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Tube Side Optimization of a Compact Heat Exchanger by Genetic Algorithm

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Abstract: The present work is concentrated on optimization of Compact Heat exchangers. For this a louvered fin flat Tube Compact Radiator is considered as case study. Optimization is carried out by means of Genetic Algorithm. The task of optimization may be considered as a design process, in which any possible variables will be evaluated based on requirements. Savings of materials or energy, as well as capital cost and operating cost, are common objectives for industrial applications of heat exchangers. In this work, the GA technique is used in the geometrical optimization of compact heat exchanger in order to obtain optimal results under specified design objectives within the allowable pressure drops. Heat Transfer rate is considered as objective function whereas Tube side parameters are taken for optimization. The outcomes of Genetic algorithm formulation showed 17.77 % increase in Heat Transfer rate that to with decrease in each considered parameter.

Keywords: Compact heat exchanger, Genetic algorithm, Optimization.

I. INTRODUCTION

Compact heat exchangers are characterized by a large heat transfer surface area per unit volume of the exchanger compared to shell-and-tube heat exchangers, resulting in reduced space, weight, support structure and footprint, energy requirements and cost, as well as improved process design and plant layout and processing conditions, together with low fluid inventory. The concept behind compact heat exchanger is to decrease size and increase heat load which is the typical feature of modern heat exchangers. A Compact heat exchanger is defined as a HE which has area density greater than 700 m^2/m^3 for gas and greater than 300 m^2/m^3 when operating in liquid or multiphase streams. Importance of compact heat exchangers has been recognized in many industries. Louvered-fin, Plate fin, Plate frame, Plain tubular, Strip-fin are various types of Compact Heat Exchangers. Compact Heat Exchangers (CHEs), including two types of heat exchangers such as plate–fin types and fin-and-tube (tube–fin) types, are widely used for gas–gas or gas–liquid applications. CHEs are employed in many industrial processes in chemical and petroleum engineering, refrigeration and cryogenics, Heating and Ventilation, Air-Conditioning (HVAC), aeronautics and astronautics, automotive, electric and electronic equipments, etc.

In the field of artificial intelligence, a genetic algorithm is a search heuristic that mimics the process of natural evolution. Principle of Natural Selection is “Select the Best, Discard the Rest”. Thus genetic algorithms implement the optimization strategies by simulating evolution of species through natural selection .Genetic Algorithms are highly applicable when there are multiple optimal solutions. Applications of GA into heat exchanger optimization have suggested that GA has a strong ability of search and combined optimization and can successfully optimize and predict thermal problems. At this point, the GA technique may be used in the geometrical optimization of heat exchangers in order to obtain optimal results under specified design objectives.

Sepehr Sanaye et al.[1] applied Fast and elitist non-dominated sorting genetic-algorithm to obtain the maximum effectiveness and the minimum total annual cost as two objective functions in Thermal-economic multi-objective optimization of plate fin heat exchanger. The optimization Technique which is employed for doing sizing Analysis for obtaining optimized set of parameters is Genetic Algorithm. G. Chaitanya and B. Ravi Sankar [2] aimed at maximizing the overall heat transfer rate of an automobile radiator using Genetic Algorithm approach. The design specifications and empirical data pertaining to a rally car radiator obtained from literature were considered and the mathematical function describing the objective for the problem was formulated using the radiator core design equations and heat transfer relations governing the radiator.

Muhammad Bilal Kadri and Waqar A. Khan [3] used Genetic algorithms to optimize dimensionless temperature in nonlinear heat conduction problems for which three common geometries were selected for the analysis and the concept of minimum entropy generation was used to determine the optimum temperatures. Cihat Arslanturk [4] investigated the heat fin space radiators having fins with temperature -dependent thermal conductivity and the nonlinear fin equation was solved using the Adomian

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decomposition method which provides an infinite series converging very rapidly.
Cihat Arslanturk et al. [5] proposed an approximate analytical model for the optimum design of central heating radiator for which radiator problem has been divided into three one-dimensional fin problems. Patrick V. Hull et al. [6] presented the development of detailed tools for the analysis and design of in-space radiators using evolutionary computation techniques. Ana Paula Curty Cuco et al.[7] applied four different multi-objective techniques to study the conceptual design of a new kind of space radiator called VESPAR. Khaled Hassan Saleh et al. [8] compared results of various optimisation techniques in order to obtain an optimised design of PHE using Genetic algorithm.

