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COUNTER FLOW HEAT EXCHANGERS' IRREVERSIBILITY MINIMIZATION

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ABSTRACT

The irreversibility minimization method of heat exchanger optimization is extended to include a term to account the exergy of the material of construction of the heat exchanger. The method permits physically realistic optimization to be conducted with the resulting optimum designs providing conceptually beneficial guideposts, which do not change with time or location. Such optima are in contrast to the optima obtained by presently advocated methods, which on one hand indicate unrealistic infinite area of the heat exchangers, and on the other hand point to optima that may change dramatically with location and time. Accompanying exergetic efficiency expressions using the same type of material exergy term show physically more realistic values than the usual expressions.

Keywords: heat transfer, irreversibility, energy, exergy, heat exchanger.

INTRODUCTION

Technique for heat exchanger analysis particularly since the work of Bejan (1977, 1980) where results regarding basic design variables were developed in a generalized, non-dimensional manner. The work in this areas has reviewed by Bejan (1987). The irreversibility minimization method is quit useful for evaluating design parameters at fixed total heat exchanger area. However, method only considers the exergy the losses associated with the heat exchanger operation, and dose not consider the exergy or economic cost of the heat exchanger itself.

As a result of this ,the global optimum usually results form an engineering design view point. Thermoeconmics, developed by Tribus & Evans (1962) has been applied to heat exchangers by various authors, including London & Shah (1983). Thermoeconomic analysis can take into account all the costs associated with building operating a heat exchanger, and global optimization yields the realistic result of a finite area heat exchanger.

Thermoeconomics also gives the designer the ability to decompose a global system into individual isolated component in away such that optimizing the in divided isolated yield a good approximation to optimum design of the global system (Evans *et al.,* 1983). The Thermoeconomically optimum heat exchanger design must change as the costs vary with location and time. Thus the Thermoeconomic optimum design for one location and time dose not serve as a good guidepost for the optimal design in another location and time .

This research presents an extension of the minimum irreversibility generation analysis wherein the irreversibility generation equation includes term that exchanger material and the application life of the heat exchanger. This method yields optimal design that do not change with time or location and that represent the desired optimal design in the limit of exergy cost begin dominant relative to labor and profits. The resulting optimal designs are physically more realistic that those obtained from the usual irreversibility minimization methods, and although the designs do not represent the optimal design form the thermoeconmics viewpoint they represent limits that may serve as guideposts for design such guideposts are quite useful conceptually and particularly important in times of rapidly changing and unpredictable economic parameters.

BASIC METHOD

The objective function for the basic irreversibility minimization analysis for a heat exchanger in a non dimensional form (Bejan, 1977).

$$Ns = \frac{\dot{I}}{T_o C_{max}} \tag{1}$$

$$Ns = Ns_{\Delta T} + Ns_m \tag{2}$$

$$\dot{I}_m = \frac{\zeta_m}{\tau} \tag{3}$$

$$Ns_m = \frac{\dot{I}_m}{T_o C_{max}} \tag{4}$$

To illustrate the method ζ_m need to be determined. The exergy of heat exchanger materials can be divided into chemical and thermomechnical exergies. Materials acquire chemical exegies when they are transformed form the dead state into their final from. materials also have thermomechaniccal exergy if they operate at temperatures or pressures different from that of the dead state into their final from. Materials also have themomechanical exergy if they store elastic exergy as a result of deformations during the manufacture of the heat exchanger. Heat exchanger material can be written as

$$\zeta_m = \zeta_{m,ch} + \zeta_{m,ph} \tag{5}$$

The thermal exergy is found by calculating the maximum work that can be obtained when the material under consideration is brought to chemical equilibrium with the components of the dead state. The method is illustrated by Moran (1982) and Kotas (1985), where a table of chemical exergy value for common materials with respect to a standard dead state is included.

