Development and Application of Collaborative Optimization Software for Plate-fin Heat Exchanger

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Abstract. This paper introduces the design ideas of the calculation software and application examples for plate-fin heat exchangers. Because of the large calculation quantity in the process of designing and optimizing heat exchangers, we used Visual Basic 6.0 as a software development carrier to design a basic calculation software to reduce the calculation quantity. Its design condition is plate-fin heat exchanger which was designed according to the boiler tail flue gas. The basis of the software is the traditional design method of the plate-fin heat exchanger. Using the software for design and calculation of plate-fin heat exchangers, discovery will effectively reduce the amount of computation, and similar to traditional methods, have a high value.

1. Introduction
With the development of science and technology, people started working on green energy and the rational use of energy and energy-efficient direction. So people started optimizing heat exchanger, and looking for new design methods to make its comprehensive performance reach the top. Due to technical problems and a lot of calculation quantity in designing and optimizing process, so in the traditional design of plate-fin heat exchanger, cold fluids, heat transfer fluid, flow and heat exchange surface were selected in the first, then tested assumed geometry for many times, until I got a heat exchanger that meets all the constraints, the so-called trial law. The quality of heat exchanger designed by this method depend on the designer's work experience, and it lead to large calculation quantity. Also, you can get only one feasible option not the optimal solution.

Currently available software

Currently have software on the heat exchanger: heat exchanger masters.

Software language: Simplified Chinese software categories: domestic software / shareware / chemical engineering calculation / container design classes

Name: master of heat exchanger

English name: Tube-Shell Heat Exchanger Master

Application platform: Win9x/NT/2000/XP/2003

The features of the software include that[9]:(1) Calculated automatically. (2) Real time response. (3) Input flexibility. (4) The intelligent correction. (5) dData set. (6) Report fine. Automatically generate Excel reports. (7) In line with national standards. But the software only suit for shell-and-tube heat exchangers, and intelligent error correction may error. When missing data or data going wrong, there is no alarm measures.
2. Recovery of heat exchanger of boiler flue gas Design
This type of heat exchanger is used to reduce boiler flue gas temperature. Using high temperature flue gas heat the bath water to reduce flue gas temperatures as well as meet the bathroom water.

2.1. Design of heat exchanger Flow chart
The title is set 17 point Times Bold, flush left, unjustified. The first letter of the title should be capitalized with the rest in lower case. It should not be indented. Leave 28 mm of space above the title and 10 mm after the title.

2.2. Formatting author names

Figure 1. Design of the heat exchanger flow diagram

(1) The cell size should be determined at first;
(2) The flow pattern of the heat exchanger is determined according to the working conditions;
(3) Select or determine the geometric parameters of fin types, and calculate a row of channel area and heat transfer area;
(4) According to the temperature and pressure to determine the physical properties of the fluid, and determine the logarithmic average temperature;
(5) According to the fluid's physical parameters and resistance preliminarily determined number of channels, and also can determine the number of channels before determines flow;
(6) Calculate Re and Pr, according to figure 2 fin performance curves to determine friction factors $f$ and heat transfer factor $j$, and calculate all fluid heat transfer coefficient $a$;
(7) Calculate the efficiency and heat transfer coefficient, and calculate the heat transfer area, determine the theoretical length and actual length;
(8) Accounting for pressure drop, if it exceeds the allowing value or dissatisfaction with the Soviet Union, repeat the steps above. Then determine the actual size.

