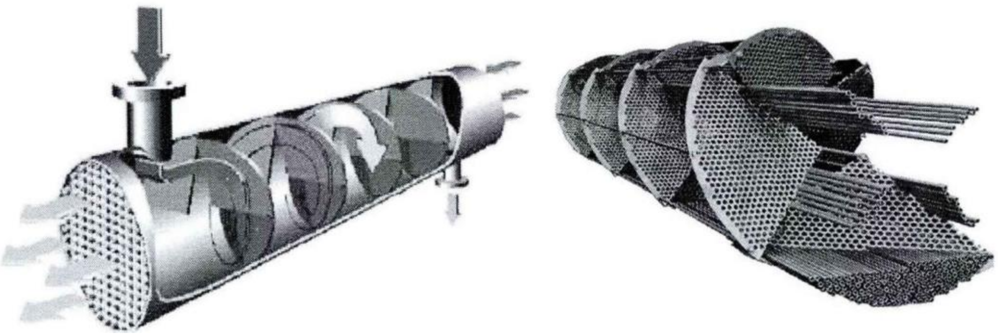
- **Background**
- **Simulation Methods**
  - Property Calculation Method
  - Algorithm Design
  - Flow and Heat Transfer Model
  - User Interface
- **Conclusions**

Background

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

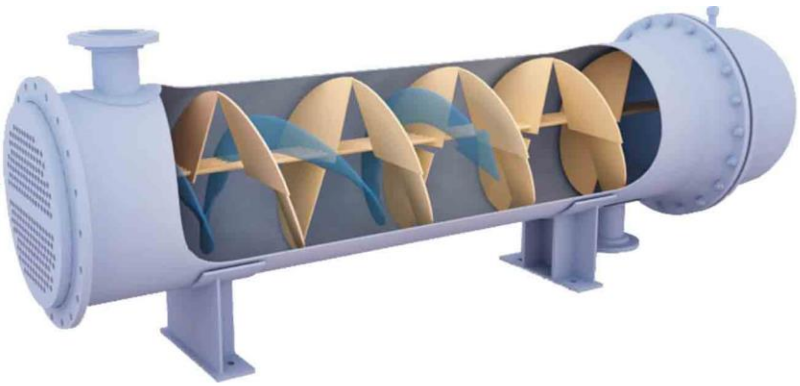
Characteristics:

- 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



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Background

Designed with reference to traditional methods.

External Structure

Inner Structure

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

Problems

design failure

Background

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 .

Approach

Property Calculation Method

Algorithm Design

Simulation

Flow and Heat Transfer Model

User Interface

Approach

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Seawater Properties Calculation

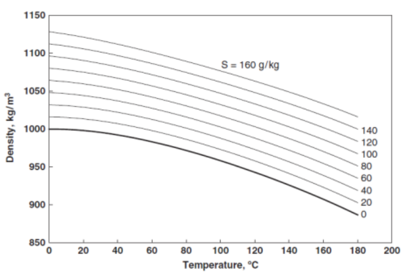
Developmets of seawater property calculation:

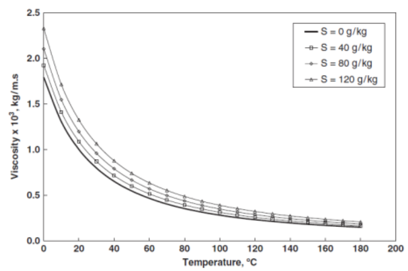
PSS-78 → EOS-80 → IAPWS-95 → IAPWS-2008

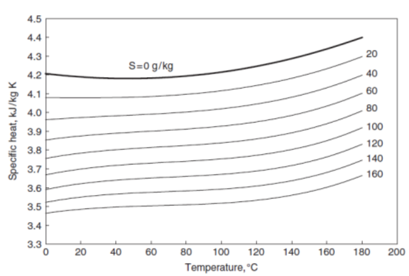
Accuracy：low → high　　Range：small → large

IAPWS-2008 is used in the simulation.

Salinity: 0%-9%　　Temprature: 0℃-100℃







Density

Dynamic viscosity

specific heat

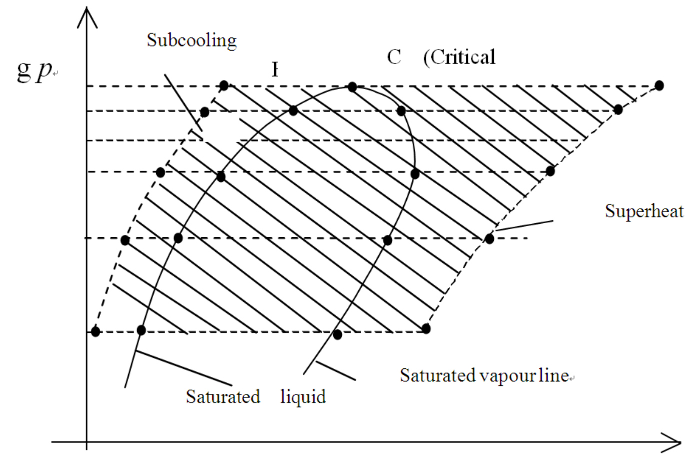
TemperatuK	Density kg/m3	Cp J/kg.K	Therm. C W/m.K	Viscosity Pa.s
274	999.84	4217.09	0.56263	0.00174
275	999.89	4213.95	0.56453	0.001682
276	999.91	4211.04	0.56643	0.0016271
277	999.92	4208.33	0.56834	0.001575
278	999.92	4205.83	0.57024	0.0015255
279	999.9	4203.51	0.57214	0.0014785
280	999.86	4201.35	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

