Heat Exchanger Exergetic Lifecycle Cost Optimization using Evolutionary Algorithms

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Abstract: Considering lifecycle cost analysis during the design phase of thermal systems gives the design effort more worth. Furthermore thermodynamic exergetic optimization is a proven useful method for determining the most lifecycle cost optimal design of thermal systems for given thermodynamic constraints. The most thermodynamic efficient heat exchanger design basing on first law analysis may not be the better method for economic lifecycle cost estimation of a heat exchanger. Nevertheless, including the second law (exergetic) analysis in the lifecycle cost optimization technique will definitely result in a thermodynamic efficient and heat exchanger design. In this study lifecycle cost optimization procedure for shell and tube heat exchanger has developed. The total cost includes capital and operating costs, which are the components of objective function. The study searches for the optimum cost if they exist, by doing the optimum first the parametric study based on both sizing and rating problems. The study also searches for the optimum (minimum cost) using the evolutionary method of optimization, and results are confirmed using genetic optimization method, direct search method and simplex method. Evolutionary Optimization has recently experienced a remarkable growth. New concepts, methods and applications are being continually proposed and exploited to provide efficient tools for solving a variety of optimization problems**.** These techniques include Genetic Algorithms, Genetic Programming, Evolutionary Programming and Evolution Strategies among others, all of which have inspired by restricted models of natural evolution. Cost of the heat exchanger has been optimized basing on different constraints, like length, shell diameter, tube pitch etc.

Key-Words: heat exchanger, operating cost, optimization, entropy generation, exergy destruction, thermodynamics, evolutionary method,

Nomenclature:

$\dot{m}_H$ Hot fluid mass flow rate (shell side)

$\dot{m}_C$ Cold fluid mass flow rate (tube side)

v_C Specific volume of cold fluid (Tube side)

v_H Specific volume of hot fluid (shell side)

$\Delta\dot{E}_{H,T}$ Rate of exergy change due to temperature of the hot fluid

$\Delta\dot{E}_{H,P}$ Rate of exergy change due to pressure drop of the hot fluid

$\Delta\dot{E}_H$ Total rate of exergy change of hot fluid

T_{Hout} Hot fluid outlet temperature

T_{Hin} Hot fluid inlet temperature

T_{Cin} Cold fluid inlet temperature

T_{Cout} Cold fluid outlet temperature

ΔP_H Hot fluid pressure drop (shell side)

ΔP_C Cold fluid pressure drop (Tube side)

exf_2 Exergy flow outside (Hot fluid)

exf_1 Exergy flow inside (Hot fluid)

exf_4 Exergy flow outside (cold fluid)

exf_3 Exergy flow inside (cold fluid)

C_{pH} Specific heat of hot fluid

C_{pC} Specific heat of cold fluid

T_o Environmental temperature

$\Delta\dot{E}_C$ Total rate of exergy change of cold fluid

$\dot{E}x_D$ Exergy destruction rate

$\dot{E}x_{q,j}$ Exergy due to heat source
$\dot{E}x_e$ Outlet exergy
$\dot{E}x_i$ Inlet exergy
$\dot{W}_{cv}$ Exergy due to work
ex_i Exergy at inlet
ex_e Exergy at exit
n_{tp} Number of tubes in one pass
L Length of heat exchanger
Np Number of passes
Ct Tube cost per meter
Ds Shell diameter
P_{pt} Tube side pumping power
P_{ps} Shell side pumping power
P_p Total pumping power
C_E Cost of electricity per kWh
C_{py} Pumping cost per year
C_{dy} Exergy destruction cost per year
N Heat exchanger life (years)
I Inflation rate
P_T Pitch
C Clearance between adjacent tubes
B Baffle spacing
C_t Cost of tube per meter
n Manufacturing cost factor
C_{HD} Cost of each header
C_{NZ} Cost of each nozzle
C_b Cost of each baffle

1. Introduction

The most thermodynamically efficient design of thermal system might not be the design of choice, because it may be too expensive to build and not cost effective to make a profit. In the exergo-economic optimization procedure it is desirable to minimize the available energy loss per unit capacity which means to minimize the per unit total cost to maximize the profit.

In this study, a two-pass shell and tube heat exchanger has optimized economically considering first and second laws of thermodynamics. The study searches for the optimums by conducting different parametric study based on both sizing and the rating problem. Cost of the heat exchanger has optimized basing on different practical given constraints like length, shell diameter, cold fluid flow velocity, etc.

Previous studies have looked at the optimization of thermal systems and components based on thermo-economics (thermodynamic analysis as well as an economic analysis). It has been concluded in all cases that optimization of lifecycle cost is extremely important in designing thermal systems [1, 2, 3, 4 and 5].

Tozer et al. [6] discusses economically optimizing the HVAC system for an absorption-cogeneration variable-air-volume system. Their objective function was annual life-cycle costs per unit cooling capacity, which has minimized.