II. GENETIC ALGORITHMS

Genetic Algorithms represent an intelligent exploitation of a random search used to solve optimization problems. GA's are the optimization techniques that mimic the process of natural evolution. Principle of Natural Selection is "Select the Best, Discard the Rest". Detailed description of this optimization Technique is given in number of references 17 and 18.

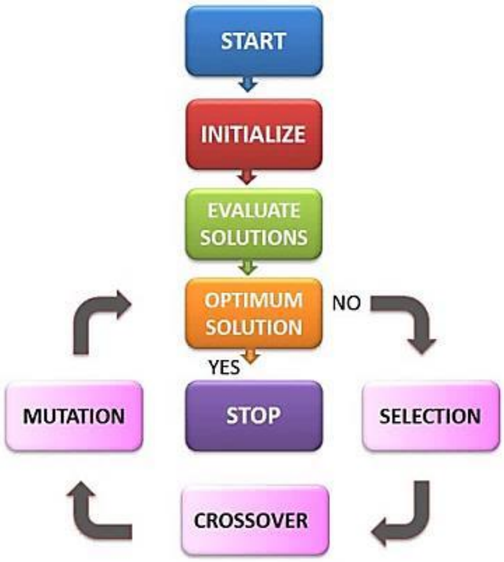

Figure 1: Flow chart of GA

The Optimization through Genetic algorithm is initialized with a set of population. The value of objective function also termed as fitness function in simple genetic algorithm decides its merit (competitiveness) in comparison with its counterparts. A simple GA works with three operators: Selection, crossover and mutation. Following are the important terms in GA:-

Selection: It is a procedure whereby good solutions in a population are identified and bad solutions from the population are eliminated so that multiple copies of good solutions can be placed in the population for mating. Individuals with higher fitness values have a higher probability of being selected for mating and for subsequent genetic production of offspring's.

Encoding: It is the process of representing a member of population in the form of a string that conveys the necessary information. Just as in a chromosome, each gene controls a particular characteristic of the individual; similarly, each bit in the string represents a characteristic of the solution. Most common method of encoding is binary coded. Chromosomes are strings of 1 and 0 and each position in the chromosome represents a particular characteristic of the problem.

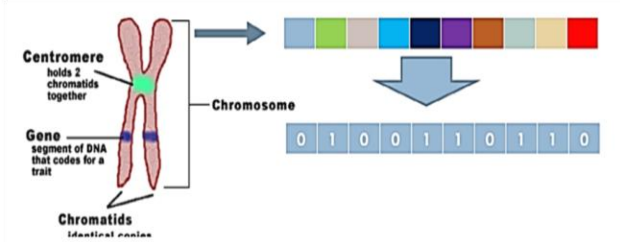

Figure 2: Encoding

Crossover: It is used to create new solutions from the existing solutions available in the mating pool after applying selection operator. This operator exchanges the gene information between the solutions in the mating pool.

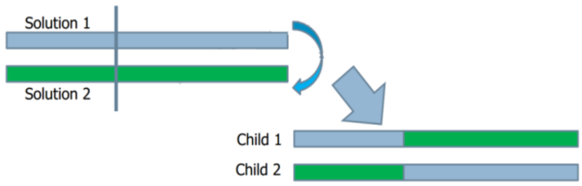

Figure 3: Crossover

Mutation: It is the occasional introduction of new features in to the solution strings of the population pool to maintain diversity in the population.