Heat exchangers operate at pressures and temperatures different from those of the dead state. Heat exchanger materials then have a themomechanical exergy different from zero. However, these exergy values are small relative to the chemical exergey of the material, and can be neglected in the analysis. The elastic exergy resulting from deforming a materal into a heat exchanger pipe is estimated here by following a simplified procedure:

$$\sigma = E\varepsilon = \frac{Ey}{r} \tag{5a}$$

where y is the radial coordinate measured from the center of the tube. The stress at the tube wall $(y = \delta / 2)$ from eq. (5a) is:

$$\sigma_w = \frac{E\delta}{2r} \tag{5b}$$

The stress varies linearly with y in the elastic region and has a constant value σ_y in the plastic region, according to the assumed $\sigma - \varepsilon$ behavior of the materials. In most practical cases the wall is thick enough so that the elastic zone is small relative to the total volume. Under these assumptions, the total exergy in the material is

$$\zeta_{m,ph} = \int_v \frac{1}{2}\sigma\varepsilon dv = \frac{1}{2}\sigma_y \frac{\sigma_y}{E} V = \frac{pl\delta\sigma_y^2}{2E} \tag{5c}$$

and the elastic exergy of the material per unit area is

$$\zeta_{m,ph} = \frac{\delta\sigma_y^2}{2E} \tag{5d}$$

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The work necessary to produce the deformation in the material is greater than the value of the elastic exergy Eq. (5a). This is because part of the work has to be spent in deforming the material physically, and this part of the work is not recoverable.

Objective Function

Consider the case of a heat exchanger with negligible pressure drop irreversibility. Equation(3) then

As previously discussed, the heat exchanger material has an exergy value at the moment of installation . the exergy value of the heat exchanger can be viewed as begin used up after a time equal application lift τ : The decrease in the material can be considered as an irrevesiblity generation rate given by.

$$Ns_m = \frac{A\dot{I}_A}{T_o C_{\max}} = \gamma\omega NTU \tag{6}$$

Where $\dot{I}_A = \frac{\dot{I}_m}{A}$ is the irrevesiblity rate per unit area of the heat exchanger and γ is the material exergy parameter defined as:

$$\gamma = \frac{\dot{I}_A}{T_o U} \tag{7}$$

When ideal gas behavior is assumed for the following fluid, and there are no heat losses to the surroundings, the heat transfer irreversibility generation number is

$$Ns_{\Delta T} = \omega \ln\left[1 + \frac{\varepsilon}{R}(1-R)\right] + \ln\left[1 + \omega\varepsilon(R-1)\right] \tag{8}$$

substitution of (6) and (8) in to (2) yields the final form of the object function

$$Ns = \omega \ln\left[1 + \frac{\varepsilon}{R}(1-R)\right] + \ln\left[1 + \omega\varepsilon(R-1)\right] + \gamma\omega NTU \tag{9}$$

This objective function can be used to optimize any heat exchanger if the $\varepsilon - NTU$ relationship is known and the assumption made during the development of this equation are satisfied. The $\varepsilon - NTU$ relationships for many heat exchanger configuration are given in Kays & London (1984) objective function (9) is used next for the design optimization of a counter flow heat exchanger.

Optimization of Counter Flow Heat Exchangers

When the marital irreversibility is not include in the analysis $Ns_{\Delta T}$ is equal to Ns, the value of $Ns_{\Delta T}$ increases form zero with increasing NTU, reaches a maximum, and then decreases to a minimum at infinity. This minimum $Ns_{\Delta T}$ has a value of zero for balanced heat exchanger, the decrease in irreversibility on the left side of the maximum was shown by Bejan (1980) to be due to insufficient heat transfer across a temperature difference of order $(T_2 - T_1)$. Bejan (1987) this region would violate the principle of thermodynamic of the component being optimized. Since the value of γ is function of overall heat transfer coefficient U , the point of minimum irreversibility generation rate corresponds to a given U . In the present analysis the value of U has to be know to calculate and NTU^*. This additional degree of freedom is due to the assumption of negligible pressure drop; therefore, U should be in a range where this assumption is not violated; however, when the pressure drop is considered, an optimum value of U for a given surface area can be obtained from the best balance between $Ns_{\Delta p}$ and $Ns_{\Delta T}$.

