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Application of Multi-objective Optimization Packages in Design of an Evaporator Coil

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***Abstract*—**A novel methodology has been used to design an evaporator coil of a refrigerant. The methodology used is through a complete Computer Aided Design /Computer Aided Engineering approach, by means of a Computational Fluid Dynamic/Finite Element Analysis model which is executed many times for the thermal-fluid exploration of several designs' configuration by an commercial optimizer. Hence the design is carried out automatically by parallel computations, with an optimization package taking the decisions rather than the design engineer. The engineer instead takes decision regarding the physical settings and initializing of the computational models to employ, the number and the extension of the geometrical parameters of the coil fins and the optimization tools to be employed. The final design of the coil geometry found to be better than the initial design.

***Keywords*—**Multi-objective shape optimization, Heat Transfer, multi-physics structures, modeFRONTIER

I. Introduction

THERMAL system of evaporator coil which can transfer maximum amount of heat by minimum thermal devices will be required for today's new refrigerant systems which need more efficiency. Influences of heat flux, coolant flow rate, and inlet temperature need to be simulated and optimized. Applying computational methods of simulation have widely utilized for quite awhile and have popularity besides other experimental methods [1]. Simulating the heat transfer is a general method of studying the heat behavior in a system. As the system of an evaporator coil is a multi disciplinary engineering problem, it needs more than one simulation to be run in order to visualize the problem for further analysis and optimization. In this regards dealing with Minimums and Maximums needs a robust, powerful and automatic Multidisciplinary Design Optimization (MDO). MDO deals with the optimal design of structural elements or systems employed in several engineering fields such as heat transfer and fluid dynamics, where improving the structure is important. The recent use of structural optimization is rapidly growing in all engineering science [2]. This is due to the increase of technological competition and the development of strong and efficient techniques for several practical applications.

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The main scientific challenges of MDO have been concerned with the development of strong and efficient numerical techniques and with the computational procedures required for the necessary coupling of disciplinary software systems. Also, the applications related to real problems such as parameter identification is very difficult due to the gap that still exists between the industrial requirements and academic research [4]. In addition to the above points, the efficiency of the optimal result depends on the efficiency of the simulation, modeling and optimization process.

The related works in the field of design of heat transfer based structures could be studied in two different research areas; Single discipline and multi-disciplinary design.

First group of research activities are mostly based on computational simulation and modeling the heat transfer which are done by Computational Fluid Dynamic (CFD) or Finite Element Analysis (FEA) in order to deliver understanding about the heat transfer in different structures. In these works the shape of the structure are modeled applying Computer Aided Design (CAD) tools and a CFD or FEA code is carried out for analyzing the system. These kinds of researches are simulations for the reason of delivering some experiments and overviews of system's functions. In this regard Ranganayakulu et al [1] modeled and simulated the heat transfer in horizontal tubes of an evaporator. In this work a three dimensional heat condition is carried out. The structure of tube is modeled and a FEA tool simulated the heat condition effects. In other related work Bart et al [2] simulated the heat transfer, utilizing a CFD code in a two dimensional domain. For the reason of solving the equation, numerical methods are applied. In such these approaches different shapes and structures are simulated and the results of analyzing deliver the understanding of the heat behavior in different geometries. Based on the result of the simulations the optimal shape between all suggested shapes is selected. For this reason it has been tried to integrate multi-disciplinary simulations in order to get a much realistic analysis [1, 2, and 3]. Figure 1 shows the workflow of this method. The project of Kamali et al [3] is based on this workflow In this research an integrated computer code has studied the flow and heat transfer in different shape configurations and at the end the optimal shape, which satisfies all objectives, is selected manually as the best shape.

However in most engineering heat transfer problems rather than heat simulation, the surrounding air flow and mass transfer are also subjected to simulation. Frontier researches go further which have tried to integrate different simulation tools. These researches try to involve all engineering simulations which are effective in the process. Masoud et al [5] has created an integrated CFD model of heat transfer of CO2 in porous tubes at different pressure. In their research, effects of some parameters such as pressure, inlet temperature, mass flow rate, wall heat flux and local heat transfer coefficients have been studied numerically. The authors have run many CFD simulations applying different parameters and different CAD shapes. Such these researches create the knowledge of system functioning, which could be useful for further design. In the above reviewed researches the design and simulation are two different processes. Therefore the results of simulations haven't been utilized for improving the design.

II. MULTI-OBJECTIVE OPTIMIZATION BASED DESIGN

The other group of researches based on the results of simulations tries to optimize the shape or even the material of the structure. The traditional ways of the optimization processes are mostly based on the try-and-error techniques. In this way according to the results of simulation the shape is improved manually to satisfy the objectives. This method in multi-disciplinary design problems couldn't be the effective way [6, 7]. A general solution for the optimization of engineering systems where more than one objective is considered could be really helpful in order to deliver the optimal shape in different industries. In a real engineering design a large number of variables and objectives are subjected to the special constraints. Multi-Objective Evolutionary Algorithms (MOEA) have utilized to deal with this problem in last few years.

