

Two-pass heat-exchanger performance By programmable method

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Abstract:

The goal of heat exchanger design is to relate the inlet and outlet temperatures, the over all heat transfer coefficient, to the rate of heat transfer between the two fluids .The use of programming method can greatly aid in optimizing the design.

In this study a programmable method [successive summation method] is developed, applied and presented here using Microsoft Visual Basic (version 6) to determine heat – transfer coefficients and the operating temperatures of a two pass heat exchanger [tube bundle permits a hot gas to pass in a-u- pattern through the exchanger with a shell side contains one – pass cooling water], has replaced the classical log-mean temperature difference , LMTD,method. As many plant heat exchanger operations are not accurately analyzed by this method, due to the correction factors associated with it, which must be obtained experimentally where complete sets of data are rare.

الخلاصة:

هدف تصميم المبادل الحراري هو إيجاد العلاقة بين درجات حرارة دخول وخروج المائع الساخن والبارد , والمعامل الإجمالي لانتقال الحرارة للمبادل مع معدل انتقال الحرارة بينهما , استخدام البرامج الحاسوبية له فائدة كبيرة في الحصول على التصميم الأمثل.

تمت في هذه الدراسة إعداد واستخدام طريقة برمجية للجمع التعاقبي باستعمال برنامج مايكروسوفت البيسك المرئي (الإصدار ٦) , لحساب المعامل الإجمالي لانتقال الحرارة ودرجات حرارة دخول وخروج الموائع لمبادل حراري (متقابل الانسياب) يحوي حزمة من الأنابيب ذو مسار على شكل حرف U يحوي الغاز الحار ومسار واحد للأسطوانة تحوي الماء البارد) , بدلاً من (استخدام طريقة المتوسط اللوغارتمي لفرق درجات الحرارة) حيث تعتمد الأخيرة على (معامل التصحيح) الذي يتم تعيينه تجريبياً , والتي تنقصها الدقة لاعتمادها على النتائج العملية .

Key words: Heat exchanger, LMTD, performance of heat exchanger, Heat exchanger calculation, Heat transfer in counter flow.

NOMENCLATURE

Symbol	Definition
A	area of heat transfer ,m ²
C _p	heat capacity ,J/kg.°C
D	diameter of tube ,m
L	length of tube , m
m	mass flow rate , kg/s
N	number of differential elements
q	heat-transfer rate , W
t	temperature shell side (water) , °C
T	temperature °C
T _i	inlet gas temperature, °C
T _i (J)	first- pass gas temperature through the j element,°C
T _o	exit gas temperature , °C
T _o (J)	second – pass gas temperature through the j element ,°C
T _{int}	intermediate temperature , °C
U	heat-transfer coefficient , W/m ² .°C

subscripts

g	subscript denoting gas
i	inlet condition ,
j	denotes differential element
o	exit condition
w	subscript denoting water

Introduction:

Heat-exchanger has been used extensively and plays an important role in the capital cost, energy efficiency and physical size of refrigeration, air conditioning and heat equipments [1]. Using the log-mean temperature difference, LMTD, method to calculate the heat-exchanger performance is not accurately analyzed and need complete sets of data [2]. To improve effectiveness and efficiency in design a programmable method was developed which greatly aid in optimizing the heat transfer coefficients and operating temperatures for a two-pass shell and tube heat exchanger. Computer models and simulation tools have been developed since the 1980s, with increasing complexity of the calculation procedure [3].

A heat exchanger analysis always begins with determination of the overall heat transfer coefficient by integrating the basic differential equation[2]. The log mean temperature difference (LMTD) results from this integration [3,4], is:

$$dq = U dA (T - t) \quad (1)$$

$$q = U A \Delta T \text{ LMTD} \quad (2)$$

The over all heat transfer coefficient is constant along the entire flow length of the heat exchanger, if it is not, then an incremental analysis of the heat exchanger is required.

For single- pass co current and countercurrent flow, calculation of ΔT LMTD is straight forward. Complications arise when multipass tube-bundles, condenser or reboiler liquid-levels, or cooling Medium cross flows must be considered. In such cases correction factors must be used to modify ΔT LMTD to fit the particular design configuration. Correction factors are experimental and lead the engineer away from the mathematical base of heat transfer [6] .In effect, the engineer is reacting to his equipment instead of predicting its performance.

The L M T D method is also applicable to cross flow arrangements when used with the cross flow correction factor.