2.3. Design of heat exchanger
This project uses a boiler in a public body as the design criteria, the public body is a University in Beijing. The basic parameters in the following table:

Figure 2. ALEX several fin performance curve
1- Straight fins, 2- serrated fin, 3- porous fin

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Table 1. Basic parameters of a boiler in colleges and universities in Beijing

| Parameter name | Flue gas volume flow (v)Nm³/h | Gas specific heat capacity at constant pressure (c-p)kJ/(kg·℃) | Flue gas temperature ℃ | Density (ρ)kg/m³ |
|----------------|-----------------------------|---------------------------------------------------------------|-------------------------|-----------------|
| Data           | 5339                        | 1.083                                                         | 200                     | 0.849           |

According to the data in table 1, thermodynamic calculation total available heat is 4.9×10⁵ kJ/h. Thermal and cold part of the properties in the following table 2:

Table 2. hot and cold fluid properties table

|                      | Cooling fluids | Thermal fluid |
|----------------------|----------------|---------------|
| Inlet temperature (℃) | 15             | 200           |
| Outlet temperature (℃) | 45             | 100           |
| The density ρ,kg/m³  | 1000           | 0.849         |
| Specific heat capacity at constant pressure cp, kJ/(kg·℃) | 4.2 | 1.083 |
| Dynamic viscosity μ,kg/(m·s) | 801.5×10⁻⁶ | 22.45×10⁻⁶ |

Fins selection: At present, the master fin type of plate fin type heat exchanger is :(1) straight fin;(2) serrated fin;(3) porous fin;(4) corrugated fins. Taking into account the problems of heat transfer coefficient, I decided to adopt a sawtooth-shaped fin. Selected product is Japan's Shinko "ALEX". Its specific parameters are shown in Table 3 below, and other geometric parameters are shown in table 4.

In order to improve the heat transfer of heat exchanger, we choose counterflow. This means that flue gas flows from top to bottom and liquid water flows from the bottom up.

Table 3. Fin-data

| Geometric parameters | The flue gas side | Liquid water |
|----------------------|-------------------|--------------|
| H, High fin          | 9.5mm             | 4.7mm        |
| δ, Fin thickness     | 0.2mm             | 0.3mm        |
| S, Fin spacing       | 1.7mm             | 2.0mm        |
| Plate thickness      | 0.8mm             | 0.8mm        |
| X, From the          | 1.5mm             | 1.7mm        |
| Y, High              | 9.3mm             | 4.4mm        |
| B Unit width         | 720mm             | 720mm        |
| L, Fin length        | 720mm             | 720mm        |

Table 4. Other geometric parameters

|                      | The flue gas side | Liquid water |
|----------------------|-------------------|--------------|
| De                   | 2.58×10⁻³m        | 2.45×10⁻³m   |
| fi                   | 5.91×10⁻³m        | 2.69×10⁻³m   |
| Fi                   | 9.144             | 4.392        |
| F₁                  | 0.862             | 0.721        |

Fin heat transfer efficiency:

$$\eta_f = \frac{\tanh(mb)}{(mb)}$$

(1) [1,6,8]
Heat transfer coefficient:

\[ K_h = K_f = \frac{1}{\alpha_h \eta_{ab}} + \frac{1}{\alpha_c \eta_{ac}} \cdot \frac{F_c}{F_h} \]

\[ (2)^{[1,6,8]} \]

Derived from above given basic calculations table 5

| Flue gas side heat transfer area, \( F_y, m^2 \) | Water side heat transfer area, \( F_w, m^2 \) | Coefficient of heat transfer of flue gas, \( K_h, W/m^2K \) | Heat transfer in water side of, \( K_c, W/m^2K \) | Heat transfer temperature difference, \( \Delta t_m, ^\circ C \) |
|---|---|---|---|---|
| 3.28 | 3.15 | 356 | 371.6 | 116.2 |

3. Software development of plate-fin heat exchanger

This software is edited by Visual Basic6.0 for various computer systems and its interface is not particularly complex. The design of this software is based on the traditional method of trial and error, which reduces the calculation of designers in designing heat exchangers. Since this software is a small software, the hardware requirements of the computer are not very high, which is applicable to all computer operating systems.

3.1. User interface design

Based on the above design methods and design calculation of heat exchangers, we began to design the software interface. Some designs assume that data is placed on the left of most of the software, such as: heat exchanger geometry; cold and thermal properties of thermal parameters; some parameters set in the right and needs to be calculated so that they do not fill in the data, preventing data fraud.