The variation of NTU^* with the capacity rate ratio ω for various values of γ is shown in Figure 1. This figure does not show a value of NTU^* for small value of ω since, as stated before, there is no optimum design for small capacity ratio. Figure 1 corresponds to an inlet temperature ratio R of 2/3 (Witt, 1983). Reducing R increases the irreversibility due to heat transfer at a given NTU and hence increases the NTU^*, and vice versa. The use of Figure 1 to obtain NTU^* for counter flow heat exchanger is illustrated by a specific application in later section.

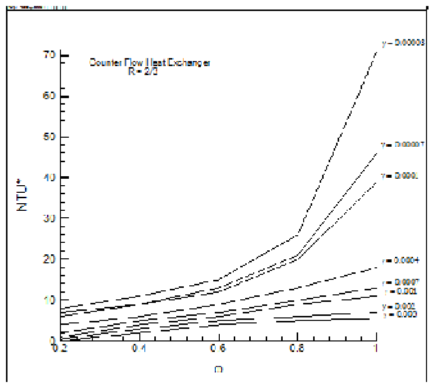

Figure 1. Optimum NTU as a function of ω and γ for counter flow heat exchanger with R=2/3.

MODIFICATION OF BASIC METHOD

Current processes to produce materials have low efficiencies , and the actual exergy expenditure for given heat exergy of the material. The objective function for irreversibility minimization analysis can be formulated to take into a count all the exergy expenses associated with the fabrication of the material contribution to the irreversibility generation equation. This analysis was based on average values for exergy expenses associated with fabrication of the material . This method was used in case by Boyd *et al.*, (1981) to analyze simplified heat exchanger model. They considered a material contribution to the irreversibility generation equation. This considered a material contribution to the irreversibility generation equation. This contribution was calculated as the exergy spent in mining, smelting, refining, milling, and transporting the heat exchanger material. The analysis was based on average values for exergy expenses and transporting distances. The material energy term in the global energy consumption equation. The material energy was estimated from the component dimensions by used empirical equations. Applying these estimates to find optimum heat exchanger designs for different objective functions based on energy, economics, and combinations of the two.

Another way of including the irreversibilites generated in the process of building a heat exchanger is to divided the material irreversibility rate by an adequate efficiency for overall efficiencies for manufacture of some important materials. The objective function expressing the global irreversibilites generated at the current state of technology is

$$Ns_I = Ns_{\Delta T} + Ns_{mI} \tag{10}$$

Where

$$Ns_{mI} = \frac{Ns_m}{\psi_m} \tag{11}$$

and ψ_m is the exergetic efficiency for the overall manufacturing process. When ideal behavior is assumed for the flowing fluid and the pressure drop irreversiblitity is small, the objective function reduces to

$$Ns_I = \omega \ln\left[1 + \frac{\varepsilon}{R}(1-R)\right] + \ln\left[1 + \omega\varepsilon(R-1)\right] + \gamma_I \omega NTU \tag{12}$$

Where

$$\gamma_I = \frac{\gamma}{\psi_m} \tag{13}$$

both objective functions given by equation (9) and (12) have the same function form, and are identical when the exegetic efficiency of the manufacturing process is unity. The same optimization procedure used for equation (9) is then applicable for (12), and an optimum NTU_I for a counter flow heat exchanger can also be obtained form Figure 1 for a given value of γ_I the optimum value of NTU is the optimum when is used in the same figure.

Exegetic Efficiency

The exegetic efficiency of a plant component is defined in a variety of ways in the literature. The following expression is selected for this research (Tsataronis & Winhold, 1985)

$$\psi = \frac{\zeta_p}{\zeta_f} \tag{14}$$

Where ζ_p is the rate exergy loss by the product, and ζ_f is the rate of exergy loss by the fuel. When the component is a heat exchanger designed for heating the rate of exergy gained by the cold stream is equal to ζ_p, and the rate of exergy loss by the hot stream is equal to ζ_f. When the irreversibility contribution form the material is not included in the analysis, the rate of exergy loss by the fuel is the rate of exergy loss designed for heating, the rate of exergy loss by the hot stream ,and is designated as ζ'_f. The exergetic efficiencies for a heat exchanger with and without the irreversibility contribution form the material are developed next.