Successive Summation method :

A programmed calculation using successive summation, Eq. (1) can be manipulated in differential elements without using a ΔT LMTD and avoiding correction factors [5,6] The over all heat – transfer coefficient ,U, and the exit gas temperature (To) , were determined for a two – pass (Fig .1) heat exchanger . A hot gas pass in a U pattern through the exchanger and one pass cooling water through the shell, water enters the shell at the right with a temperature, t_i and increases in temperature as it proceeds through each element by the amount:

$$\Delta t = \Delta q / m_w C_{p_w} \quad (3)$$

The temperature of the water leaving the differential element , j , (at the left) ,is equal to the entering temperature plus Δt :

$$t_{(j+1)} = t_j + \Delta t \quad (4)$$

The sum of the rates in the upper and lower section (represent the rate of heat transfer in the differential element), $dq (j)$,

$$dq_{(j)} = dq_{(j)} (\text{upper}) + dq_{(j)} (\text{lower}) \quad (5)$$

The rate of heat transfer in the upper and (lower) sections of the element is:-

$$dq_{(j)} (\text{upper}) = U (A/2) (T_{i(j)} - t_{(j)}) / N \quad (6)$$

$$dq_{(j)} (\text{lower}) = U (A/2) (T_{o(j)} - t_{(j)}) / N \quad (7)$$

The Δt of the cooling water through the differential element is calculated from Eq (3),(4),(5) to be:-

$$\Delta t = t_{(j+1)} - t_{(j)}$$

$$\Delta t = \frac{dq_{(j)}(\text{upper}) + dq_{(j)} (\text{lower})}{m_w C_{p_w}} \quad (8)$$

For the upper section and the lower section, of the element :-

$$\begin{aligned} \Delta T_i = T_{i(j+1)} - T_{i(j)} &= \frac{dq_{(j)} (\text{upper})}{m_g C_{p_g}} \\ &= \frac{U (A/2) (T_{i(j)} - t_{(j)})}{N m_g C_{p_g}} \end{aligned} \quad (9)$$

$$\Delta T_o = T_{o(j)} - T_{o(j+1)} = \frac{dq_{(j)} \text{ lower}}{m_g C_{p_g}}$$

$$\Delta T_o = \frac{U (A/2) (T_{o(j)} - t_{(j)})}{N m_g C_{p_g}} \quad (10)$$

Eq(4 to 10)are the components of the calculation of the program used.

Using Successive Summation program

The program calculates the performance of a two –pass gas-flow, single pass water-flow heat exchanger. Using Microsoft Visual Basic (version6).

In the successive summation method an initial guess of the intermediate temperature, T_{int} is used to start with at the (water inlet) and progress to the (water exit)- **Fig(1)**. For the first element $j=1$, T_{int} is equal to both $T_{o(1)}$, and $T_{i(1)}$. The calculation then proceeds through –N-elements (15 to 20 elements are practical).

To Produce values for the gas inlet temperature, $T_{o(N)}$ and gas exit temperature, $T_{i(N)}$. Next ,the program compares the calculated $T_{i(N)}$ with given input T_i . If they are not equal, anew T_{int} is

calculated and the program is restarted. Convergence of T_{int} with the correct value will allow $T_i(N)$ to be equal to T_i , if they are equal (or within convergence criteria limits) , then $T_o(N)$ is the predicted gas exit temperature and the calculation is finished.

If U is to be calculated, $T_o(N)$ is compared to the given (input) T_o .if U is correct, $T_o(N)$ will be equal to T_o . If they are not equal, a new value for U is calculated and the program is restarted. Again once U converges with the correct value, $T_o(N)$ will be equal to T_o , $T_i(N)$ will be equal to T_i , and the calculation is finished.

Data required

The structure of the program is shown **Fig (2)**. After calling for general input, it sets up the information needed for the type of calculation to be done for either T_o or U . Firstly which variables can be calculated:-

- 1- either the over all heat – transfer coefficient, U , or
- 2- the surface area required, A , or
- 3- the gas outlet temperature, T_o .

So data needed are :

For U - surface area and gas temperatures

For A -overall heat –transfer coefficient and gas temperatures.

For T_o - surface area and overall heat-transfer coefficient and for all cases gas flow rate, gas heat capacity, gas inlet temperature and water inlet temperature and outlet temperature. The next step either " U ", " A " or " T " should be entered depending on which calculation is to be made. Data is entered upon prompting from the program, once all the data is put in, the requested variables is calculated. As well, the exchanger duty and water requirement are determined.

In some cases, the calculations cannot be made so the data should be checked and start again.

The Results

By applying the program (Microsoft Visual Basic version 6) for a typical problem of a two-pass exchanger with the values of specification and operating conditions (**Table 1**), predict the overall heat – transfer coefficient. As well the exchanger duty and water requirement are determined. (**Table 2**).