Summerer [7] suggests a method for estimating absorption system costs for the optimum design. He based the total cost of the system on the heat exchangers' cost as a first estimate and maximized the coefficient of performance (COP). He fixed the amount of heat exchanger surface area and varied the distribution of area, and finally he selects the system, which had the largest COP.

Tsatsaronis et al. [8] analyzed a power plant from an exergoecnomic basis. The evaluation was able to identify several changes to improve cost effectiveness. They investigated the power plant strictly from an exergy viewpoint as well as the cost viewpoint, which included the cost of exergy flows and destruction. They included initial and running cost as well.

Zalewski et al. [9] solved two thermo-economic objectives for designing an evaporative fluid cooler. The first objective was to design a cooler that maximizes heat transfer duty at minimal total costs (capital and running costs). The second objective was to design a cooler that minimizes operating costs.

Fowler and Bejan [10] determined the optimum Reynolds number for external flows over several simple geometries. They used entropy generation as a minimization method to determine the optimal solution. It has first shown that the optimal Reynolds number scaled with the size of the device, but with ever-increasing entropy generation. They showed that the size of the device should increase to minimize losses, but the tradeoff for larger size is the cost. The tradeoff of cost was the cost of entropy generation or exergy destruction by heat transfer dissipation and the cost of size.

In the present study lifecycle, cost analysis for specified shell and tube heat exchanger has conducted. The analysis aims to minimize the total cost (capital and operational cost) basing on the implementation of the second law of thermodynamics. Methods used for optimization are evolutionary method, genetic optimization method, direct search method and simplex method to verify the result one method with the other.

2. Thermodynamic Model

In addition to the optimizing algorithm, heat exchanger lifecycle optimizing model includes a comprehensive thermal and hydraulic design procedure. The design procedure bases on both sizing and rating technique. [11] [13] [15].

2.1 Exergetic Analysis

Combining exergy concepts with principles of engineering economy in optimizing the design of thermal systems gives the known thermoeconomic analysis, which allows the real cost sources at the component level.
Exergy loss or the available energy destruction presents the most important item for the exergetic analysis of thermal systems. This type of loss in the available energy caused due to process irreversibility imposed by the flow characteristics and process boundary conditions.

2.1.1 Exergy change for the hot fluid

The exergy change for any fluid flowing through thermal system exerting temperature and pressure changes comprises of two components, exergy change because of change in temperature and that due to change in pressure [12]. Equations-1 and 2 give the rate of exergy change for the hot fluid because of changes in temperature and pressure respectively as it flows through the heat exchanger. The total rate of exergy change for the hot fluid has given by equation-3

$$\Delta \dot{E}_{H,T} = \dot{m}[C_{PH}(T_{Hout} - T_{Hin}) - T_o C_{PH} \ln(\frac{T_{Hout}}{T_{Hin}}) \quad (1)$$

$$\Delta \dot{E}_{H,P} = \dot{m}_H \, v_H \Delta P_H \quad (2)$$

$$\Delta \dot{E}_H = \dot{m}_H(exf_2 - exf_1) = \dot{m}_C[C_{PH}(T_{Hout} - T_{Hin}) + v_H \Delta P_H - T_o C_{PH} \ln(\frac{T_{Hout}}{T_{Hin}})] \quad (3)$$

Similar to the hot fluid, the exergy change for the cold fluid has calculated using the change in cold fluid temperature and pressure, as it flows through the heat exchanger.

$$\Delta \dot{E}_C = \dot{m}_C(exf_3 - exf_4) = \dot{m}_C[C_{PC}(T_{Cout} - T_{Cin}) + v_C \Delta P_C - T_o C_{PC} \ln(\frac{T_{Cout}}{T_{Cin}})] \quad (4)$$

2.1.2 Control volume Exergy Balance:

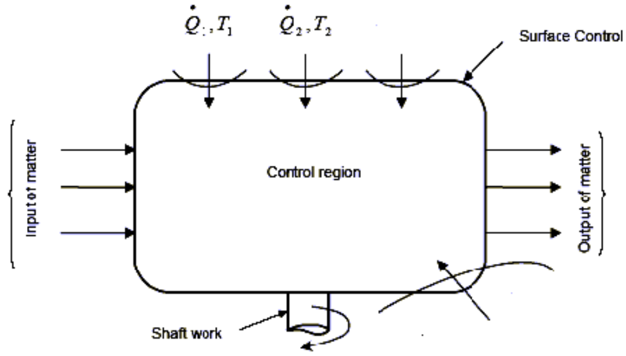

Fig.1 Steady state process in a control region

At steady state, the exergy balance for the control volume within a thermal system as shown in figure-1 per unit time takes the form

$$0 = \sum_j \dot{Ex}_{q,j} - \sum \dot{W}_{cv} + \sum_i \dot{Ex}_i - \sum_e \dot{Ex}_e - \dot{Ex}_D \quad (5)$$