The exergy gained by the product is

$$\zeta_p = \zeta_{1e} - \zeta_1 \tag{15}$$

When the material irreversibility rate is not include , the exergy loss the fuel is

$$\zeta'_f = \zeta_2 - \zeta_{2e} \tag{16}$$

When the material irreversibility rate is not include , the exergy loss the fuel is given by

$$\zeta_f = \zeta_2 - \zeta_{2e} + \dot{I}_A A \tag{17}$$

For an ideal gas, when pressure drop irreversibility and heat losses to the surrounding are negligible, the above equations can be written as

$$\zeta_p = C_{\min} T_1 \varepsilon \left[\frac{1}{R} - 1 \right] - T_0 C_{\min} \ln \left[1 + \varepsilon \left(\frac{1}{\zeta} - 1 \right) \right] \tag{18}$$

$$\zeta_f' = C_{\max} T_1 \varepsilon \omega \left[\frac{1}{R} - 1 \right] + T_0 C_{\max} \ln [1 - \varepsilon \omega (1 - R)] \tag{19}$$

$$\zeta_f = C_{\max} T_1 \varepsilon \omega \left[\frac{1}{R} - 1 \right] + T_0 C_{\max} \ln [1 - \omega \varepsilon (1 - R)] + \gamma T_o C_{\min} NTU \tag{20}$$

where T_1 is the inlet temperature of the cold stream. The value of γ is released by γ_I to take into account all the irreversibilites associated with the manufacturing process at the current state of technology. The exergetic efficiencies with and without the material irreversibility rate ψ and ψ', respectively can now be written as:

$$\psi = \omega \left[\frac{(\frac{T_1}{T_0}) \varepsilon (R^{-1} - 1) - \ln [1 + \varepsilon (R^{-1} - 1)]}{\left(\frac{T_1}{T_0} \right) \omega \varepsilon (R^{-1} - 1) + \ln [1 - \omega \varepsilon (1 - R))] + \gamma \omega NTU} \right] \tag{21}$$

$$\psi' = \omega \left[\frac{(\frac{T_1}{T_0}) \varepsilon (R^{-1} - 1) - \ln [1 + \varepsilon (R^{-1} - 1)]}{\left(\frac{T_1}{T_0} \right) \omega \varepsilon (R^{-1} - 1) + \ln [1 - \omega \varepsilon (1 - R))]} \right] \tag{22}$$

The equations developed above for the exegetic efficiency are now applied to both counter flow and parallel flow heat exchangers. The effectiveness equations can be taken from Donald(2000) as follows:

$$\varepsilon_{pf} = \frac{1 - \exp[- NTU (1 + \omega)]}{1 + \omega} \tag{22a}$$

$$\varepsilon_{cf} = \frac{1 - \exp[- NTU (1 - \omega)]}{1 - \omega \exp[- NTU (1 - \omega)]} \tag{22b}$$

The variation of exergetic efficiencies ψ and ψ' with effectiveness for counter flow and parallel flow heat exchangers with the same γ(γ=0.01), are shown in Figure 2. This figure is for abalanced capacity rate with the cold stream inlet temperature equal to the dead state temperature. The exergetic efficiency ψ is always less than ψ'. At the infinite heat exchanger limit ($\varepsilon = 0.5$ for parallel flow heat exchanger $\varepsilon = 1$ for the counter flow heat exchanger) ψ tends to zero while ψ' is a miaximum. The exergetic efficiency ψ_{pf} for parallel flow heat exchanger at a given ε is always lower than ψ_{cf} for a counter flow heat exchanger and this difference can be clearly seen at values of the effectiveness close to 0.5. The exergetic efficiencies ψ' for the parallel and counter flow heat exchangers are the same. However, for a given duty (a given effectiveness in Figure 2) a counter flow heat exchanger is known to be more attractive than a parallel flow unit because of the reduced area, this is properly shown in the exegetic efficiency if the material irreversibility is included in Figure 2. The irreversibility

