Economic Analysis of Heat Exchangers

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Abstract. The efficient use of energy in production facilities reduces manufacturing costs. The design, fuel selection and efficiency of energy units are very important. In this study, the irreversibility and cost of a heat exchanger resulting from the change in surface area, the thermodynamic values of the operating conditions are taken as basis and calculated theoretically in terms of thermoeconomically. The optimum surface area of the heat exchanger, which equivalent to the least energy cost, has been determined. In addition, since it is a forward-looking investment, energy production is evaluated as an annual unit cost. *The surface area of the heat exchanger has also been determined as an economic value. For this, based on the n' year period, it is provided by equating the capital return multiplier (a^c) with the irreversibility the cost value.*

Keywords: Exergyeconomics, Thermoeconomics, Heat Exchanger Design, Heat Transfer, material cost, installation cost

1. Introduction

Since the economics of thermal systems are considered in terms of thermodynamics, they are defined as thermoeconomics. The most efficient use of the energy of the systems can be briefly defined as exergy. In this context, exergy methods are applied while applying economic analysis to the systems. For this reason, it is necessary to evaluate the price of energy within the scope of exergy. The aim of thermoeconomic optimization is to achieve a balance between capital costs and exergy costs, which will give the minimum cost of the factory product within a given system structure. If the thermal system has a complex structure, it becomes a little more difficult to determine its thermoeconomic efficiency. Ways of simplification are sought to clearly determine efficiency. For this purpose, thermoeceonomic analysis was performed for a selected heat exchanger. Depending on the surface area size of the heat exchanger, the thermoeconomic cost of the investment cost and efficiency has been evaluated.

There are many studies in which thermal systems are evaluated thermoeconomically using the exergy method. A study was conducted on solar-powered agricultural product drying technologies. They studied the use of different types of solar dryers based on direct, indirect and mixed modes. In addition, energy, exergy, economic and environmental analyzes are presented to determine the main lines, [1]. Another thermoecological work on energy production systems is [2, 3, 4, 5, 6, 7, 8, 9]. The cost of leveled storage has been studied exergy economically. Comparisons were made when using waste heat source and geothermal energy [10]. In another economic study, economic analyzes of the investment, operation, maintenance and fuel costs of the systems were made [11, 12, 13]. Tsatsaronis mentions in his study that exergoeconomics is based on exergy cost and is generally applied in the business component [14]. They have worked on the design and optimization of different thermal systems. In these designs, thermodynamic analysis, energy and exergy analysis were performed for the effective use of the limited fossil fuel available [15].

In study, mentioned that the most widely used method for the analysis of the energy conversion process is the first law of thermodynamics. However, he mentioned that concepts such as energy and exergy losses can be used to evaluate the efficiency with which the available energy is consumed [16].

In study, some assumptions were made for the working conditions of the heat exchanger. These admissions are annual working hours Z_{op}=8760, economic life (n), fixed interest rate (i_R), heat exchanger installation cost, rate of irreversibility.

2. Thermoeconomics Of Facilities

In systems where thermal energy is used, the main purpose is to supply the energy needed, to increase efficiency, to reduce cost expenses, are the most important purposes of the facilities. The sum of the minimum annual operating and capital cost of a facility determines the minimum unit cost of the product. In order to determine the exergetic efficiency of the product, the energy flow and irreversibility of the unit must be determined. The cost of the units used in energy systems is proportional to the energy cost. It is very important to determine the thermal energy and exergy unit cost transferred from a heat exchanger. The producer will decide to continue the production according to this cost value.