Where the first term refers to the exergy transfer due to the heat exchange, the second term refers to the work exchange, third and fourth terms refer to the exergy exchange with the incoming and outgoing fluid streams respectively and the last term refers to the exergy destruction due to the process irreversibility. Explicitly equation-5 has reformulated as following;

$$0=\sum_j (1-\frac{T_o}{T_j})\dot{Q}_j - \dot{W}_{cv} + \sum_i \dot{m}_i\, ex_i - \sum_e \dot{m}_e\, ex_e - \dot{Ex}_D \quad (6)$$

In case of shell and tube heat exchanger

$$Q_j = \dot{W}_{cv} = 0 \quad (7)$$

Hence the final equation for the exergy balance for the heat exchanger is

$$0 = \sum_i \dot{m}_i\, ex_i - \sum_e \dot{m}_e\, ex_e - \dot{Ex}_D \quad (8)$$

2.2 Lifecycle Cost of Heat Exchanger

Heat exchanger lifecycle cost has divided into two parts, capital cost and the operating cost. The capital cost is the sum of material cost and the construction or manufacturing cost. Operating cost include pumping cost and exergy destruction cost.

Once the total operating cost of the heat exchanger for the entire heat exchanger life has formulated, the present cost estimation due to inflation rate has included.

2.2.1. Capital Cost

Material cost includes mainly tube, baffle, nozzle and shell material cost.

Capital cost = Material cost + Manufacturing cost (9)

Tube Cost = N_{tp}*L*n_p*C_t (10)

Baffle Cost = N_b * C_b (11)

Headers Cost = N_{HD} * C_{HD} (12)

Nozzles Cost = N_{NZ} * C_{NZ} (13)

Where N_{tp} Is the number of tubes in a pass,
L Is the Length of each pass,
N_p Is he number of passes and
C_t Tube cost per meter

Shell cost = ($\pi D_s L$) x (cost/m^2) (14)

Manufacturing cost is the cost incurred in manufacturing the heat exchanger, which is commonly assumed as a certain factor of the material cost, which is usually used in that industry.

Manufacturing cost = n x Material cost (15)

Where, n is the manufacturing factor, which assumed to be given a value from 2 to 3.

2.2.2. Operating Cost

For heat exchanger operating cost, it incorporates pumping cost for hot and cold fluids and the exergy destruction cost due to the irreversibility. Since the energy used for operation is electricity, the operating cost has related to the electricity cost. Equation-13 and 14 present the pumping power and pumping cost for shell and tube heat exchanger.

P_p= P_{pt} + P_{ps} (16)

C_{py} = P_p x Nh x 365 x C_E (17)

Where, P_p, P_{pt}, P_{ps} is the total, tube and shell pumping power,
Nh Number of working hours per day,
C_E is the cost of electricity per kWh and
C_{py} is the pumping cost per year.
Cost associated with the exergy destruction per year has formulated as following

C_{dy} = $\dot{E}_{xd}$ x Nh x 365 x C_E (18)

Where, is $\dot{E}_{xd}$ the exergy destruction rate.
Equation-19 gives the lifecycle operating cost for the heat exchanger incorporating the inflation.

$$\text{Operating}\cdot\text{Cost} = \frac{(C_{dy} + C_{py})((I+1)^N - 1)}{I} \quad (19)$$

Where, I is the inflation rate and
N is the life of heat exchanger in years.

2.3. Optimization Problem Description:

The optimization procedure intends to find out the minimum value for the total lifecycle cost of the heat exchanger, which presents the objective function subjected to the following constrains.

a. Specified values for hot fluid inlet and outlet temperatures,
b. Specified value for hot fluid mass flow rate,
c. Specified value for cold fluid inlet temperature,

The optimization has carried out using the recommended limiting values of the different design parameters (tube diameter, hot fluid velocity, cold fluid velocity, cold fluid mass flow rate, tube arrangements, tube pitch and heat exchanger length.)

Optimization has carried by using the evolutionary technique by using MATLAB® and the results have verified by other methods like direct search, genetic optimization and simplex method using EES® professional version.

2.4. Evolutionary Optimization

Evolutionary optimization procedures derive inspiration from the Darwinian Theory of evolution. The principle idea as opposed to classical optimization methods is that, instead of using the analytical model of a function *f(x)* and the corresponding gradients for guiding the search along suitable directions a stochastic procedure is used. This procedure has initiated by randomly generating a set of possible solutions. Each solution has referred to as an individual and the set itself has referred to as the population. For reasonable performance of the optimization procedure, it is necessary that these individuals be scattered through the entire solution space. Once initialized, these individuals are evaluated using the function *f(x)*.The value thus returned from the function is referred to as the fitness value of the individual. After evaluation, the individuals with the lowest fitness values have selected to form the next generation of individuals and the remaining have discarded. This process has then repeated until a stopping criterion has achieved. This could be either a fixed number of generations or a minimum value of the fitness function.