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rate in building and operation an infinite area heat exchanger make the exegetic efficiency in the larger heat exchanger area limit tend to zero when the application life is finite. Hence; including the material irreversibility result in physically realistic value for the exegetic efficiency

The parameter γ is inversely proportional to the application life of the heat exchanger τ when the application life approaches zero, γ tends to infinity and the exergetic efficiency ψ is equal to zero in the limit. However, if the heat exchanger has infinite application life then γ is equal zero and the exergtic efficiency ψ equal to ψ'. The variation of the exergitic efficiency ψ with effectiveness for a balanced counter flow heat exchanger is shown in Figure 3, for different value of γ. This figure is for a heat exchanger inlet temperature ratio of 2/3 and the cold stream inlet temperature equal to the dead state temperature.

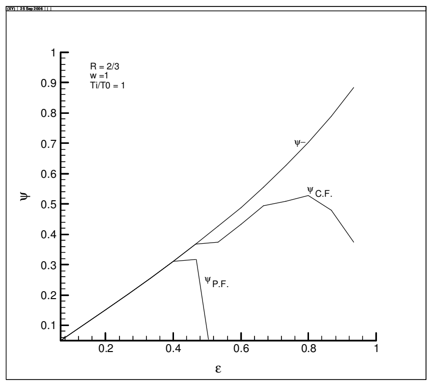

Figure 2. Exergetic efficiency for counter flow heat exchanger with ψ and ψ', the effective material irreversibility for R=2/3, ω =1, T_i / T_0 = 1 and γ= 0.01.

Figure 3 show that ψ_{cf} increases with decreasing γ (increasing application life τ), for a given value of ε, and has a maximum for the value of γ. The dotted line on Figure 3 shows the locus of the maximum exergetic efficiency ψ^*, with the arrow indicating the direction of increasing application life τ. When the heat exchanger is reversible ($\psi = 1$) then $\gamma = 0$, and $\varepsilon = 1$. This shows that an infinite area balanced counter flow heat exchanger with an infinite application life is reversible. Hence, including the material irrevesibility term result in adding a time constraint in the reversible heat exchanger limit.

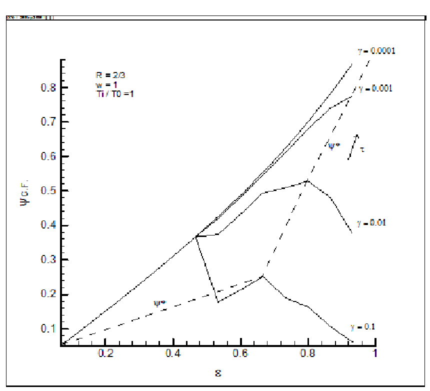

Figure 3. Exergetic efficiency of a counter flow heat exchanger as a function of ε For different values of the material exergy parameter.

Thermoeconomic Analysis

In thermoeconmics, the objective function becomes the total cost of operation. This includes capital costs and irreversibility penalty costs. Assuming that the capital costs are proportional to the area, the objective function becomes:

$$C_T = C_A + C_{\Delta T}\,\dot{I}_{\Delta T} + C_{\Delta p}\,\dot{I}_{\Delta p} \tag{23}$$

The objective function can be nondimensionlized as follows:

$$Nc = \frac{C_T}{C_{\Delta T} T_o C_{\max} \tau} \tag{24}$$

Under the assumptions of ideal gas behaviour and negligible pressure drop irreversibility, the objective function becomes:

$$Nc = \omega \ln\left[1 + \frac{\varepsilon}{R}(1-R)\right] + \ln\left[1 + \omega\varepsilon(R-1)\right] + \gamma_c \omega NTU \tag{25}$$