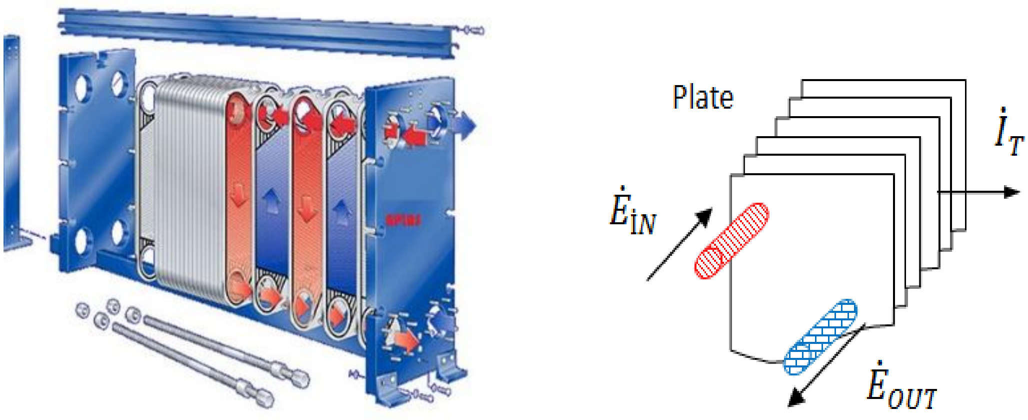

Figure 1.
Plate heat exchangers

A heat exchanger can be defined as any device that transfers heat from fluids at different temperatures to another. There are many types of designs according to the purpose of use, place of residence and material of manufacture. Parametric variation of heat exchanger volume used in production systems (P_{srf}) is also effective in changing the irreversibility ratios of the facility and entails a change in cost. When the system is evaluated as a whole in terms of energy, the exergy equation can be written as:

$$\dot{E}_{İN}\ (P_{srf}) = \dot{E}_{OUT} + \dot{I}_T\ (P_{srf}) \qquad (1)$$

Here $\dot{E}_{OUT}$ is the exergy output of the plant products and independent of (P_{srf}). The rate of irreversibility $I_T\ (P_{srf})$ and exergy $\dot{E}_{OUT}$ are seen as the exergy consumption in the system required to form the product. If there is any increase in exergy consumption, the exergy input of the system should increase at $\dot{E}_{İN}(P_{srf})$. In general, thermal systems are examined as incoming, outgoing and irreversible energy within a certain boundary conditions. When these systems are evaluated in terms of cost, the exergy input is considered as a single fixed unit cost. The annual cost of plant operation (C_T) is formulated as follows [17].

$$C_T\ (P_{srf}) = Z_{op} C_{İN}^{\varepsilon} \dot{E}_{İN}\ (P_{srf})\ + a^c \sum_{x=1}^{n} C_x^c\ (P_{srf}) +\ b^c \qquad (2)$$

Here, it is necessary to know the energy cost spent for the product obtained in the production facilities.

The energy released from the surface of the heat exchanger to the environment is considered as irreversibility. In determining the exergy of the systems, the derivative of equation (1) is taken according to the parametric variation of the heat exchanger surface area (P_{srf}) and (2) applied to the equation.

$$\frac{\partial \dot{E}_{İN}}{\partial P_{srf}} = \frac{\partial \dot{I}_T}{\partial P_{srf}} \quad (3)$$

Derivative of equation (2)

$$\frac{\partial C_T}{\partial P_{srf}} = Z_{op} C_{İN}^{\varepsilon} \frac{\partial \dot{I}_T}{\partial P_{srf}} + a^c \sum_{x=1}^{n} \frac{\partial C_x^c}{\partial P_{srf}} \quad (4)$$

If equation (4) is rearranged to determine the cost, [17 p. 215].

$$a^c \sum_{x=1}^{n} \frac{\partial C_x^c}{\partial P_{srf}} = a^c \sum_{x'=1}^{n} \frac{\partial C_{x'}^c}{\partial P_{srf}} + a^c \frac{\partial C_b^c}{\partial P_{srf}} \quad (5)$$

x' denotes a single panel in the system. Accordingly, if equation (5) is rearranged,

$$\sum_{x=1}^{n} \frac{\partial C_{x'}^c}{\partial P_{srf}} = \frac{\partial \dot{I}_b}{\partial P_{srf}} \sum_{x'=1}^{n} \left(\frac{\partial C_{x'}^c}{\partial \dot{I}_b}\right) = \frac{\partial \dot{I}_b}{\partial P_{srf}} \zeta_{b,i} \quad (6)$$

$$\zeta_{b,i} = \sum_{x'=1}^{n} \left(\frac{\partial C_{x'}^c}{\partial \dot{I}_b}\right)_{P_{srf}=var,\ x'\neq b} \quad (7)$$

$$\frac{\partial \dot{I}_T}{\partial P_{srf}} = \sigma_{b,i} \frac{\partial \dot{I}_b}{\partial P_{srf}} \quad (8)$$

Using equations (5)-(8), equation (4) can be rearranged as follows. [17 p. 216].

$$\frac{\partial C_T}{\partial P_{srf}} = Z_{op} C_{b,i}^{l} \frac{\partial \dot{I}_b}{\partial P_{srf}} + a^c \frac{\partial C_b^c}{\partial P_{srf}} \quad (9)$$

$$C_{b,i}^{l} = C_{İN}^{\varepsilon} \sigma_{b,i} + \frac{a^c}{Z_{op}} \zeta_{b,i} \quad (10)$$