The evolutionary optimization method of choice for this investigation is Evolutionary Strategies. Figure-2 shows the flow chart of this method. The first step is to generate a random population of individuals each representing a potential solution. These individuals have also referred to as the parent individuals, and their number has denoted by μ. In the recombination step, λ pairs of these parent individuals have chosen and their values have recombined to produce λ offspring individuals. Recombination has given, either by taking average values or by exchanging randomly chosen components of the parent pair [16]. Once generated, Gaussian noise has added to the solutions represented by these offspring individuals in the *mutation* step. This step is necessary to allow stochastic exploration of the design space. The degree of noise has added is a subject of significant interest in Evolutionary Strategies literature [16].

After the mutation step is completed the fitness of each offspring individual is evaluated using the function *f(x)* and the μ best individuals are chosen as parent individuals for the next generation. This process has repeated until the predefined stopping criterion has attained.

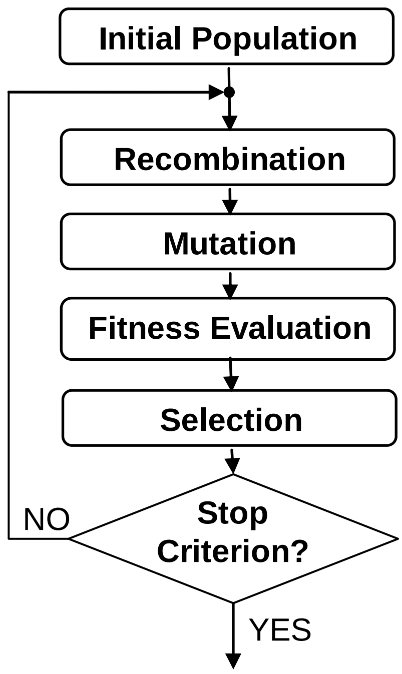

Fig.2. Evolutionary Strategies flow chart

3. Results and Discussion

A computer simulation program has been developed in MATLAB® to do the optimization using evolutionary technique shown in Fig.(2).

Another program has made in EES® (Engineering Equation Solver) professional version to design a heat exchanger and minimize its lifecycle cost considering thermo-economic analysis, using direct search method, genetic optimization method and simplex method optimization method, to verify the evolutionary optimization method results. The program made in EES® has also used to do the parametric study.
As a case study it is decided to design a shell-and-tube heat exchanger for cooling engine oil and then to investigate the effect of the different design and operating parameters on its lifecycle cost. Moreover, the simulation model designed to determine the lifecycle cost of economic and the most efficient heat exchanger design.

Analysis has been performed for heat exchanger under different, tube arrangement, design and operating parameters, tube diameters ranging from (15.88mm, 19.05mm, 25.4mm), and cold fluid velocity ranges from 0.6 m/s to 1.5 m/s. Tube and shell-side velocity ranges are according to TEMA standards, to avoid sedimentation at low velocity and flow induced vibrations at higher velocity. These velocities are also one of the constraints.

For different tubes arrangements like (triangular, square and square rotated at 45°) and varying the cold fluid mass flow rate it has found that there is no significant variation in total cost. It is evident from figure-2 that the tube arrangement has a negligible influence on the heat exchanger lifecycle cost.

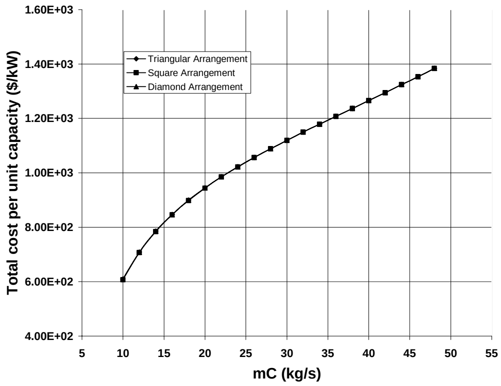

Fig.3. Cold fluid mass flow rate and tube arrangements effect on total cost

The effect of the cold fluid mass flow rate on the capital,

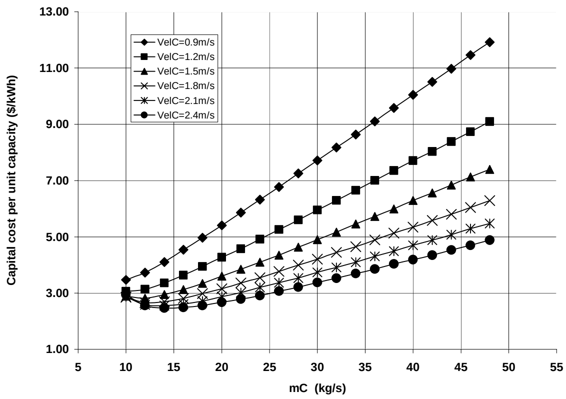

Fig.4. Effect of mass flow rate and cold fluid velocity on capital cost.