Where

$$\gamma_c = \frac{C_A}{C_{\Delta T} T_o U \tau} \tag{26}$$

Note that the thermoeconomic objective function given by equation (25) has the same functional form as the two previously derived irreversibility rate based objective functions given by equation (9) and(12). The only difference is that the value of γ_c has to be used instead of γ or γ_I. This property simplifies the optimization procedure since Figure 1 can be used to obtain the optimum NTU, when the heat exchanger begin optimized is a counter flow unit. The optimum NUT obtained from thermoeconomic analysis is designated NTU_c^*. The next section show the relationship of NTU^*, NTU_I^*, and NTU_c^* for a specific case.

Specific Application

The evaluation of the optimum value of NTU for a counter flow heat exchanger based on minimum irreversibility or minimum cost of irreversibility is illustrated by the following specific case. This section also includes discussion on the significance of the results.

We need to determine NTU^*, NTU_I^*, and NTU_c^* for a counter flow heat exchanger for values of the application life τ of 5 and 10 years, and for U =40 and 70 $W/m^2.K$. The capacity rate ratio and the inlet temperature ratio are ω =0.7 and R =2/3, respectively. The heat exchanger is shell and tubes are made of carbon steel, and some data for the steel tubes are given in Table 1.

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Table 1. Data for Carbon Steel Tubes

ρ	$7770\ kg/m^3$
δ	$3.2\times10^{-3}\ m$
$\zeta_{m,ch}$	$6764 kJ/kg$
σ_y	$2.896\times10^{8}\ Pa$
E	$2.068\times10^{11}\ Pa$

The cost of heat exchanger area is approximately 72 $\$/m^2$ (from Matley, 1983), an estimate for the gross energy requirement to produce steel tubes is $35.7\times10^3\ J/kg$ (from Chapman and Roberts, 1985), and the cost for heat transfer irreversibility is $0.056\$/kW.hr$. The temperatures $T_o = 298K$ and $T_1 = 298K$. The procedure of solution as follows:

1- thermomechanical exergy of the material can be calculated form equation (5d) as

$$\zeta_{m,ph} = \frac{\delta\sigma_y^2 A}{2E} = 649\ A$$

2- the chemical exergy of the heat exchanger material is

$$\zeta_{m,ch} = \rho\delta A \times chemical\ exergy = (7770)3.2\times10^{-3} A\times$$
$$6764\times10^3 = 1.6818\ A$$

The thermomechanical exergy of the material is much smaller than the chemical exergy, then the total material exegy is $\zeta_{m,ch}$.

3- the effectiveness of the manufacturing process for carbon steel tubes can be calculated as :

$$\psi_m = \frac{chemical\ exergy}{gross\ exergy} = \frac{6764}{3.5\times10^3} = 0.19$$

4- the cost of heat transfer irreversibility is

$$C_{\Delta T} = \frac{0.056}{3600\times1000} = 1.556\times10^{-8}\ \$/J$$

5- the values of γ ,γ_I, and γ_c can now be calculated by using equations (7) ,(13) ,and (27), respectively, as

$$\gamma = \frac{\dot{I}_A}{T_o U} = \frac{\zeta/\tau A}{T_o U} = \frac{1.6818\times10^8}{298U\tau}$$
$$= \frac{564\times10^3}{U\tau(12\times30\times24\times3600}$$

$$\gamma_I = \frac{\gamma}{\psi} = \frac{\gamma}{0.19} = \frac{2970\times10^3}{U\tau}$$

$$\gamma_c = \frac{C_A}{C_{\Delta T} T_o U \tau} = \frac{72}{1.556 \times 10^{-8} (298) U \tau}$$

RESULTS AND DISCUSSION

The results are summarized in Table 2. The NTU^* values can be obtained from Figure 1 or by solving the objective functions as shown in Figure 3. The results are summarized in Table 3.