IAPW-2008 Model　　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%

  Average Error<0.5%
- Speed: 10^4 times faster than GERG

Approach

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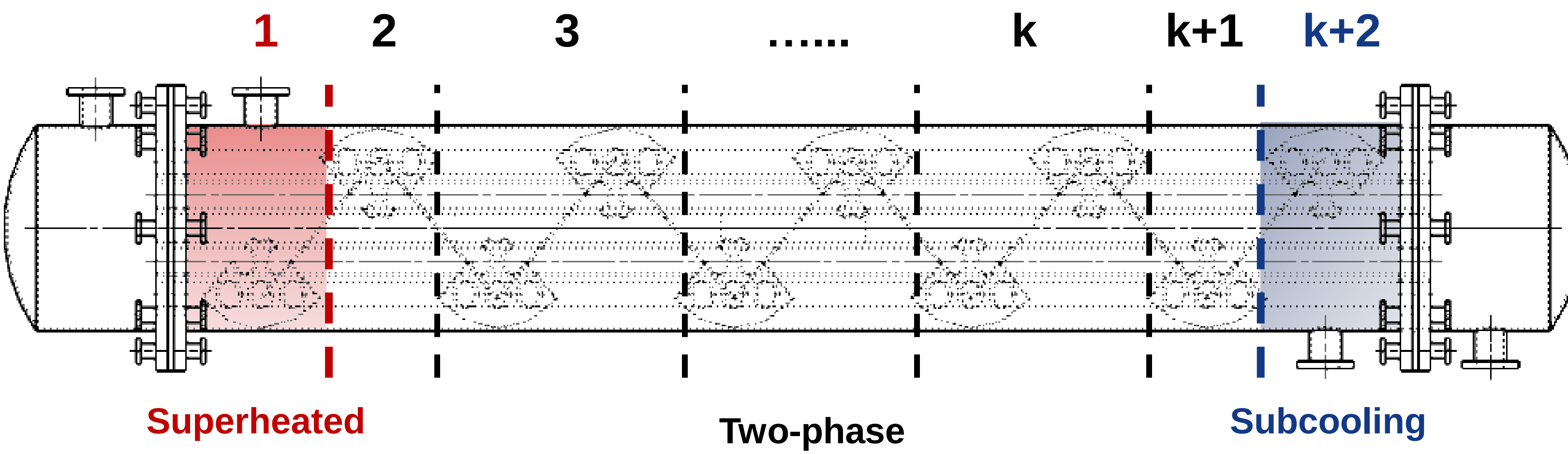
Algorithm Design

Control units

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

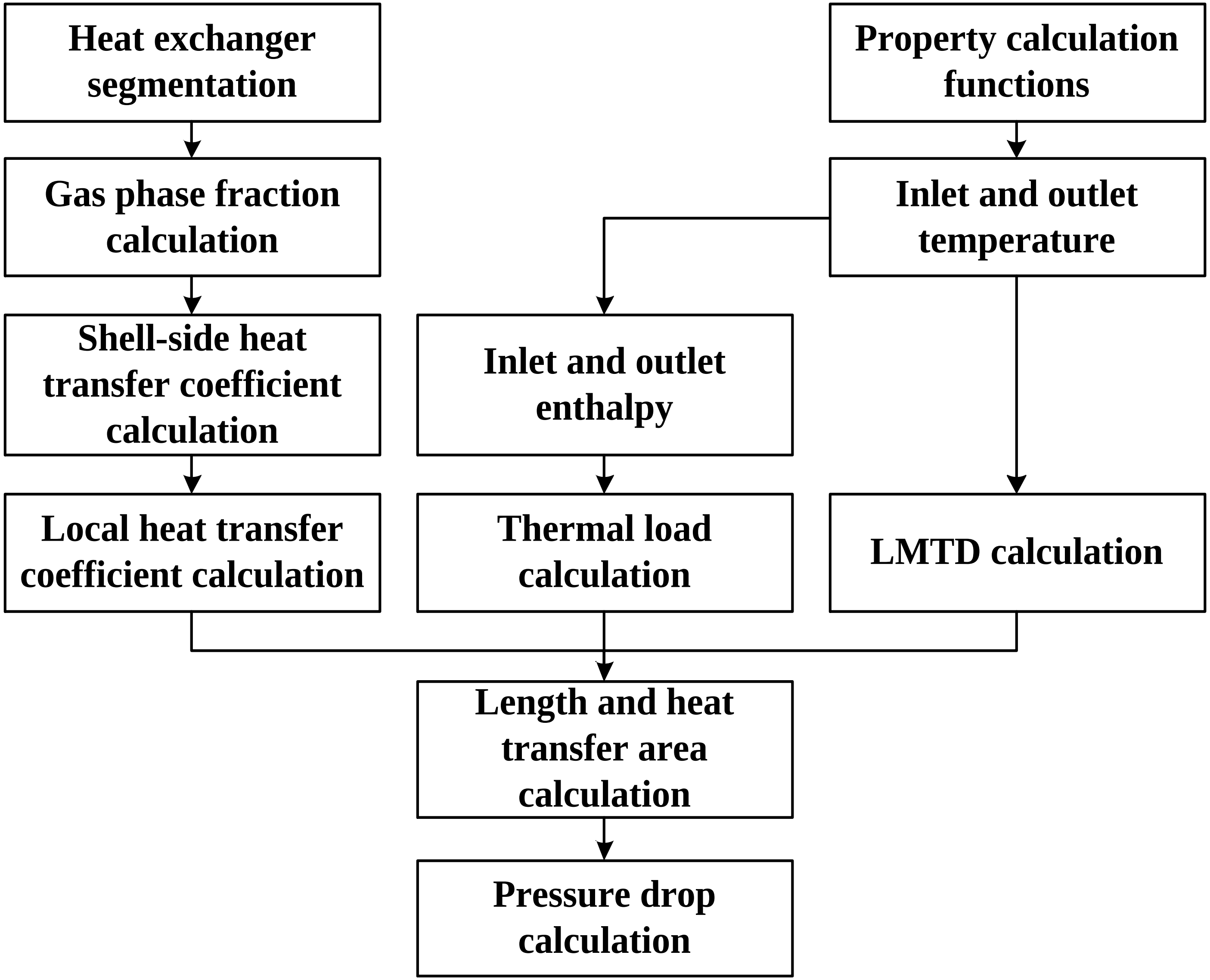
Subcooling and superheated sections should be calculated separately.