It is evident from figure-4 that the capital cost increases by increasing the mass flow rate and decreasing the velocity of the cold fluid. This could be the reasoned to increased number of tubes and larger shell size for both options by either increasing cold fluid mass flow rate with the same velocity or reducing its velocity for the same flow rate.

It is clear from figure-5 that the capital cost reduces by using larger tubes and increasing the cold fluid velocity. This result is due to the less number of tubes required in both cases to achieve the same capacity.

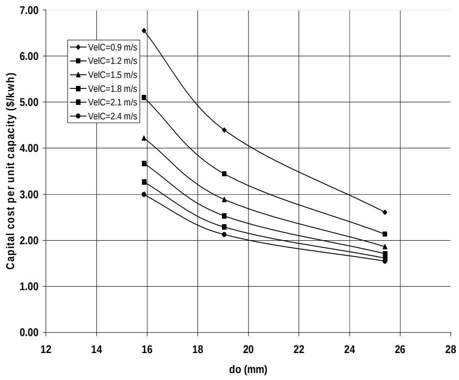

Fig.5. Effect of tube diameter and cold fluid velocity on capital cost

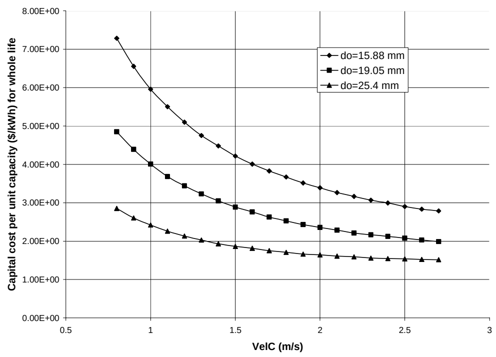

Fig.6. Effect of tube diameter and cold fluid velocity on capital cost

Figure-6 shows the effect of both tube diameter and velocity of the cold fluid on capital cost. It is clear from figure that the capital cost decreases with the increase of cold fluid velocity. Convective heat transfer coefficient increases with the increase in velocity. Capital cost decreases with increasing tube diameter, because less number of tubes required for large tube diameter.

Figure-7 shows the effect of cold fluid mass flow rate at different cold fluid velocities on operating cost. Since, the operating cost composed of pumping and exergy destruction cost. This is because of increase of pumping cost and the increase of the irreversibility due to the increase of the temperature difference between hot and cold fluids, which results in an increase in the exergy destruction cost.

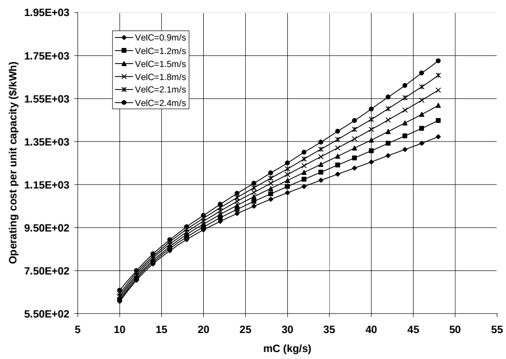

Fig.7. Effect of mass flow rate and cold fluid velocity on the operating cost.

It is evident from figure-8 that the operating cost decreases with increasing the tube diameter and keeping the velocity constant. This is due to the lower pressure drop, which leads to lower pumping cost and decreased irreversibility, which leads to lower exergy destruction cost, and both effects result in lower operating cost.

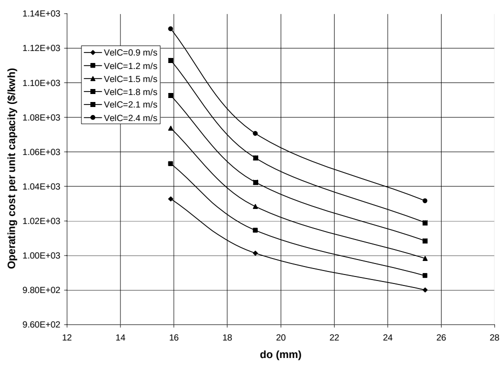

Fig.10. Effect of tube diameter and velocity of the cold fluid on the operating cost.

On the other hand, the same figure-10 shows that the decrease in cold fluid velocity reduces the operating cost. That could be the reason to the lower pressure drop results from applying lower velocity, which gives the same effect as it mentioned in the previous paragraph.

Figure-11 shows the effect of cold fluid velocity at different tube diameter. It is evident from the figure that the operating cost increases with the increase in velocity due to increased pumping cost and higher irreversibility due to pressure drop. Operating cost is higher for the smaller tube diameter because of higher velocity in small tube diameter tubes, which results larger pressure drop and irreversibility.