Table 2.Values of γ, γ_I, and γ_c for heat exchanger

τ (years) / $U\ (W/m^2K)$	5			10		
	$\gamma \times 10^5$	$\gamma_I \times 10^4$	$\gamma_c \times 10^3$	$\gamma \times 10^5$	$\gamma_I \times 10^4$	$\gamma_c \times 10^3$
40	8.942	4.709	2.462	4.471	2.355	1.231
70	5.1098	2.6908	1.407	2.555	1.345	0.7035

The variation of Ns with NTU for the three objective functions considered, when the overall heat transfer coefficient is 40 W/m^2K and the application life is 5 years, is shown in Figure 4. The magnitudes of the optimum NTU are in the order $NTU^* > NTU_I^* > NTU_c^*$. The value of NTU^* and the corresponding irreversibilites are constant, independent of time and location. The irreversibility corresponding to this optimum is the absolute minimum and corresponds to the case when all the manufacturing processes of the heat exchanger are ideal. As discussed previously, NTU_c^* is a time and location dependent due to the costs C_A and $C_{\Delta T}$. The value of NTU_I^* is weaker function of time and location than NTU_c^*.

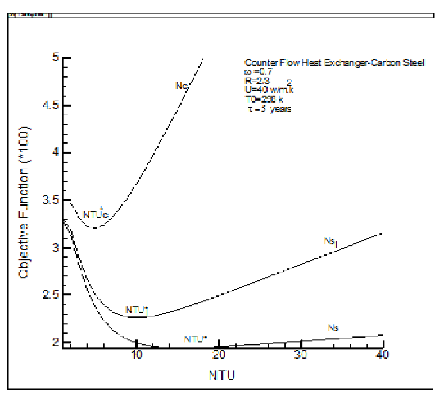

Figure 4. Values of NTU with minimum irreversibility generation (Ns), minimum irreversibility generation at present state of technology (Ns_I) and minimum thermoeconomic cost (Nc).

This is because NTU_I^* is a function of the exergetic efficiencies of the heat exchanger manufacturing processes which only varies with an improvement in the technology and is relatively insensitive to political environment, location, etc. In a world of diminishing fuel resources, we can expect we can

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expect NTU^*_c to move toward NTU^*_I. However, the cost of material might increase with increasing fuel cost. The collection and analysis of heat exchanger data over a period of time should be undertaken to establish this relationship . This would allow the heat exchanger design engineers to decide on the best possible NTU^* value for the heat exchanger for the most efficient operation during its application during its application life period.

Table 3. Values of NTU^* for heat exchanger

$U\ (W/m^2K)$ \ τ (years)	5			10		
40	NTU^*	NTU^*_I	NTU^*_c	NTU^*	NTU^*_I	NTU^*_c
	15.5	10	5	18	12	7
70	17.5	12	6.5	19.5	14	8.5

CONCLUSIONS

(1) The method presented in this research, which adds an irreversibility term due to the material of construction of the heat exchanger in the overall irreversibility minimization of the heat exchanger in the overall irreversibility minimization equation for heat exchanger optimization to be conducted. The resulting optimum designs provide conceptually beneficial guideposts that do not change with time or location. Such optima are in contrast to the optima obtained by presently advocated methods which on one the other hand indicate unrealistic infinite area heat exchangers and on the other hand point to optima that may change dramatically with location and time.

(2) The optima obtained by the method indicated here are conceptually similar to the economic optimization , and ,in fact the same nondimensionalized curves may be used , in some instance for both optimizations .The optima obtained from the basic method delineated here specify heat exchanger areas that are significantly larger than those corresponding to an economic optimization and their use is upper limits. With modifications to represent the current state of technology the method delineates optima that are substantially closer to those specified by current thermoeconomoic optimizations.

(3) Exergetic efficiency expressions that similarly include an irrevesiblity term due to the material of constructions of the heat exchanger show physically more realistic values than the usual expressions that do not include such a term. Such exergetic efficiencies clearly show the thermodynamic advantage of counter flow as compared to parallel flow arrangements, and they showed a value of zero for all infinite application lives. This is in constant to same other usual exergetic expressions that show counter flow and parallel flow units having equal efficiencies and that can yield values of 100 percent for infinite area heat exchangers.