In most optimization problems the general objectives are listed as follow [5].

1. To minimize the production time
2. To minimize the Weight
3. To maximize the Quality
4. To maximize the Efficiency
5. To minimize the Cost of material

Nowadays there are many algorithms available for multi-objective optimization. These algorithms are based on mathematical equations which make the process complicated for engineers [7, 8]. These methods of optimization are mostly theoretical rather than the engineering way of solving the design problems. Copiello et al [7] utilized genetic algorithms for multi-objective optimization of heat transfer from longitudinal wavy fins. In this work, the optimization of the heat transfer by a laminar flow under conditions of forced convection and from a multi-objective point of view are investigated. The problem is addressed by means of a finite element method which allows computing the velocity and the temperature distributions in a finned conduit cross section under conditions of imposed heat flux. Thereafter, the fin profile is optimized by means of multi-objective genetic algorithm which aims to find geometries that maximize the heat transfer and minimize the hydraulic resistance. The geometry of the fins is parameterized by means of a polynomial function and several orders are investigated and compared. Also in other related research Samad et al [8] optimized a multi objective heat transfer problem. In this method the problem is formulated numerically and optimized with hybrid multi-objective evolutionary algorithm and Pareto optimal front. As Pareto optimal front produces a set of optimal solutions, the trends of objective functions with design variables are predicted by hybrid multi objective evolutionary algorithm.

There are some CFD/FEA based optimizations for problems involving heat transfer [8, 9]. In each of these approaches one method of multi objective shape optimization is introduced. The techniques of geometric parameterization and shape optimization differ in each method. The geometries of shape are parameterized by evolutionary methods. After a comprehensive classification and description of optimization methods and algorithms the optimum shape is created. After a preliminary series of CFD/FEA analyses the 3D model can be substituted by a series of mathematical functions and the computational time is considerably reduced.

The considered objectives are the maximization of the heat transfer rate and the minimization of friction factor, with the additional objective of minimization of heat transfer surface for the recuperator module. In a recent study by Kim et al [9] a shape subjected to the heat transfer is modeled and optimized to enhance the heat transfer performance. In this research some design variables are introduced to maximize the heat transfer rate compromising with friction loss. According to the variables ten designs are generated by a mathematical based sampling. Optimum shape of fins depends on weighting factor which measures importance of the friction loss term in the objective function. The thermal performances are much higher than that of the straight pin-fin at sampling optimum points with different weighting factors.

The above researches present a theoretical evolutionary multi-objective optimization method which is quite effective to solve the problem, but it couldn't be properly applied by an engineer. This method because of dealing with mathematical equations has its complexity which makes the process rather confusing [8]. Figure 2 shows the optimization procedure of this method.

III. METHODOLOGY

This study concerns the development of the evaporator cooling systems. Due to the maximum amount of required heat transfer a very efficient cooling system is required in order to improve its efficiency. This means using a certain amount of cold air directly extracted from outside with a significant negative impact on the refrigerant performance. The refrigerant effect is mostly dependent on the evaporator coil. In this regard the arrangement and the shape of the fins are important for the reason of the heat transfer. On the other hand the position of the fins on the tubes as well as the shape of the fins is generally the most important determination of the flowed air around the coil, and therefore the cooling performance of the system. There are many different types of the coil fins that could be modeled into finned tube heat exchanger coils. These varied fin types have their own features and advantages and when properly applied for the particular cooling /heating application, are able to provide an economical coil with a long service life [8, 9]. Meanwhile in an attempt to achieve the optimal shape of coil, besides of the coil surrounding air, other simulation variables such as pressure and temperature of refrigerant flow in the tubes must be simulated and analyzed. Identifying the variables and objectives is the first step of optimization.

A. Variables of Design and Simulation

Some Input variables are linear dependent and some variables are not. The plate fin is a continues metal strip has holes for tubes punched for a particular tube, in a pattern and established distance. Fin Enhancements are available in different shapes. Besides the shape, the fin spacing also has an important effect on heat transfer of an evaporator. Therefore a group of variables deal with the shape of the coil which is modeled by CAD tools. Variables of the shape and the dimensions of the evaporator coil is subjected to the physical space in which it can be located is limited by other components. The fins dimensions and the place of the holes are the first series of the variables.

Surrounding air variables such as quality and behavior including the speed of airflow, air flow direction, moisture and temperature are critical to designing the coil circuits for proper and efficient operation. These variables must be included in the simulation carefully. The incorrect initializing the air flow and compromising the system temperature setting in the simulation workflow can lead to coil-system failure. A proper simulation of coil can help minimize the error issues. According to the limitation of design variables, possible shapes for the simulation process are identified [2, 3].