The optimum irreversibility of the parametric variation P_{srf}, is as follows.

$$\left(\frac{\partial \dot{I}_b}{\partial P_{srf}}\right)_{OPT} = -\frac{a^c}{C_{b,i}^{l} Z_{op}} \frac{\partial C_b^c}{\partial P_{srf}} \quad (11)$$

While the quantities related to the system are determined by equation (4), the selection of the appropriate element is determined by equation (9). The unit cost of irreversibility in plant components is expressed as $C_{b,i}^{l}$. In this case, the unit cost of the system is determined by equation (12).

$$\left(C_{b,i}^{l}\right)_{\zeta_{b,i}=0} = C_{İN}^{\varepsilon} \sigma_{b,i} \quad (12)$$

The total surface area of the heat exchangers P_{srf} face directly affects both the performance and the investment cost of the heat exchangers. The investment cost of a particular design can often be expressed as an empirical equation as a function of the heat transfer area.

Based on the changing surface area of the heat exchanger, equation (11) is rearranged with its irreversibility at constant temperature and other thermodynamic values.

$$\left(\frac{\partial \dot{\mathrm{i}}_{\mathrm{b}}}{\partial P_{srf}}\right)_{OPT} = - \frac{Q^2 T_o}{U_{o,srf}^l T_u^2} \frac{1}{(P_{srf})^2} \quad (13)$$

Equations (11) and (13) are equated to each other. And equality is rearranged.

$$- \frac{a^c}{C_{b,i}^l \ Z_{op}} \frac{\partial \mathrm{C_b^c}}{\partial P_{srf}} = - \frac{Q^2 T_o}{U_{o,srf}^l T_u^2} \frac{1}{(P_{srf})^2} \quad (14)$$

The unit surface cost is considered as equation (15).

$$\frac{\partial \mathrm{C_b^c}}{\partial P_{srf}} = 1945\,(P_{srf})^{0,582-1} \quad (15)$$

Equation (13) is obtained numerically by calculating from the given values.

$$\left(\frac{\partial \dot{\mathrm{i}}_{\mathrm{b}}}{\partial P_{srf}}\right)_{OPT} = -\,0{,}313408\mathrm{x}10^6 \frac{1}{(P_{srf})^2}$$

Unit exergy cost C_{iN}^{ε} entering the system, capital recovery factor (a^c), efficiency (η), and temperatures (T_u and T_o), total heat coefficient U_o, at the given values $C_{b,i}^I$ were calculated. Provided that $\sigma_{b,i}=1$ for certain values, the input exergy cost $C_{\mathrm{iN}}^{\varepsilon}$ is equal to 11x10^{-6} \$/kJ, and according to equation (12), the irreversibility cost of a single component is accepted as $C_{b,i}^I = C_{\mathrm{iN}}^{\varepsilon}$.

Table 1.

The constant thermodynamic values used.

Q_u (kW)	U_o (kW/m^2-K)	T_u (K)	T_o (K)	C_b^I (\$/kJ)	$\sigma_{b,i}$
20000	3	353,15	293,15	11x10^{-6}	1

The cost of unit investment in facilities is financially important. The economic life of the system (n-years) and a fixed interest rate (i_R) are determined on the financial return of the investment. The annual return cost multiplier value (a^c) of the investment is determined from equation (16). In future cost calculations, the scrap value of the heat exchangers is often neglected.

$$\mathrm{a^c} = \frac{\mathrm{i_R}(1+\mathrm{i_R})^{\mathrm{n}}}{(1+\mathrm{i_R})^{\mathrm{n}}-1} \quad (16)$$

Accepted values were found to be a^c= 0.214. This value is written in equation (11). After the necessary operations, the equations in (14) are rearranged.

$$-\left(\frac{0.214}{8760\ x\ 3600\ x 11\ x\ 10^{-6}}\right) 1945\ \frac{1}{\left(P_{srf}\right)^{0.418}} = -\ 0.313408\mathrm{x}10^6 \frac{1}{(P_{srf})^2}$$

The optimum heat exchanger surface area to be obtained from equation (14) is determined. In the system, energy cost and irreversibility were evaluated together. Figure 2. was created according to the data obtained. The cost analysis cut-off point with irreversibility gives the optimum surface area of the heat exchanger. In the study, it was investigated how much the change of the surface area of the heat exchanger affects the irreversibility. In addition, it was evaluated in terms of unit cost and the optimum surface area was determined.