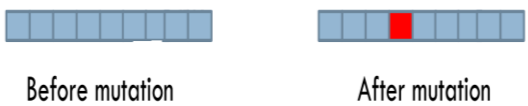

Figure 4: Mutation

Convergence to global optimum solution cannot be guaranteed by Genetic Algorithm, therefore a stoping Criteria is required. The GA can be terminated when there is no improvement in the objective function's value for a defined number of consecutive generations within a prescribed tolerance range, or when it covers a pre-specified maximum number of generations. GA can be formulated as an unconstrained optimization in the simplest form. In the present work GA has been used for constrained maximisation.

III. SELECTION OF HEAT EXCHANGER

For sizing analysis of Compact Heat Exchanger, firstly the type of Compact Heat Exchanger is finalised which is a Louvered fin flat tube type of Compact Radiator shown as follows:

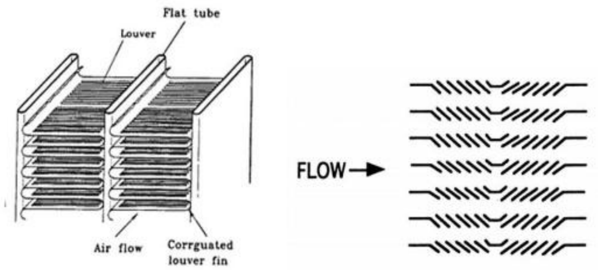

Figure 5: Louvered fin flat Tube Compact Heat Exchanger and flow through louvers

Specifications of Radiator:
Length of Radiator = 14 inches
Height of Radiator = 14 inches
Breadth of Radiator = 1 inch
Length of Tubes = 12 inches
Tube pitch = 8 mm
Elliptical Tube minor axis = 2 mm
Elliptical Tube major axis = 1 inch
Equivalent Diameter = 5.65 mm
No. of Tubes = 31 units
Tube thickness = 0.8 mm

IV. OPTIMIZATION FUNCTION

Q = fitness function which has to be maximised

$Q = f(T_p, T_{ma}, T_{mi}, T_L, N)$
Length of Radiator = $N * T_{mi} + (N-1)*T_p$
Height of Radiator = T_L
Breadth of Radiator = T_{ma}
Therefore, Volume = $\{(N * T_{mi} + (N-1)*T_p) * T_L * T_{ma}\}$

Heat transfer Rate (Based on equivalent diameter, D_O)
When elliptical section of tube is considered to be a circular section giving same dynamic properties through it. i.e. $Q = f(D_O, T_L, T_t, N)$

$$Q = \frac{\pi * D_O * T_L * N * \frac{T_e - T_i}{\ln\left\{\frac{T_e}{T_i}\right\}}}{\frac{0.375 * D_o}{k} + \frac{D_o}{2k} * \ln\left\{\frac{D_o}{D_o - 2T_t}\right\}}$$

Where,

$$D_o = \frac{\{Tma * Tmi\}^{0.625}}{\left\{\sqrt{\left\{\frac{Tma^2}{2}\right\} + \left\{\frac{Tmi^2}{2}\right\}}\right\}^{0.25}}$$

= Equivalent diameter of Tube

Where,
K = Thermal conductivity of Tube material
T_t = Thickness of Tube
Q = Heat Transfer rate in watts
T_p = Tube pitch in mm
T_{ma} = Major axis of elliptical tube in mm
T_{mi} = Minor axis of elliptical tube in mm
T_L = Tube length in mm
N = No. of tubes
T_e = Exit side Temperature difference
T_i = Inlet side Temperature difference

Constraints of the sizing parameters
The required constraints for optimization are:
D_O –> (1 – 5.6) mm
T_L –> (150 – 310) mm
T_t –> (0.5 – 1) mm
N –> (15 – 31) units