Table2 Heat Exchanger

Input Exchanger Surface, $m^2 = R1$	92.903
Input Gas Rate $kg/s = R4$	3.779
Input Gas Heat capacity $J/kg.c = R5$	2093.4
Input Gas Inlet Temperature $c = R2$	572
Input Gas Outlet Temperature $c = R3$	302
Input Water Inlet Temperature $c = R7$	158
Input Water Outlet Temperature $c = R8$	239
Q = Exchange Duty, w	65940.75
W = Water Requirement kg/s	6.299
Coefficient $w/m^2. c = R9 = U$	5.67826

Buttons: Compute (U), Compute (A), Compute (T)

To compare between the LMTD method and the successive summation method (**Table 3**) illustrate the values for a typical problem (two-pass exchanger) using correction factor from the text [7], to get the value of the over all heat transfer coefficient (U).

(**Table 4**) shows the values for the predictive value of the overall heat transfer coefficient (U) as well as the exchanger duty. By applying the program (Microsoft Visual Basic version 6) and with no need to the correction factor.

Table 4 Heat Exchanger

Input Exchanger Surface, $m^2 = R1$	25.3
Input Water Rate $kg/s = R4$	3
Input Water Heat capacity $J/kg.c = R5$	4180
Input Water Inlet Temperature $c = R2$	20
Input Water Outlet Temperature $c = R3$	70
Input Oil Inlet Temperature $c = R7$	180
Input Oil Outlet Temperature $c = R8$	80
Q = Exchange Duty, w	627000
W = Oil Requirement kg/s	2.67
Coefficient $w/m^2. c = R9 = U$	348

Buttons: Compute (U), Compute (A), Compute (T)

Discussion and Conclusion

Many plant heat exchange operations are not accurately analyzed by the log-mean temperature difference, LMTD, method for calculating heat transfer. Besides heat exchanger analysis using the LMTD method with its correction factors needs complete sets of experimental data which is rare in the plant situation, [4, 6].

The successive summation method can be used to make the decision to predict the heat –transfer coefficients for each heat-exchanger in the plant situation, and this useful especially during the maintenance. In general if three of the four inlets and exits temperatures are known the successive summation method will calculate the fourth, if two of the four are known, the third can be determined by trial and error.

The predictive nature of the method used is an important tool for the one of the most common type of the heat exchanger (a two-pass heat exchanger), but its concepts are applicable to many other heat transfer problems. Due to the large number of heat exchanger configurations which is widely used in the chemical process industries, the method presented here could be regarded as a base to be used to fit different types of heat exchangers with a different flow (parallel, counter or cross flow). [4]

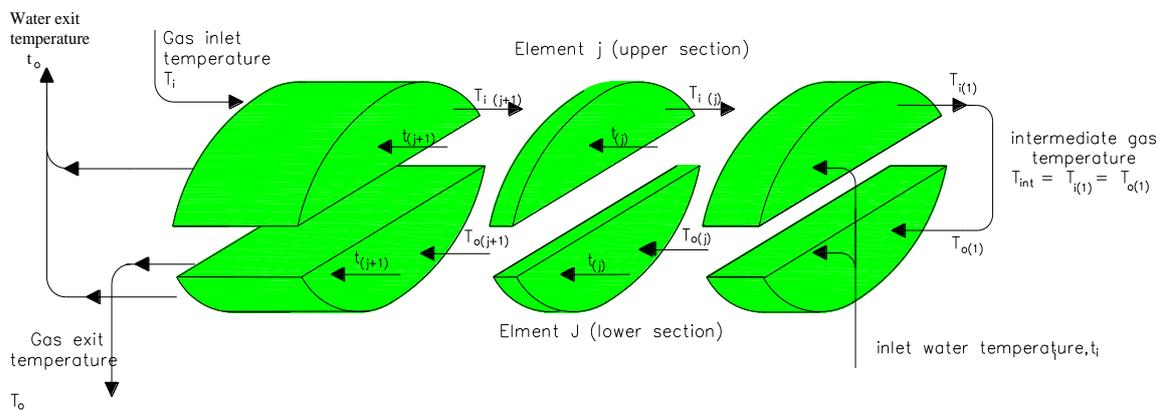


Fig-1- two pass exchanger(heat flow through the differential element)

