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Genetic Algorithm Based Optimization of Compact Heat Exchangers: A Review

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Abstract: The present study is concentrated on optimization of Compact Heat exchangers. The task of optimization may be considered as a design process, in which any possible candidates 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.On the other hand, 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. Applications of GA into heat exchangers optimization have suggested that they have a strong ability of search and combined optimization and they 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 within the allowable pressure drops.

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 the optimization techniques that represent an intelligent exploitation of a random search used to solve optimization problems. 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. Thus applications of GA in the field of thermal engineering are new challenges. 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.

II. LITERATURE SURVEY

Sepehr Sanaye et al., [1] presented Thermal modeling and optimal design of compact heat exchangers. Є-NTU method was applied to estimate the heat exchanger pressure drop and effectiveness. Fin pitch, fin height, fin offset length, cold stream flow length, no-flow length and hot stream flow length were considered as six design parameters. Fast and elitist non-dominated sorting genetic-algorithm (NSGA-II) was applied to obtain the maximum effectiveness and the minimum total annual cost (sum of investment and operation costs) as two objective functions.

The results of optimal designs were a set of multiple optimum solutions, called ‘Pareto optimal solutions’. The sensitivity analysis of change in optimum effectiveness and total annual cost with change in design parameters of the plate fin heat exchanger was also performed.The results revealed the level of conflict between the two objectives. Fin pitch, fin height, fin offset length; hot stream flow length and cold stream length (in smalleffectiveness values) were found to be important design parameters which caused a conflict between effectiveness and the total annual cost. On the other hand, no-flow length had no effect on the conflict between two optimized objective functions. Furthermore, the correlation between the optimal values of two objective functions was proposed.

G.N. Xie et al., [2] demonstrated successful application of genetic algorithm for searching, combining and optimizing structure sizes of Compact Heat Exchanger. In there study a plate–fin type of Compact Heat Exchanger (CHE) was considered for optimization. The minimum total volume or/and total annual cost of the CHE were taken as objective functions in the GA, respectively. A generalized procedure had been developed to carry out the optimization to find the minimum volume and/or annual cost and pressure drop of the heat exchangers, respectively, based on the e-NTU and the genetic algorithm technique. A case study was presented to show the optimized results by the proposed method. The geometries of the fins were fixed while three shape parameters were varied for the optimization objectives with or without pressure drop constraints, respectively. Performance of the CHE is evaluated according to the conditions of the structure sizes that the GA generated, and the corresponding volume and cost were calculated. It was shown that with pressure drop constraints the optimized CHE provided about 30% lower volume or about 15% lower annual cost, while without pressure drop constraints the optimized CHE provided about 49% lower volume or about 16% lower annual cost than those presented in the literature It was concluded that the genetic algorithm can provide a strong ability of auto-search and combined optimization in design of heat exchangers compared to the traditional designs in which a trial and error process may be involved.

G.Chaitanya et al., [3] 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 in the present work. The mathematical function describing the objective for the problem was formulated using the radiator core design equations and heat transfer relations governing the radiator. The overall heat transfer rate obtained from the present optimization technique was found to be 9.48 percent higher compared to the empirical value present in the literature. Also, the enhancement in the overall heat transfer rate was achieved with a marginal reduction in the radiator dimensions indicating better spacing ratio compared to the existing design.The Genetic Algorithm had successfully addressed the two principal objectives of the work i.e. To improve the performance efficiency of the radiator and To provide better spacing ratio. Out of the six design parameters, the tube corner radius was found to have the least impact on the objective function.

Joshi Neel M et al., [4] investigated how the optimum configuration of plate heat exchanger can be carried out with reduction of cost of Plate heat exchanger in laminar flowwith the aim of improving heat exchanger compactness. Plate heat exchanger optimized considering two objective functions including the total rate of heat transfer and the total annual cost of the system. Several geometric variables including the total length of the hot and cold side of the heat exchanger, fin height, fin frequency, lance length of the fin, fin thickness and the number of fin layers were considered as optimization parameters. Optimization of all parameters was possible if they are reduced proportionally to the square root of the flow depth reduction given that the flow remains laminar. Square root of the flow depth reduction was possible proportionally to variables like plate thickness, the plate pitch, the fin thickness, and the fin pitch. The fin frequency also affects the heat transfer rate and pressure drop characteristic.This analysis was utilized for optimization of the system and achieving set of optimal solutions each of which was a trade-off between the highest total of heat transfer and the least total annual cost.The principal advantage of this work wasproviding a wide range of optimal solutions which allows the user to choose the best design parameters regarding the application and the total annual cost of the system. This analysis was useful to obtain the configuration of a more compact heat exchanger from the existing configuration.