V. METHODOLOGY FOR OPTIMIZATION

Heat exchanger design involves complex processes, including selection of geometrical parameters and operating (dynamic) parameters for the design, cost estimation and optimization. In recent years, applications of Genetic Algorithm (GA) in thermal engineering have received much attention for solving real-world problems. Here, Heat Transfer rate is taken as objective function and tube side parameters are considered for optimization. Genetic Algorithm formulation is carried out in MS-Excel. Firstly a new population is created for initializing the Genetic Algorithm formulation. For this, various Excel functions available in Excel Library are used which are DEC2BIN for converting decimal number into binary string to apply Genetic Algorithm for the formation of mating pool, LEFT(), MID(), RIGHT() for splitting up the digits in binary string for performing Selection, Crossover and Mutation, CONCATENATE() for merging the splited digits whereas BIN2DEC for converting the binary string into corresponding decimal number for fitness function calculation. For optimization process, four such Genetic Algorithm formulations are worked out.

VI. RESULT AND DISCUSSION

The following figure 6 shows variation in fitness values for corresponding number of individual in the first Genetic Algorithm formulation.

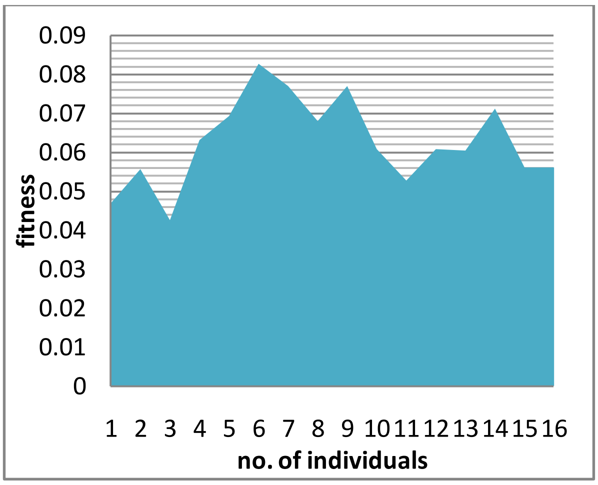

Figure 6: Fitness variation of no. of individuals for 1st GA formulation

As by calculations of the objective function for original dimensions of Heat Exchanger, it was found that Heat Transfer rate of the radiator was 296.5 KW whereas from above figure 6 it can be concluded that maximum Heat Transfer rate obtained is equal to 256.5KW which is at a

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fitness of 8.26% at D_o, T_L, T_t and N equal to 6mm, 298mm, 0.82mm and 25 respectively.

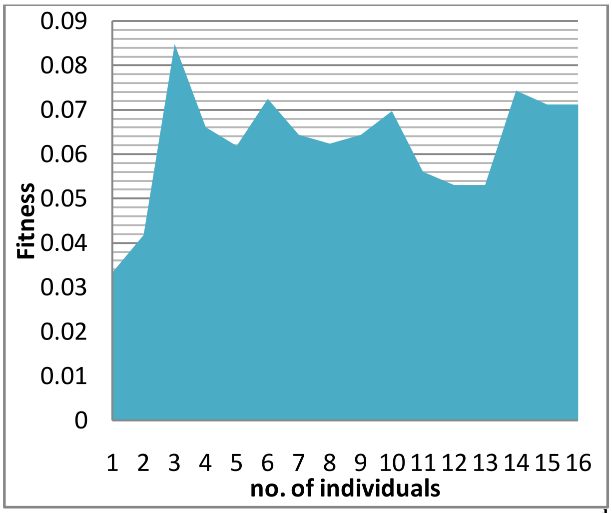

Figure 7: Fitness variation of no. of individuals for 2d GA formulation

From above figure 7 it can be concluded that maximum Heat Transfer rate obtained is equal to 286.9 KW which is at a fitness of 8.5 % at D_o, T_L, T_t and N equal to 3.8mm, 282mm, 0.44mm and 28 respectively.