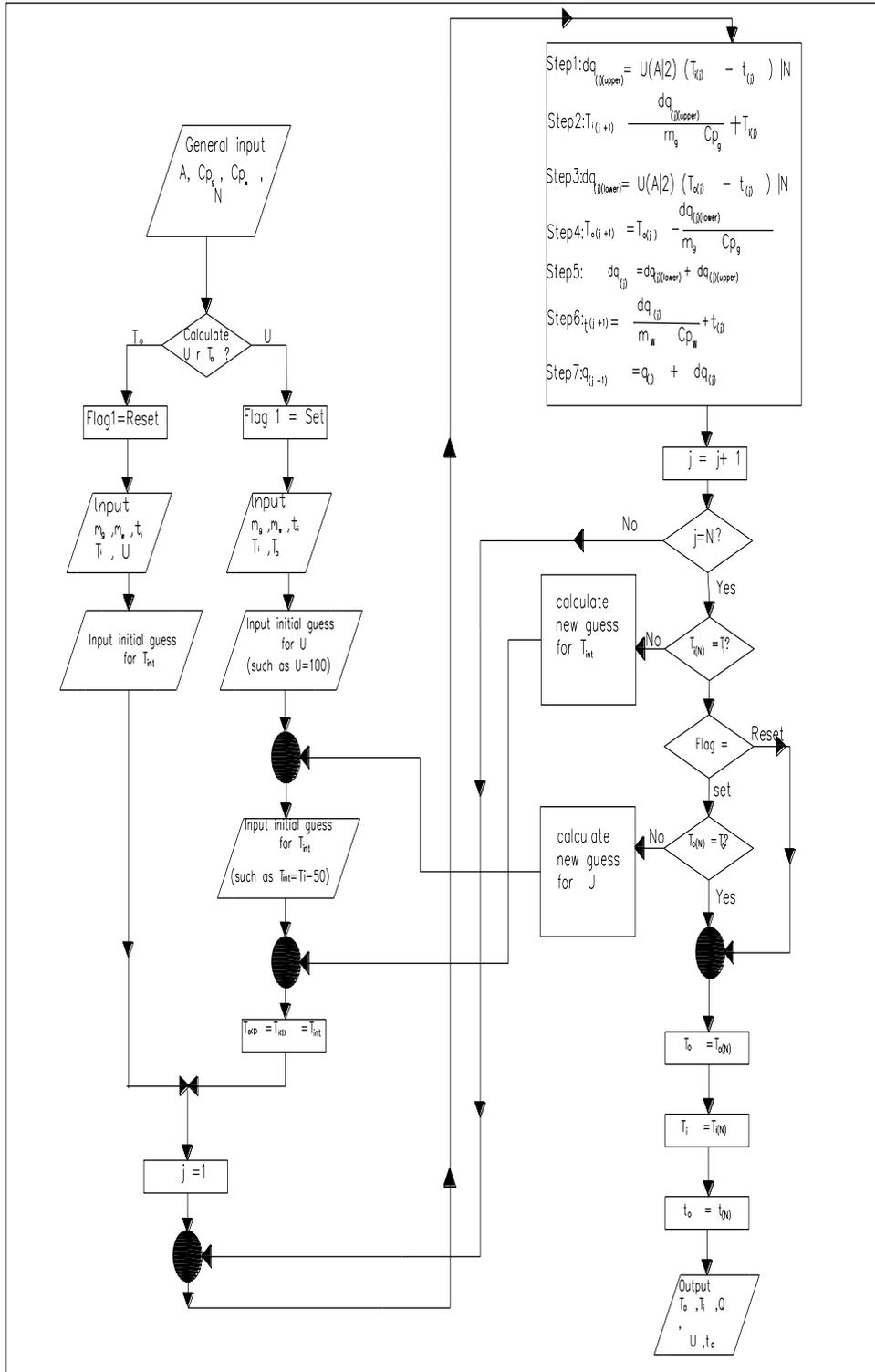


Fig2: Program flowchart for a two-pass heat exchanger

Item	Value
Inlet gas temperature (°C)	572
Outlet gas temperature (°C)	302
Inlet water temperature (°C)	158
Outlet water temperature (°C)	239
Total area(m ²)	92.903
Gas heat capacity (J/kg. °C)	2093.4
Water heat capacity (J/kg.°C)	4286.8
Gas flow rate (kg/s)	3.779

Table:1 Values for a typical problem (specification and operating conditions)
Of a two – pass exchanger

Item	Value
Inlet water temperature (°C)	20
Outlet water temperature (°C)	70
Inlet oil temperature (°C)	180
Outlet oil temperature (°C)	80
Total area(m ²)	25.3
Water heat capacity (J/kg. °C)	4180
oil heat capacity (J/kg.°C)	2350
water flow rate (kg/s)	3.
LMTD	82.5
Correction Factor	0.68
heat transfer Coefficient,W/ m ² .°C	350

Table:۲ Values for a typical problem (specification and operating condition)
Two-pass exchanger using LMTD method

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