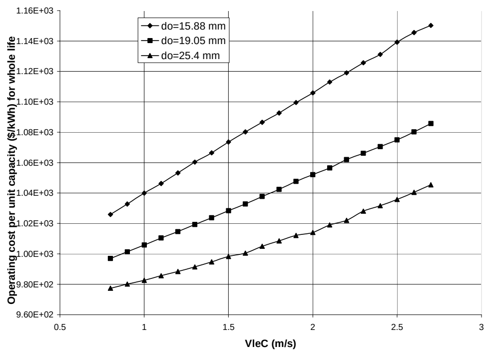

Fig.1

Fig.11. Effect of tube diameter and velocity of cold fluid on the operating cost.

To show the comparison of capital and operating cost magnitude on one graph will give the better comparison of the two components of costs. Figure-12 shows this effect.

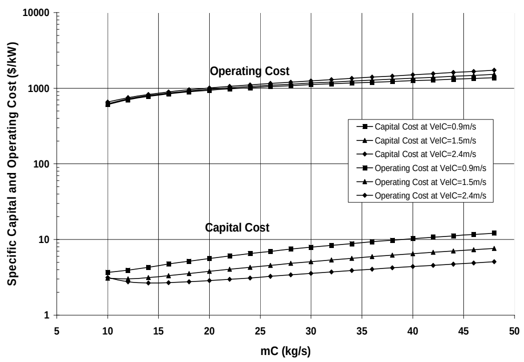

Fig.12. Comparison of capital and operating costs with varying cold fluid mass flow rate and velocity.

It is evident from figure-12 that the capital cost increases by increasing the cold fluid mass flow rate. This could be the reason that to maintain velocity with increasing mass flow rate more tubes and larger shell diameter has needed. It is also evident that at a particular mass flow rate, lower velocity results in a higher capital cost, due to more number of tubes required as well as larger shell diameter.

Upper part of the figure shows the effect of both mass flow rate and velocity of the cold fluid on the operating cost. It is clear from the figure that the operating cost increases with the increase of mass flow rate and the velocity of cold fluid. Since the operating cost consist of pumping and exergy destruction cost, the previous phenomena could explained with the increase of the pumping cost and the increase of the irreversibility due to the increase of the temperature difference between hot and cold fluids which results in an increase in the exergy destruction cost.

Comparison of capital and life cycle operating cost shows a huge difference between capital and life cycle operating cost. It is evident from the figure that capital cost contributed a very small portion of life cycle cost. Hence, operating cost is the dominant factor once we are considering the life cycle cost of heat exchangers.

3.1 Evolutionary Optimization

This section illustrates the application of the mentioned evolutionary optimization method for the determination of optimal values of tube outer diameter, tube pitch and cold fluid mass flow rate for the minimum heat exchanger life cycle cost.

3.1.1 Initialization

The population has initialized by generating individuals randomly such that they lie within specified constraints. Each individual consists of numerical values that represent the tube outer diameter, tube pitch and cold fluid mass flow rate. The number of parent and offspring individuals in each generation has fixed at five and thirty-five respectively. Each simulation run of the evolutionary optimization procedure consist of hundred generations.

3.1.2 Fitness Function

The objective of the optimization procedure is to determine do, mC and Pt such that for given operating conditions heat exchanger life cycle cost is minimized. The fitness function is therefore, defined simply as

f = Life cycle cost

subject to,

$$VelC \in [VelC\min \quad VelC\max]\, m/s$$
$$VelH \in [VelH\min \quad VelH\max]\, m/s$$
$$\dot{m}C \in [\dot{m}C\min \quad \dot{m}C\max]\, kg/s$$
$$do \in [do\min \quad do\max]\, mm$$
$$Pt \in [Pt\min \quad Pt\max]\, mm$$

In this case, the minimum life cycle cost has determined by the given limits of cold fluid velocity, hot fluid velocity, cold fluid mass flow rate, tube outer diameter and tube pitch.

3.1.3 Recombination and Mutation

Once generated the parent individuals have recombined using the intermediate recombination operator and the Gaussian noise has added to the individuals to enable stochastic exploration of the design space. These procedures have utilized to generate thirty- five offspring individuals in each generation.

3.1.4 Fitness Evaluation and Selection

The offspring individuals thus generated has evaluated using the analytical model [13] [14] [15] and best five of these have chosen as parents for the next generation.

For the purpose of this paper, the length of heat exchanger has taken 3.6m; do, VelC, VelH within the constraints as mentioned earlier. The hot fluid inlet temperature is fixed (130°C) and outlet temperature is (115-60°C) varying to get the cost at different capacities. Violation of constraints has avoided by adding penalty terms.

Figure-13 illustrates the convergence of the best fitness values with respect to the generations. It has seen clearly that as the generations pass, the best fitness values of the individuals has minimized. Figure-14, 15 and 16 illustrates the convergence of the individuals (do, mc, Pt) to the optimal value. Each individual has indicated by a cross. As illustrated in the figure, the individuals have scattered through out the entire design space for the first five generations, after which they start to converge and reach the optimal value.