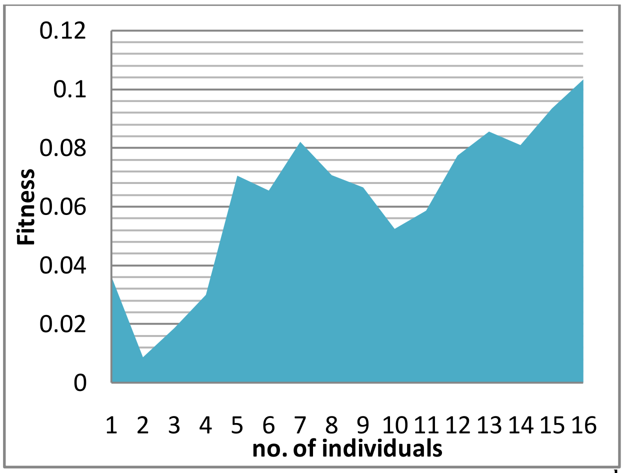

Figure 8: Fitness variation of no. of individuals for 3rd GA formulation

From above figure 8 it can be concluded that Heat Transfer rate obtained at point 13 is equal to 315.711KW which is at a fitness of 9.34% at D_o, T_L, T_t and N equal to 5.1mm, 300mm, 0.66mm and 30respectively. Also, Heat Transfer rate obtained at point 16 is equal to 349.2KW which is at a fitness of 10.33% at D_o, T_L, T_t and N equal to 5.3mm, 308mm, 0.6mm and 31 respectively.

From above figure 9 it can be concluded that Heat Transfer rate obtained at point 14 is equal to 331.9 KW which is at a fitness of 7.7 % at D_o, T_L, T_t and N equal to 5.1mm, 268mm, 0.34mm and 30 respectively. Also, Heat Transfer rate obtained at point 15 and 16 is equal to 349.2KW which is at a fitness of 8.1% at D_o, T_L, T_t and N equal to 5.3mm, 308mm, 0.6mm and 31 respectively, which is 17.77 % more than that of Heat Transfer rate calculated from original dimensions.

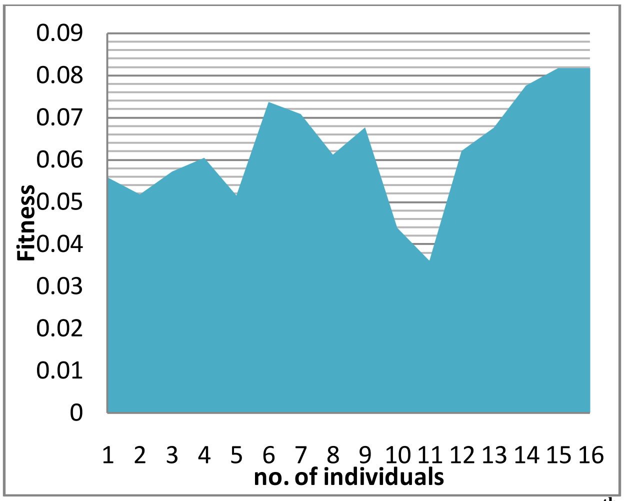

Figure 9: Fitness variation of no. of individuals for 4th GA formulation

VII. CONCLUSION

From above Genetic Algorithm formulation it is clear that Heat Transfer rate of the Heat Exchanger with optimized dimensions was found to be 17.77 % more than that of Heat Exchanger with original dimensions. Also these optimized dimensions have much reduced values as compared to the original dimensions. Therefore it can be concluded that the genetic algorithm can provide a strong ability of auto-search and combined optimization in the design of Compact heat exchangers compared to the traditional designs, which involve a trial-and error process. By application of the genetic algorithm in designing, the heat exchanger configurations or structures can be optimized according to different design objectives such as minimum surface area and cost. Genetic Algorithm can also be used in optimization of different types of heat exchangers, other than compact heat exchangers. Further, the outcomes of Genetic Algorithm can also be coupled with professional tools like Computational fluid Dynamics for better Performance analysis.

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