Energy balance equations:

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

Algorithm Design



Calculation flow chart for each section

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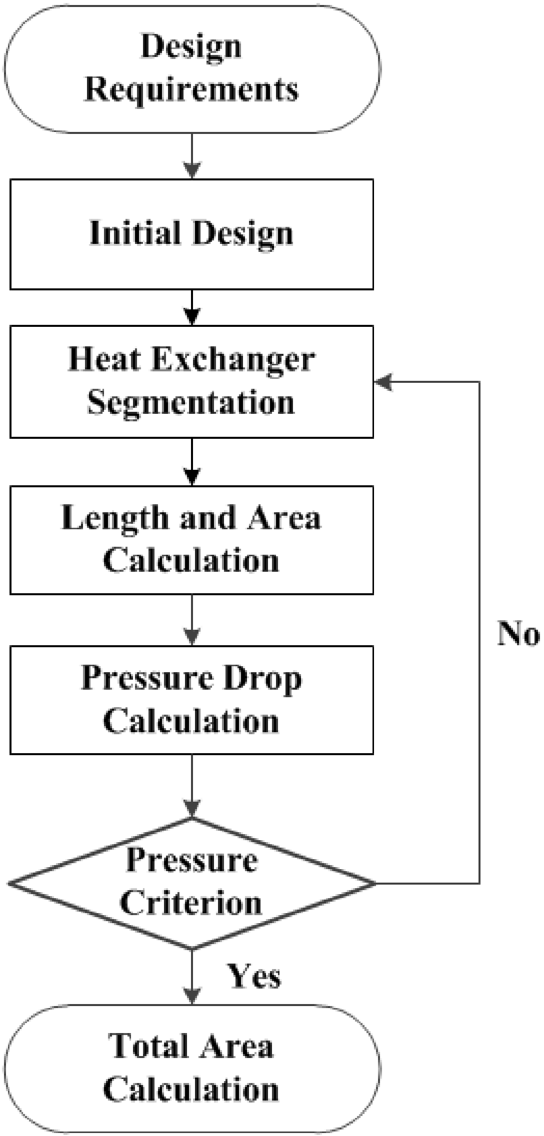
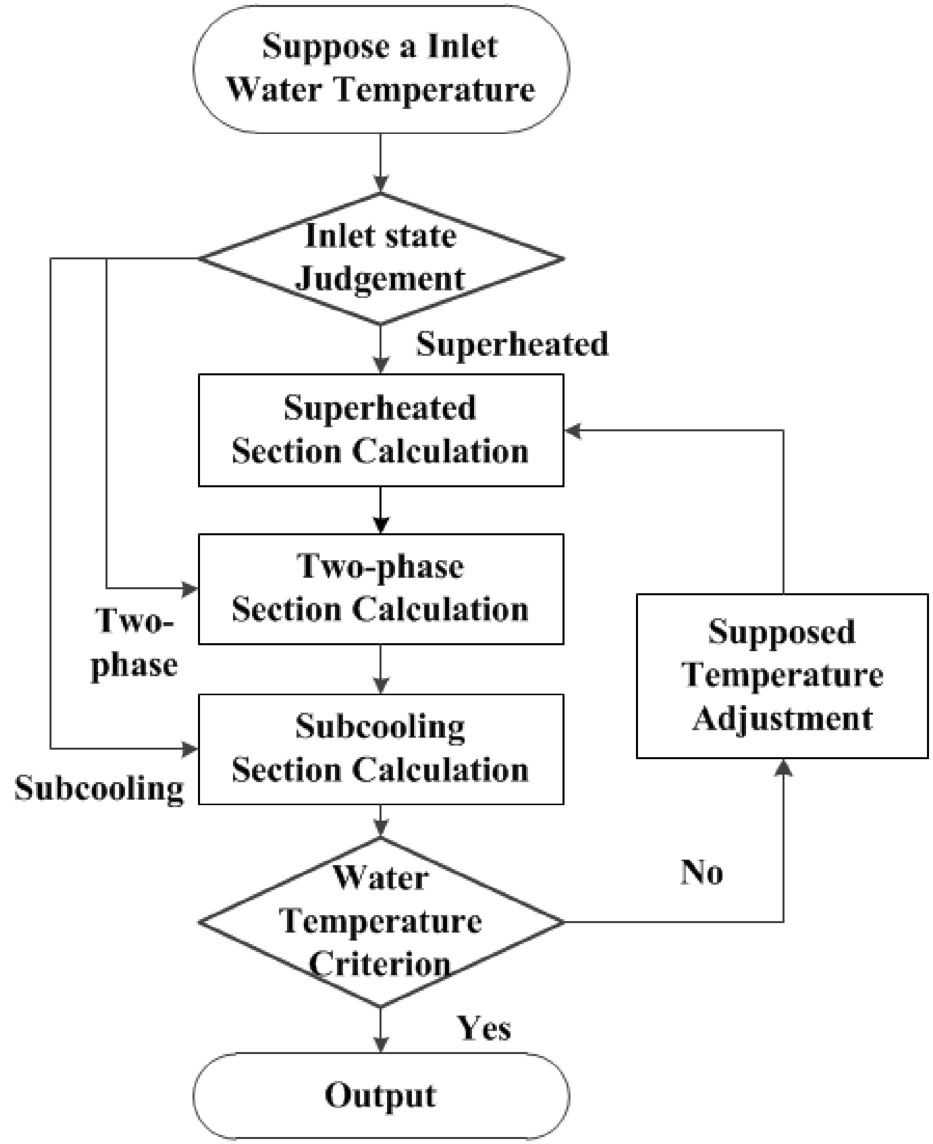
Algorithm Design