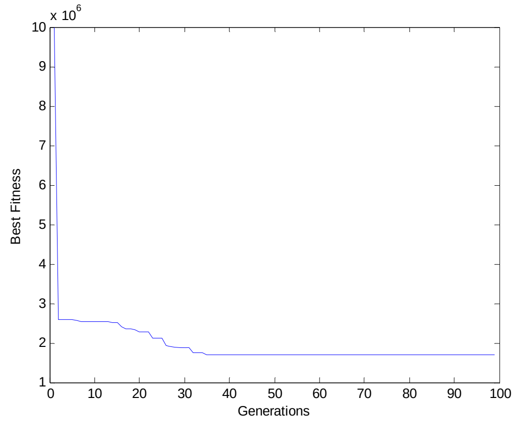

Fig.13. Convergence of fitness with respect to generations.

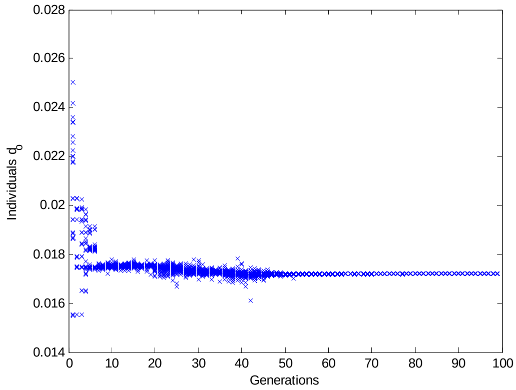

Fig.14. Convergence of populations with respect to generations of do.

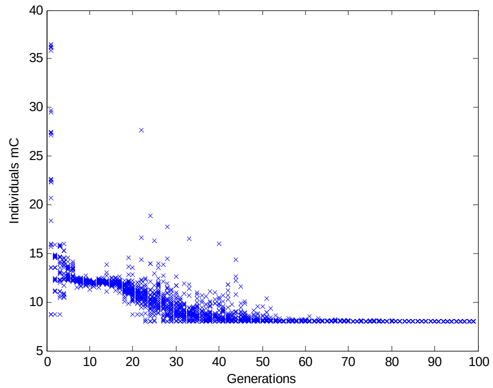

Fig.15. Convergence of populations with respect to generations of mC.

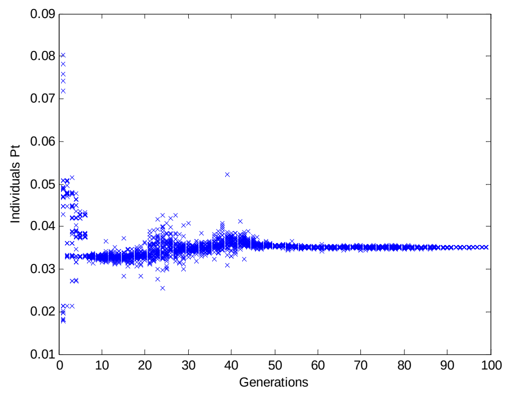

Fig.16. Convergence of populations with respect to generations of Pt.

The optimal values of do, mC and Pt determined using the evolutionary procedure are 25.4 mm, 7.872 kg/s and 39.4 mm respectively. These values are calculated for the Thin=130 °C and THout=90°C. Minimum specific life cycle cost obtained is 443$/kW.

3.2 Comparison of Evolutionary results with other techniques

To verify the results obtained using the evolutionary technique, this problem has also optimized in EES® professional version using direct search, genetic algorithm and simplex method at different heat exchanger capacities. Results obtained using these techniques have similar values. This has shown in figure-17.

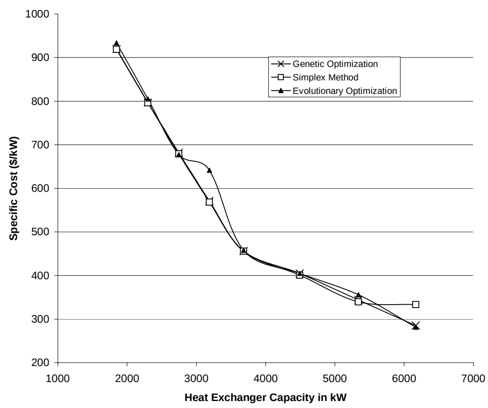

Fig.17. Optimized minimum cost at different Heat exchanger capacities using genetic optimization, simplex method and evolutionary optimization techniques

Figure-17 shows a negative trend in specific cost it is because of that the rate at which capacity increases the capital and operating costs have not increased to the same extent, which is according to the concept of economy of scale.

Figures 18 to 20 showed the trend of specific cost at optimized tube diameter, cold fluid mass flow rate and tube pitch. These figures have plotted at THin=130° and THout=90°C (capacity=3682kW). Figure-19 gives the effect of tube pitch on the lifecycle cost. Total specific cost first decreases to the optimum value of the pitch and then increases, because initially pumping cost is higher compared to exergy destruction cost, but after the minimum point of cost the exergy destruction is higher and pumping cost going to reduce, therefore, total operating cost increases. Figure-18 gives the trend of pitch on cost.