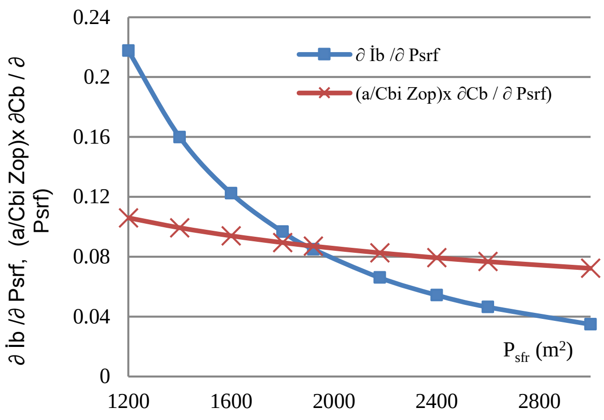

Figure 2.
Optimum surface area of the heat exchanger

In exergy production; the surface area, efficiency, material cost and installation cost of the heat exchanger are important factors. The wide variety of heat exchanger design shapes requires different cost analyzes. Based on the energy (exergy) used in such energy transfer systems, the unit energy cost is determined. When obtaining product cost, future value should also be considered. Interest rate i_R and a^c by country should be determined in advance. Such changes will affect the cost over time and this will cause unit energy cost changes. As the surface area of the heat exchanger increases, its efficiency increases and its irreversibility decreases. The design of a product is very important in terms of production cost and energy saving. In this context, to determine an efficient heat exchanger surface area annual cost expenses and change in irreversibility are evaluated together. Figure 3 shows capital return multiplier and variation of optimum heat transfer surface area $(P_{srf})_{OPT}$ during n' years.

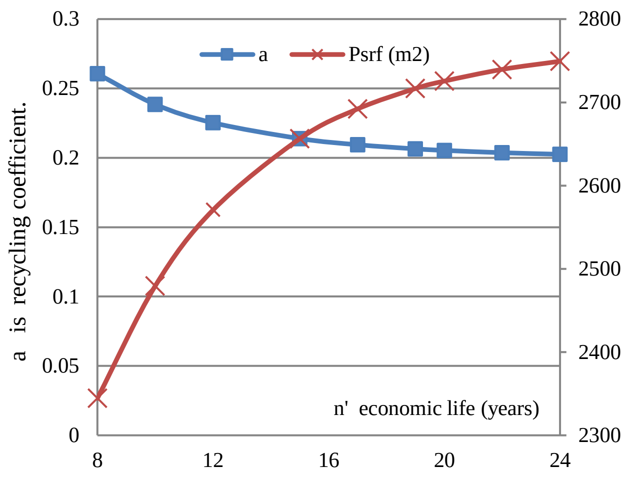

Figure 3.
Depending on the year change, the surface area change and the recycling factor.

The surface area of the heat exchanger has also been determined as an economic value. For this, based on the n' year period, it is provided by equating the capital return multiplier (a^c) with the irreversibility the cost value. The annual interest rate (i_R) is 20% and when evaluated on the basis of its economic life (n), it provides a more appropriate economic advantage in the 15 th year.

3. Results

The size of the heat exchangers in the manufacture is directly proportional to the energy transfer. As a system, both the energy cost and the manufacturing cost were evaluated together and the most suitable heat exchanger volume (surface) size was determined in line with some thermodynamic and cost values. In terms of thermodynamics, the irreversibility of the system was accepted as the surface energy and the cost calculation was made. In accordance with the given values, the thermoeconomic surface area P_{srf} = 2655 m^2 has been determined. The efficient use of energy in thermal systems has recently increased its importance. Global warming, the decrease in natural energy resources, economic conditions and workplace volume constraints have led manufacturers to manufacture heat exchangers at optimum cost.

Symbols

$(P_{srf})_{OPT}$ Suitable heat exchanger surface flux
C_{IN}^{ε} Unit cost of input exergy to the system.
C_{x}^{c} Intermediate panel capital cost.
C_T Total annual cost
C_P^c Exchanger installation cost ($)
i Annual interest rate
a^c Capital recycling multiplier
bc The portion of the annual cost that is not affected by the optimization.
$\zeta_{b,i}$ The cost of capital coefficient.
Z_{op} Annual working hours
n Economic life

Referance

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