Design Module



Check Module

Approach

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Heat transfer equations

- Heat transfer equations

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

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

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

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

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

Heat Transfer Calculation

- Tube-side heat transfer coefficient：

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

- Shelll-side heat transfer coefficient：

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

Two-phase $\alpha_o = 10^{-0.25} \times 0.655 \times \left[\frac{\rho_{R,\mathrm{sat},l}\left(\rho_{R,\mathrm{sat},l} - \rho_{R,\mathrm{sat},g}\right) g \lambda_{R,\mathrm{sat},l}^{3} h_{\mathrm{lg}}}{\mu_{R,\mathrm{sat},l} q d_0}\right]^{1/3} \times Y_1^{'} \times Y_2^{'}$

Pressure Drop Calculation

- Tube-side pressure drop:

$$\Delta P_i = (\Delta P_L + \Delta P_r) F_t N_p + \Delta P_n$$

$$\Delta P_L = \lambda \frac{l}{d}\left(\frac{\rho u^2}{2}\right) \qquad \Delta P_r = 3\left(\frac{\rho u^2}{2}\right) \qquad \Delta P_n = 1.5\left(\frac{\rho u^2}{2}\right)$$

$$\begin{cases} \lambda = \dfrac{64}{\mathrm{Re}} & Re<2000 \\ \lambda = \dfrac{0.3164}{\mathrm{Re}^{0.25}} & Re>2000 \end{cases}$$

- Shell-side pressure drop:

$$\Delta P = \Delta P_{ideal} \cdot Z_1 \cdot Z_2 \cdot Z_3 \cdot Z_4$$

$$\Delta P_{ideal} = 2 f_{shell} \rho u^2 \frac{D_s}{D_e}$$

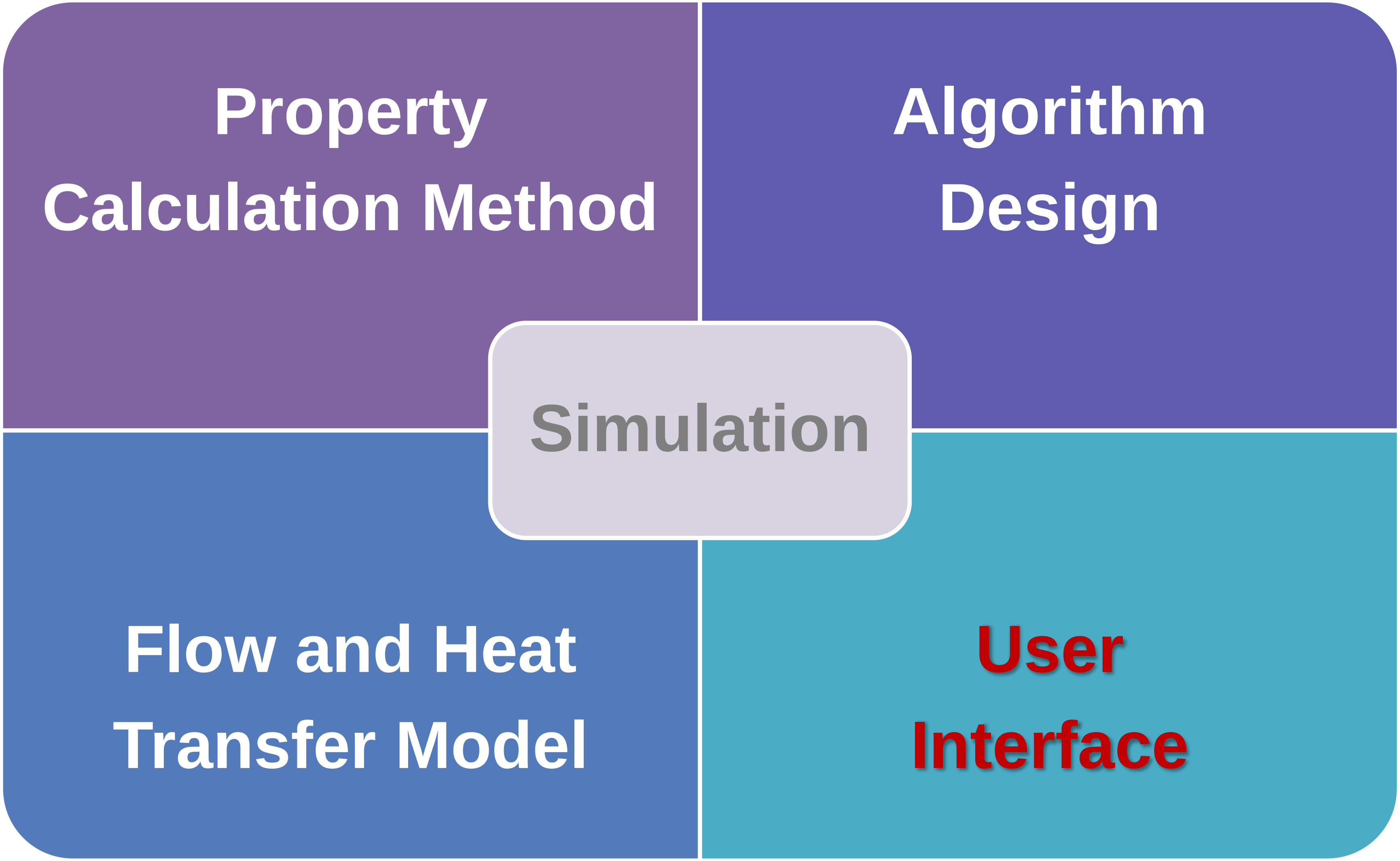
- Two-phase multiplier for two-phase fluid:

$$\Delta P_{tp} = \Delta P \times \varphi_{\mathrm{L}}{}^2$$

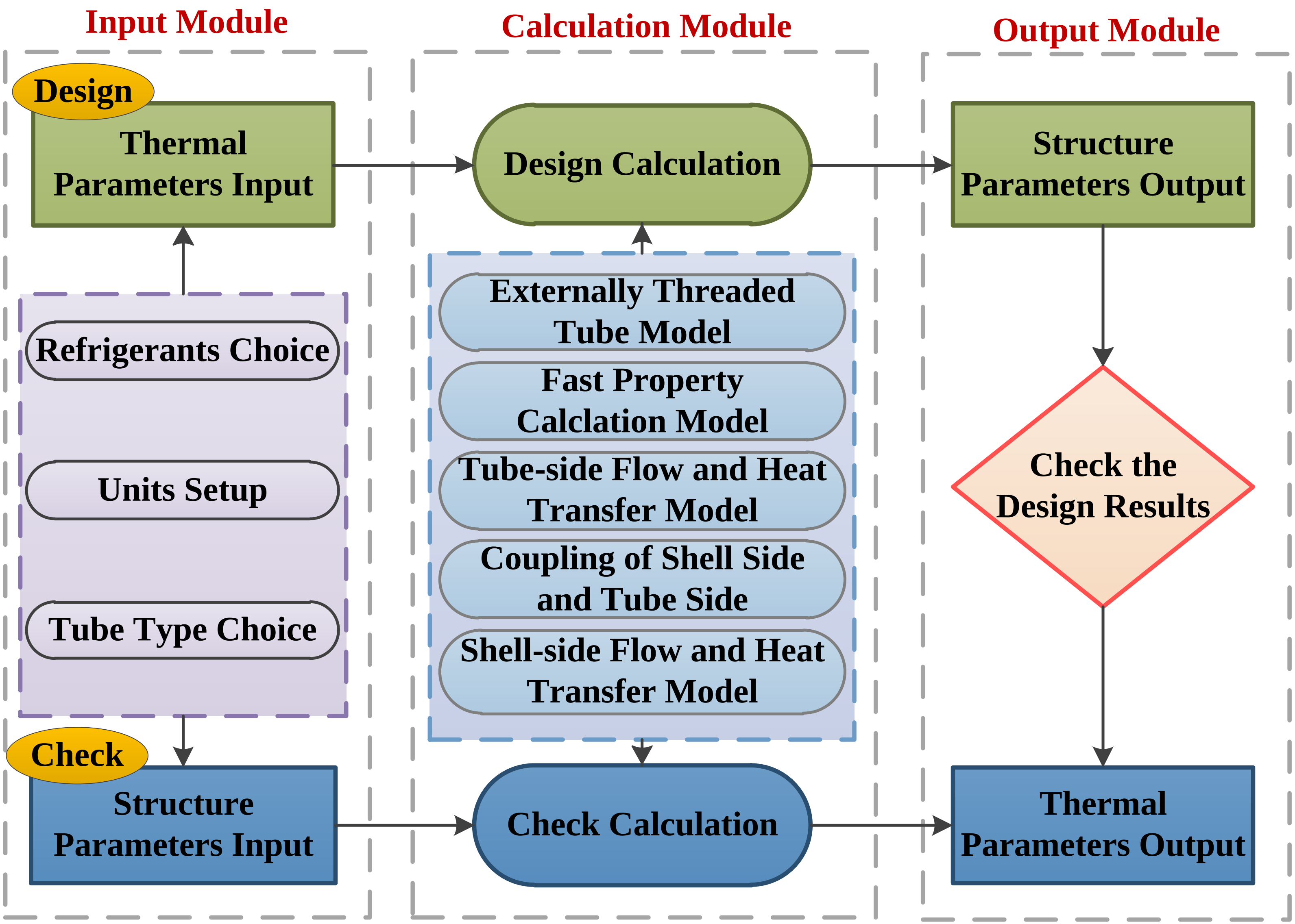
$$\varphi_{\mathrm{L}}{}^2 = 1 + \frac{C}{X_{tt}} + \frac{1}{X_{tt}{}^2}$$