Ana Paula Curty Cuco et al., [5] applied different multi-objective techniques to study the conceptual design of a new kind of space radiator called VESPAR (Variable Emittance Space Radiator), the radiator had an effective variable emmitance which made it able to reduce or avoid the demand for heater power to warm up equipment during cold case operations in orbit. The multiobjective approach was aimed at obtaining a radiator that minimizes its mass and at the same time minimizes the need for heater power during cold case. Four multi-objective algorithms were used: Nondominated Sorting Genetic Algorithm II (NSGA-II), Multi-Objective Genetic Algorithm (MOGA), Multi-Objective Simulating Annealing (MOSA) and Multi-objective Generalized Extremal Optimization (M-GEO). The first three algorithms are part of the mode FRONTIER® optimization software package, while the MGEO is a recently proposed multi-objective implementation of the Generalized Extremal Optimization (GEO) algorithm. The Pareto frontier showing the trade-off solutions for the radiator mass as a function of heater power consumption had been obtained by the four algorithms and the results have been compared. An assessment of the performance of the M-GEO on this problem, compared to the other well-known multi-objective algorithms had also been made.

Patrick V. Hull et al., [6]presented a design method to create minimal mass highly efficient heat rejection radiators. The design problem formulation included several steps as described in this paper, FEA thermal analysis, genetic algorithm search and two novel shape change methods for the radiators. This design procedure was then demonstrated using both presented design parameterization schemes on a common problem in radiator design. A user of the presented design method may change the boundary conditions, material type and heat application to suit the needs of a given radiator minimization problem. The problems presented here were to prove the concept only, currently a parameter set was been formulated to optimize variable thickness radiator designs. It was not the intent of this design tool to produce a radiator design to be cost effective, but to determine the optimal shape with given boundary conditions and forces. In addition, the shapes of radiators given in the example problems for this paper were strictly driven by the heat load along the driving temperature side and the radiation heat loss. A more detailed radiator optimization tool would include other factors such as shield half angle and stow packaging.

Manish Mishra et al., [7] developed a genetic algorithm based optimisation technique for cross flow plate-fin heat exchangers using offset-strip fins.The algorithm took care of large number of continuous as well as discrete variables in the presence of given constraints. The optimisation program aimed at minimising the number of entropy generation units for specified heat duty under given space restrictions. The results had also been obtained and validated through graphical contours of the objective function in the feasible design space. The effect of variation of heat exchanger dimensions on the optimum solution hadalso been presented.A model for optimisation of cross flow plate-fin heat exchanger having large number of design variables of both discrete and continuous type had been developed using genetic algorithm. The case of multilayer plate-fin heat exchanger had been solved for minimum entropy generation units. The study showed the application and importance of design approach based on second law of thermodynamics and also the suitability of genetic algorithm for optimisation of such complex problems. The effect of some selected design variables on the optimum result, i.e. on irreversibility's associated and the pressure drops on the two sides, was anticipated. The result showed the effect of an additional constraint on the optimum solution and the corresponding power requirement in terms of pressure drops. The results could well be used for designers to start with or to have an initial guess.

Hamidreza Najafi et al., [8] considered a plate and fin heat exchanger and defined air, as an ideal gas, in both sides of the heat exchanger as the working fluid. Several geometric variables within the logical constraints were considered as optimization parameters. Two different objective functions including the total rate of heat transfer and the total annual cost of the system were defined. Since mentioned objectives were conflicting, no single solution can well-satisfy both objective functions simultaneously. In other words, any attempt to increase the value of the total rate of heat transfer led to the higher total cost of the system which was certainly undesirable. Therefore, multi objective optimization using genetic algorithm wasutilized in order to achieve a set of optimal solutions, each of which was a trade-off between objectives and could satisfy both objective functions in an appropriate level. The main advantage of this work was providing a set of optimal solutions each of which could be selected by the designer based on the project's limits and the available investment. A sensitivity analysis was also presented in order to investigate the effect of some geometric parameters on each objective functions. Since Increasing the total heat transfer rate necessitated raising the heat transfer area and any increment in the area resulted in more expensive design, the considered objectives were conflicting and no single solution can satisfy both objectives simultaneously. The principle advantage of this work was to provide a wide range of solutions which allows the user to choose the best design of parameters regarding the energy and total cost of the system.