Nomenclature

A: Area , m^2

C: Cost, $\$$

$C_{\min}, C_{\max}$: Capacity rate, $J/kg.s$

E: Elasticity modulus, Pa

l: length, m

Nc : Economic objective function to be minimized

Ns : Irreversibility generation number

NTU : Number of transfer units

p : Width of the plate, m

T : Temperature, K

U : Overall heat transfer coefficient, $W/m^2.K$

R : Inlet temperature ratio

ζ : Exergy, J

$\dot{I}$: Irreversibility rate, W

τ : Application life, s

γ : Material exergy parameter, $\dfrac{\dot{I}_m}{AT_oU}$

ε : Heat exchanger effectiveness

σ_y : Yield stress, Pa

ψ : Exergetic efficiency

ω : Capacity rate ratio, $C_{\min}/C_{\max}$

δ : Thickness, m

Subscripts

o : Dead state

1 : Cold stream

2 : Hot stream

c : Thermoeconomic value

cf : counterflow

ch : Chemical

e : Exit

f : Fuel

I : Value at current state of technology

m : Material

p : Product

ph : Thermophysical

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ΔT : Heat transfer

y : Yield point

Superscripts

*: Optimum value

': Conventional values not including material exergy

REFERENCES

Bejan, A. (1977). The Concept of Irreversibility in Heat Exchanger Design: Counter Flow Heat Exchangers for Gas-Gas Applications, *Asme Journal of Heat Transfer*, Vol. 99, pp. 374-380.

Bejan, A. (1980). Second Law Analysis in Heat Transfer, *Energy,* Vol. 5, pp. 721-732.

Bejan, A. (1987). Thermodynamics of Transfer Devices, Second Law Analysis of Thermal Systems," Proc. IVth Intel. Symp. On 2nd Law Analysis of Thermal Systems, Moran, M.J. and Sciubba, E. eds., ASME, New York, pp. 1-15.

Boyed, J.M., Bluemel, V., Keil, T.H., Kuncinkas, G.R. and Molinari, S. (1981). The Second Law of Thermodynamics as a Criterion for Heat Exchanger Design, *Energy* Vol. 6, pp. 603-609.

Chapman, P.F. and Roberts, F. (1985). *Metal Resources and Energy,* London: Butterworth,

Donald, R.P. (2000). *Theory and Problems of Heat Transfer,* New York: McGraw-Hill.

Evans, R.B., Kadaba, P.V. and Hendrix, W.A. (1983). *Exergetic Functional Analysis for Process Design and Synthesis,* Efficiency and costing , ACS Symposium Series, pp. 239-261.

Kays, W.M. and London, A.L. (1984). *Compact Heat Exchangers,* New York: McGraw-Hill.

Kotas, T.J. (1985). *The Energy Method of Thermal Plant Analysis,* London: Butterworths.

London, A.L. and Shah, S.R.K. (1983). *Costs of Irreversibilities in Heat Exchanger Design,* Heat Transfer Engineering, Vol. 4, No. 2, pp. 59-73.

Matly, J. (1984). *Modern Cost Engineering: Methods and Data,* Vol. II, New York: McGraw-Hill.

Moran, M.J. (1982). *Availability Analysis: A Guide to Efficient Energy Use,* New York: Prentice-Hall.

Tribus, M. and Evans, R. (1962). *Thermoeconomics,* UCLA Report N. 62-63.

Tsatsaronis, G., and Winhold, M. 1985, "Exergoeconomics Analysis and Evaluation of Energy Conversion Plant. A New General Methodology," Energy Vol. 10, pp. 69-80.

Witte, L.C. and Shamsundar, N. (1983). A Thermodynamic Efficiency Concept for Heat Exchange Devices, *Asme Journal Of Enginering For Power*, Vol. 105, pp. 199-203.