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

Approach


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

Software framework



User Interface

Main interface

- Input

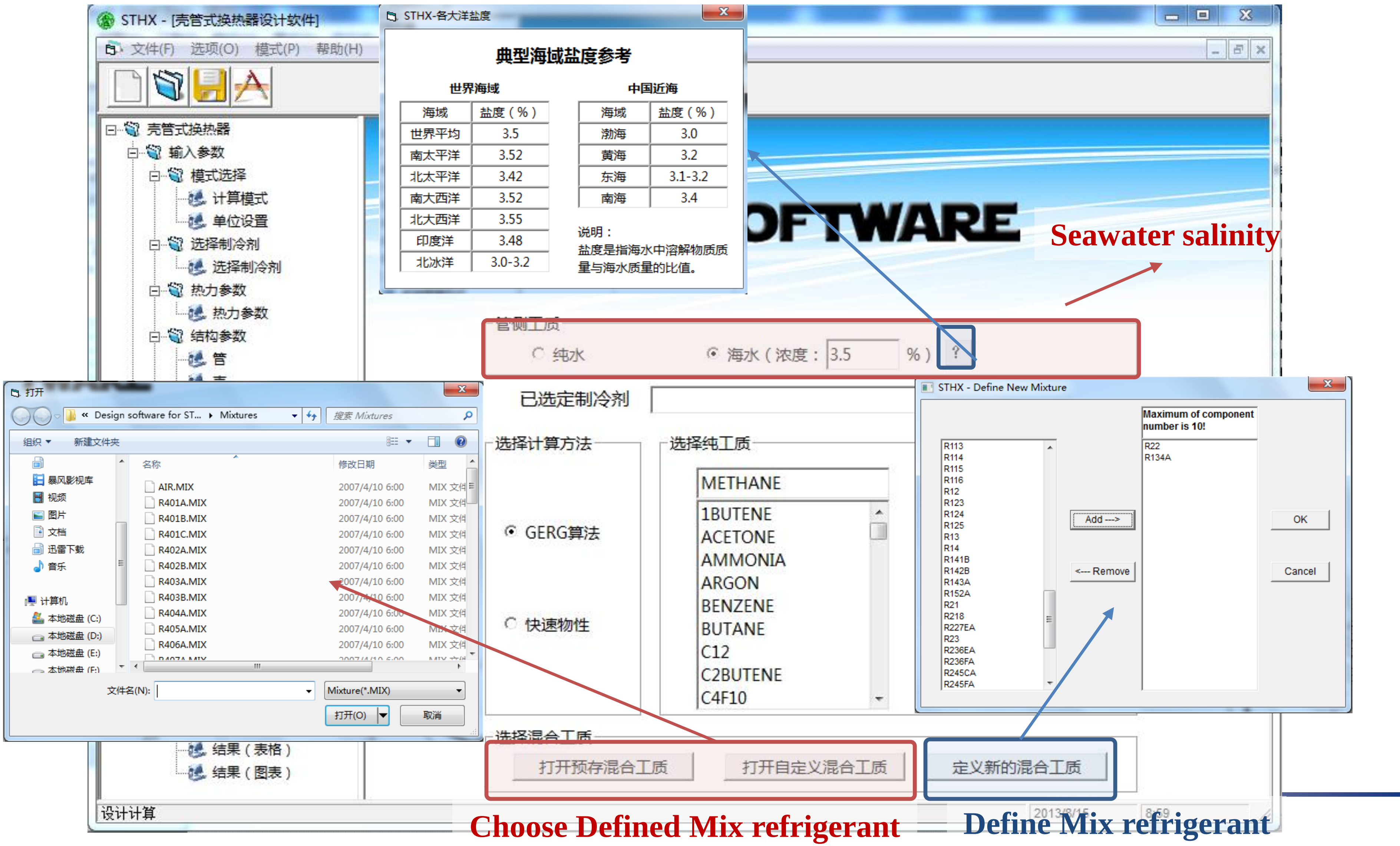
Calculation Mode
Refrigerant
Thermal parameters
Structural parameters
Main components
Additional conditions