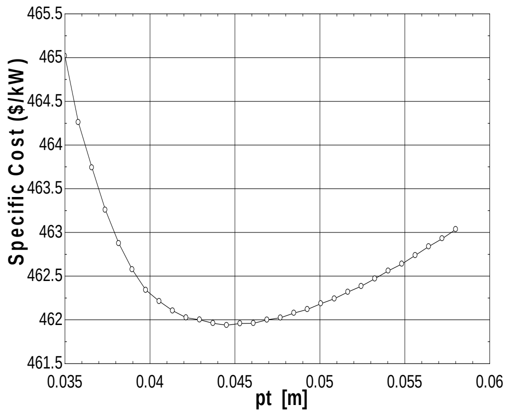

Fig.18. Effect of tube pitch on the total cost

Figure-19 shows that the effect of tube diameter on lifecycle cost. Lifecycle cost first increased sharply then it decreases to its minimum value at do=0.0244 m. It is because of that by increasing the diameter to a certain point (the minimum point) the pressure drop decreases and hence the pumping cost reduces, which is the dominant factor up to that point, but it violates the shell-side velocity constraint (1.5 m/s). After that position, the number of tubes reduces to a point that the exergy destruction cost dominates the pumping cost.

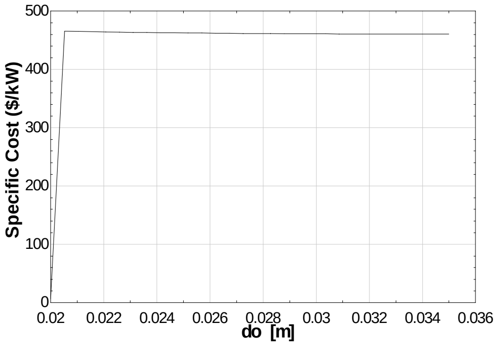

Fig.19. Effect of tube diameter on total specific cost

Figure-20 clearly shows that total specific cost increase as the cold fluid velocity (tube side velocity) increases. This is because of that, both exergy destruction cost and pumping cost and hence the operating cost increases with increasing cold fluid velocity. The vertical shaded line shows the minimum limit of the cold fluid velocity (0.9 m/s).

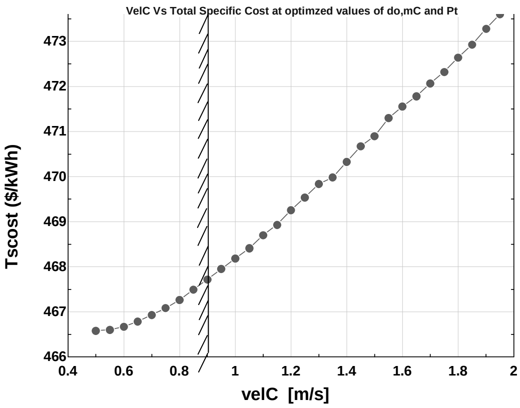

Fig.20. Effect of cold fluid velocity on total cost

Minimum cost obtained at THin=130°C, THout=90°C the different cost component are as follows. Figure-22 shows that the major portion in the life cycle cost of a heat exchanger is operating cost and the capital cost is very small portion of it.

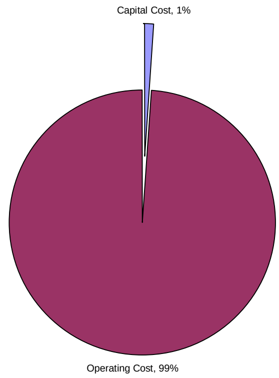

Fig. 21. Comparison of capital and operating cost

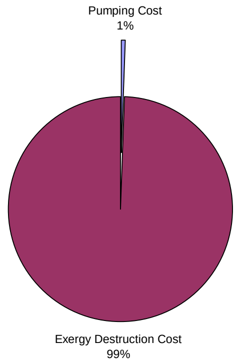

Fig. 22. Comparison of pumping and exergy destruction cost

Figure-22 shows that the exergy destruction cost is the dominant factor among the operating cost components and hence the exergoeconomic optimization is the better way of optimization.

4 Conclusion

From the previous discussion, following conclusions made:

- Shell and tube heat exchanger has optimized using the evolutionary technique and results have matched with genetic and simplex methods.
- Evolutionary method gave the similar results as in case of genetic and in simplex method.
- Operating cost is the dominant cost factor in a shell and tube heat exchanger.
- Within operating cost exergy, destruction cost is a dominant factor.
- Exergetic optimization of a Shell and Tube Heat Exchanger is a better

method for its thermoeconomic optimization.

- The tube arrangement has no significant effect on total cost.
- Second law optimization proved to be a better method to optimize a shell and tube heat exchanger because exergetic destruction cost dominates the operating cost.

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