R.V. Rao et al., [9] explored the use of particle swarm optimization (PSO) algorithm for thermodynamic optimization of a cross flow plate-fin heat exchanger. Minimization of total number of entropy generation units for specific heat duty requirement under given space restrictions, minimization of total volume, and minimization of total annual cost were considered as objective functions and were treated individually. Based on the applications, heat exchanger length, fin frequency, numbers of fin layers, lance length of fin, fin height and fin thickness or different flow length of the heat exchanger are considered for optimization. Heat duty requirement constraint was included in the procedure. Two application examples were also presented to demonstrate the effectiveness and accuracy of the proposed algorithm. The results of optimization using PSO were validated by comparing with those obtained by using genetic algorithm (GA).Parametric analysis was also carried out to demonstrate the effect of heat exchanger dimensions on the optimum solution.The algorithm's ability was demonstrated using application examples and the performance was compared with GA approach given by previous researchers. Improvement in the results were observed using PSO technique compared to GA approach given by the previous researchers, showing the improvement potential of the PSO technique for plate-fin heat exchanger optimization. Furthermore, the effect of some important design variables as well as PSO algorithm's parameters on optimum results was also presented. The proposed PSO algorithm could be easily extended to the design optimization of other types of heat exchangers, e.g, shell-tube heat exchanger, fin-tube heat exchanger, etc.

Cihat Arslanturk et al., [10] used an approximate analytical model to evaluate the optimum dimensions of a central heating radiator. The radiator problem was divided into three one-dimensional fin problems and then the temperature distributions within the fins and heat-transfer rate from the radiator were obtained analytically. The optimum geometry maximizing the heat-transfer rate for a given radiator volume and the geometrical constraints associated with production techniques, and thermal constraints had been found. The problems have been solved to evaluate the temperature distributions within the fins using the boundary conditions of the radiator and the continuity of temperature and heat current at the junctions of the fins. The temperature differences have been used within the heat transfer rate from the radiator to the environment. The optimum radiator geometry maximizing the heat transfer rate had been obtained by using the approximate analytical model. The present optimization technique can be extended to central-heating radiator with more complex geometry.

Khaled Saleh et al., [11] presented a comparison between different multiobjective optimization approaches that can be used to optimize the design of thermal equipment. Plate heat exchanger was taken as case study to apply different optimization techniques. The thermal-hydrodynamic characteristics of single phase turbulent flow in chevron-type plate heat exchangers with sinusoidal-shaped corrugations had been used in this paper. The computational domain contains a corrugation channel and the simulations adopted the shear-stress transport (SST) κ-ω model as the turbulence model. Two different approximation assisted optimization approaches were tested. Offline approximation assisted optimization, and online approximation assisted optimization were compared to optimize plate heat exchanger design. For both approximation techniques (offline and online), design optimization was performed using multiobjective genetic algorithm based on meta-models that were built to represent the entire design space. In offline approximation, globally accurate meta-models were built which requires adding more samples. However in online approximation assisted optimization, samples were added just to improve the metamodels performance in the expected optimum region. Approximated optimum designs were validated using computationally expensive actual CFD simulations. Finally, a comparison between offline and online approximation assisted optimization is presented with guidelines to apply both approaches in the area of heat exchanger design optimization. The methods presented in this paper were generic and can be applied to optimize different types of heat exchangers, electronic cooling devices and other thermal system components.

Cihat Arslanturk [12] used Adomian decomposition method to evaluate the efficiency of a radiating rectangular fin with variable thermal conductivity. Because the resulting complicated fin efficiency expression was not convenient for further optimization calculations, the data from the present solutions was correlated for a suitable range of problem parameters. The correlation equations were used to find the optimum dimensions of space radiators which maximize the heat transfer rate per unit radiator mass. The optimization results were conveniently represented as two identical correlation equations for calculating the optimum dimensions.The nonlinear fin equation was solved using the Adomian decomposition method which provided an infinite series converging very rapidly. The efficiency of the fin was expressed in terms of thermo-geometric fin parameter for making the optimization calculations easily. Optimization results were correlated for suitable ranges of the problem parameters. The correlations of optimum dimensions can be used for a wide range of thermal conductivity parameter describing the variation of thermal conductivity.

III. CONCLUSION

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 involvea trial-and error process. By application of the genetic algorithm in designing, the heat exchanger configurations orstructures can be optimized according to different design objectives such as minimum surface area and cost. Genetic Algorithm can alsobe 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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