- Output

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

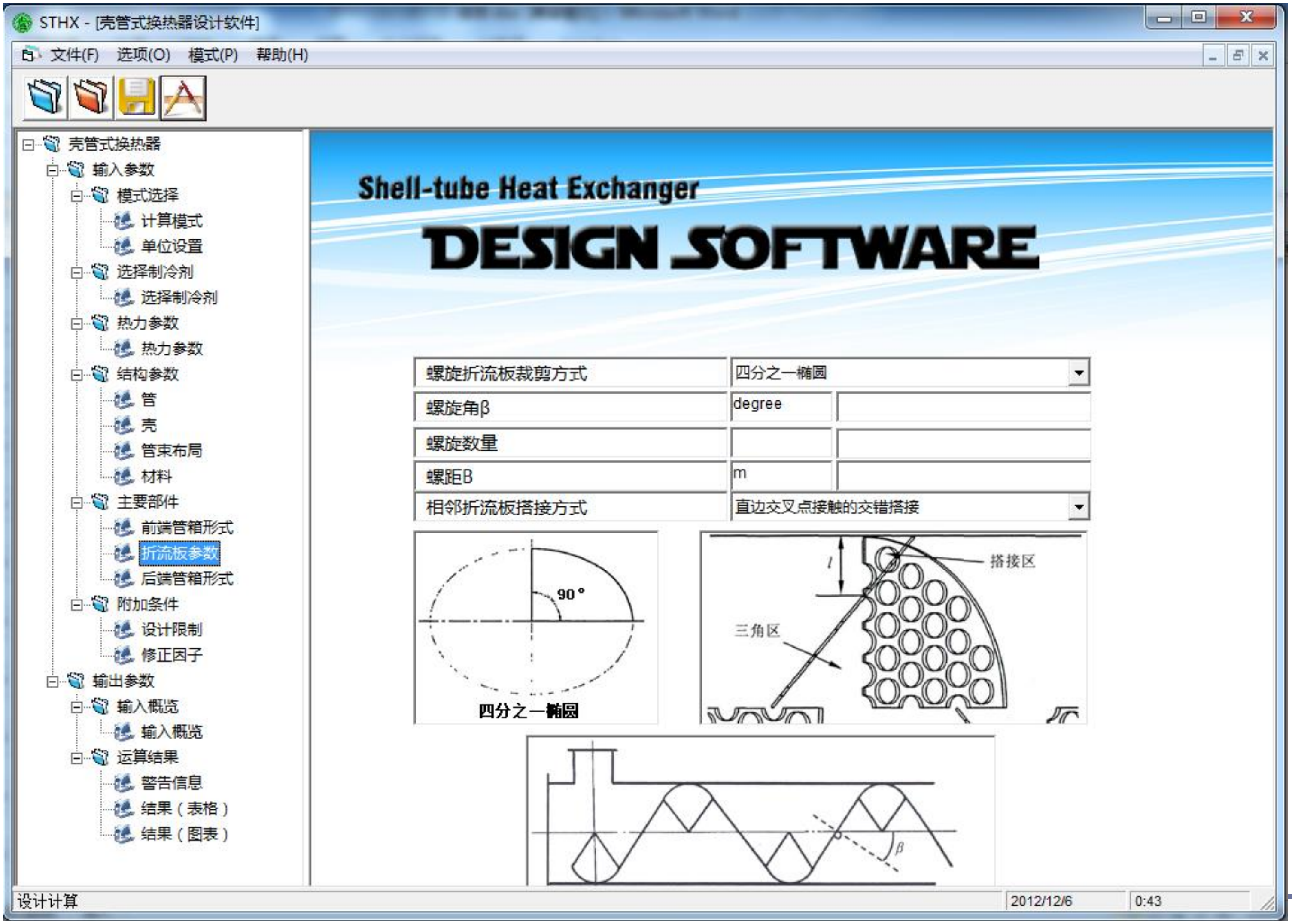
User Interface

Refrigerant Properties



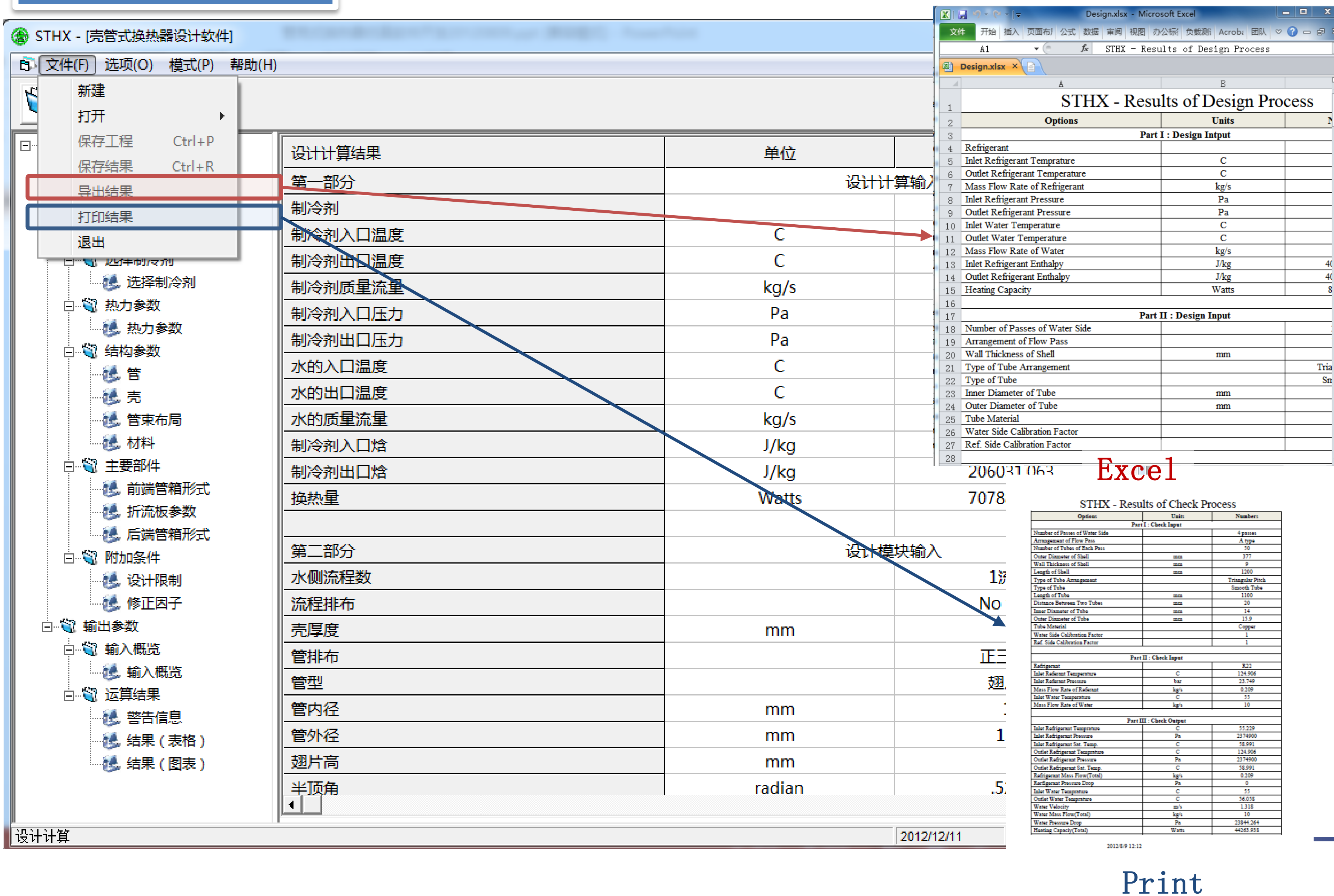
User Interface

Structural parameters



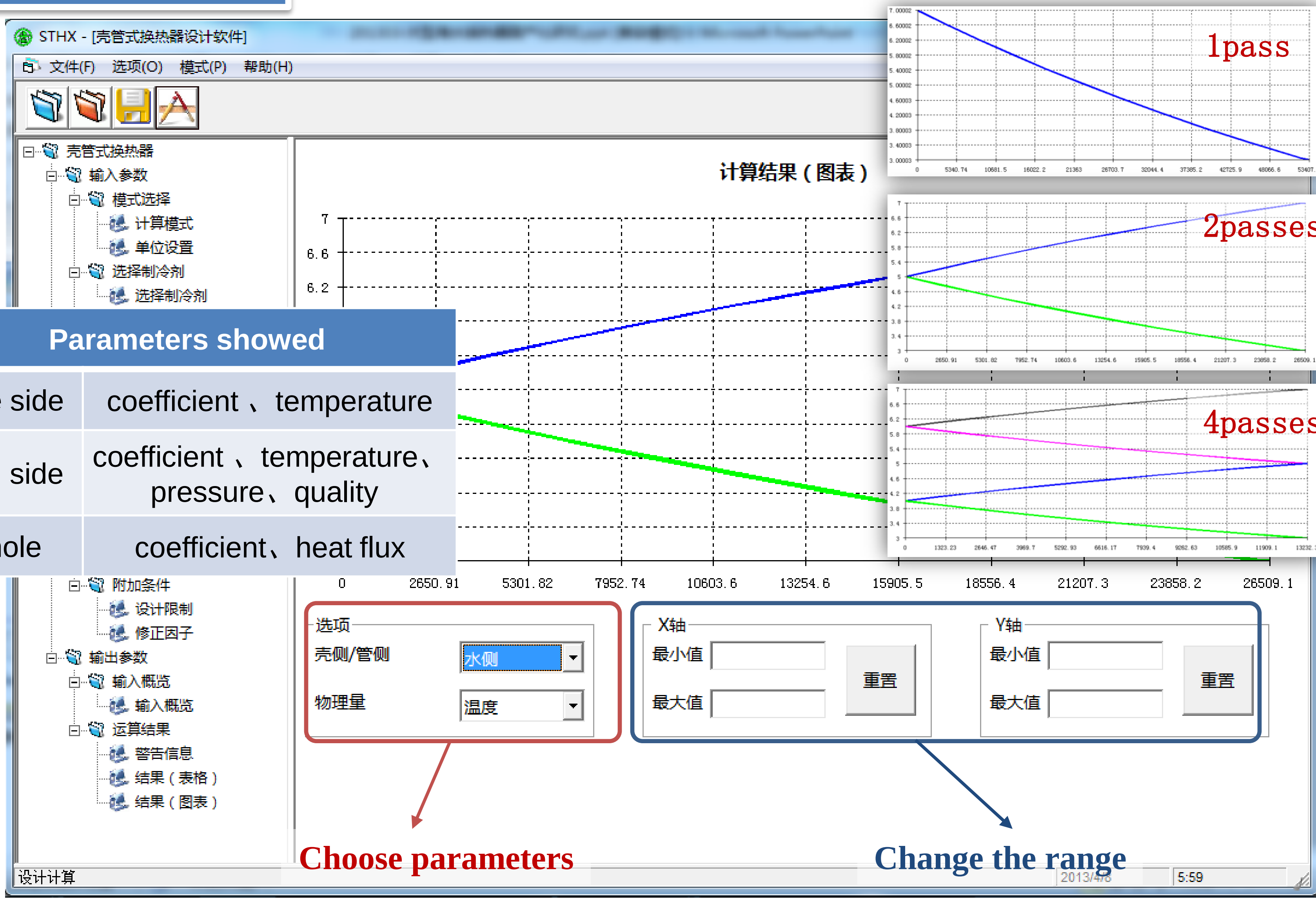
User Interface

Results (table)



User Interface

Results (chart)



Parameters showed	
Tube side	coefficient 、temperature
Shell side	coefficient 、temperature、 pressure、quality
Whole	coefficient、heat flux

Choose parameters

Change the range

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Conclusions

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！