Specific interface consists of the following figure 3:

**Figure 3. Operation interface diagram**

3.2. Edit formula

First, you are going to assign values to fill in the data, this is because VB cannot directly read during processing Text data. The code about the operation interface make the text attribute of the calculated data is not available which ensures the accuracy of computation and human error. Taking into account the above calculation is applied to the hyperbolic cosine functions and the hyperbolic tangent function, and Visual Basic6.0 without on their logic and calculations, so you need feature them on the Edit so that the software can operate on them:

```vbnet
Function HCos(X) As Double
End Function
```
HCos = (Exp(X) + Exp(-X)) / 2
End Function

Function HTan(X) As Double
HTan = (Exp(X) - Exp(-X)) / (Exp(X) + Exp(-X))
End Function

For other computing procedures, not only need to meet the Visual Basic6.0 logic, but also need to meet the needs of heat exchanger design. We used Val function to make the input text into numeric values assigned, used format function to ensure that the calculation of the results correct significant figures. While application of Visual Basic6.0 in the message box function (MSG) on data not fill alarm or alarm the data calculation errors.

3.3. Test

After the completion of the preparation of the software code, the most important part is the test part, and it is important to the success of steps. In addition to the above-mentioned test methods, we will also use the block test and the overall test. Bringing examples in the book and the design conditions into account, we found that the calculations can be completed, it means that software writing is successful.

The trial results are shown in Figure 4.
Figure 4. Calculation of the results

Test case: fill in the known parameters (A), then (B) data generated in this part of the calculation, and then fill in (C) heat and other physical parameters in, and then fill in (D) in the shape size and thermal conductivity of metals and click generate to calculate Reynolds number. Then according to the Reynolds number (table 2. Fin performance curve) to identify friction factor and heat transfer factor-click generate again after that (D) other data generated. Click on the (E), (F), and can directly calculate the data to calculate click generated on the right side will be (G).

Warning figure 5: when there is a missing time and number wrong time alarm examples.

4. Conclusion

Based on status quo that the fin type heat exchanger will appear large number of the amount of calculation in the process of design and optimization, we used VB to develop calculation software. Applying examples as test data of the calculation software, the results show that the software effectively solve the problem of large amount of calculation, it can quickly calculate the new data after change one or two sets of data. At the same time as the software has a false alarm and fill in the data leakage alarm, it not only reduce the amount of computation in design, but also abat the error caused by human negligence so as to affect the design and calculation of the final result.
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References
[1] Shi Meizhong, Wang Zhongzheng . Principle and design of the heat exchanger (5) [m]. Nanjing: Southeast University Press, 2014.
[2] Guo Jiangfeng, Xu Mingtian, Cheng Lin, etc. Number of field synergy application in optimal design of tube-shell heat exchanger [a]. China engineering Thermal Physics of heat and mass transfer Conference [c], 2008.
[3] Wang Yanping, Lu Chih-min, Liu Xiaoxia, etc . Optimal design of plate-fin heat exchangers. Journal of Inner Mongolia University of technology, 2004, 23 (4): 261-264
[4] He Guangwen . Structural parameters optimization and heat transfer performance of plate heat exchangers [d]. Guangzhou, South China University of technology, 2010.
[5] Software development and Technology Alliance. C # learning video tutorial [m]. Beijing, Tsinghua University Press, 2014.
[6] Weihuayinglang (Japanese), heat exchanger design handbook, Beijing: petroleum industry press, 1982.
[7] Ling Xiang, g.c.SIH, s.t.TU, Lu Weiquan. Research and application of plate-fin heat exchanger development, petroleum machinery, 2000, 28 (5): 54-58.
[8] Li Boqiang, Yuan xiugan, Li. Dynamic model of plate-fin heat exchangers. Journal of chemistry, 1994 (6): 673-677.
[9] Information on http://www.onlinedown.net/soft/36298.htm
[10] Wang Songhan et al., plate-fin heat exchanger [M]. Beijing: chemical industry press, 1984.