B. Design objectives

The ejected air must cover all the surfaces in order to create a cold film between the hot fin and the surroundings. As the coil region is characterized by a 3D flow field, it is very difficult and time consuming to optimize the cooling system using standard design methodologies also considering the other fin tip requirements such as minimizing the hot leakage air from pressure to suction side, which has a negative impact on the evaporator coil aerodynamic efficiency. For these reasons, the area of the coil is investigated with a parametric CFD approach. A parametric model is run several times guided by an optimization package, such that an optimal solution in terms of performance can be found. This kind of approach requires linking the optimization package into a 3D CFD code subjected to reach the optimal values of coil's shape variables as a consequence of the geometrical complexity of the problem and high computational time. This presents an optimization problem with 11 conflicting objectives. The list of objectives is as follow.

1. To Minimize the coil material
2. To Conform to the package volume
3. To maximize the resulting flash temperature
4. To minimize air friction
5. To maximize the coil strength
6. To maximize the vibration
7. To maximize thermal conductivity
8. To maximize the compact fin bundle
9. Maximize the vertical and horizontal airflow
10. Maximize the heat transfer

C. Workflow

Everything is automatically managed by the multi-objective optimization's package of modeFRONTIER after a series of initializing. Workflow initializing is done by giving some values and limitations to the input variables, output variables and objectives. For the reason of simulation, there are software packages such as CAD and CAE which easily could be integrated in the workflow. Performing the FEA and CFD each of them takes hours. Limited number of simulations could be run in the limited time. In order to find the optimal design in shorter time there is need for running minimum number of simulations. One way is to apply some methods of optimization package's tools such as Design Of Experience (DOE) for getting maximum information from minimum number of simulations. DOE explores the design space and automatically chooses the minimum set of designs which contains the maximum amount of information. Each single CAE simulation takes hours or even days. Finding the optimal configuration of the products could be shortened if some virtual time-consuming simulation is applied. Some simulations are as expensive as it is not possible to run those for more than a limited number of calculations. DOE can deliver enough initial calculations which allow the optimization algorithm learns the behavior of design parameters in order to take the best decision. There are many parameters of shape dimensions, materials and arrangements involved in the design of an evaporator. Governing parameters could vary in different values. DOE starts from values of governing parameters. Parameters' variation and properties identify the governing parameters. Varying the governing parameters from their initial values to the maximum possible limitation gives the different designs with a variety of characteristics. Furthermore, through the large number of experiences gained the several simulations run by the optimizer generate virtual database of fins configurations, allowing the designer to find laws, functions and correlations between input parameters and output performance, with a further and deeper insight into this specific design coil cooling problem.

A parametric batch procedure allows the creation of different geometrical models, the mesh generation and the CFD analyses of the coil in an automatic way. A series of preliminary CFD simulations is planned and a screening is performed in order to build an input-output database. The error of the expert system is a known value and is the parameter which yields the accuracy of the interpolator relative to the database of real experiments so far acquired. It is up to the designer to choose the final value of the expert system. Basically, the more CFD analysis makes the expert system more trained and the more accurate, but with an increase of the CPU effort. One of the available Multi-Objective Optimization Algorithms investigates runs with further CFD Virtual analysis, exploring the space of possible solutions on the coil. Basically a virtual optimization of the cooling system is carried out without further CPU expensive CFD analysis. The best virtual solutions are selected and the virtual solutions are validated by a real CFD analysis. The virtual optimization can be executed again and new and more performing designs can be found. This procedure is repeated

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till the desired convergence to the set of optimal solutions is achieved. Finally, a layout of cooling fins is found by the optimizer and validated by a CFD analysis. The final design chosen proved to yield the same heat transfer performance with a reduction of approximately 10% of the cooling air required. Figure 3 and 4 show the workflow of the Evolutionary Multi-Objective Optimization Design.

IV. CONCLUSION

A general strategy for developing the geometry of an evaporator coil using Multi-Objective Optimization Package has been presented. This work has demonstrated the effectiveness of Multi-Objective Optimization techniques in improving thermal-fluid problems.

A remarkable increase of performance of 10% is obtained by an innovative complete CAE design process with CFD parametric models evolved by a multi-objective optimization package.

The use and integrating of optimization tools and innovation capabilities are intended to provide a means for automatically varying the shapes reached from the evaluation made by CAE systems without any needs of high-level understanding of mathematical equations involved in CAD/CAE and Optimizer procedure.

This is a step closer to building a CAE innovation system that goes much further into the evolution of technical systems, as an automatic evolution.

The proposed methodology, which relies on optimization packages capabilities can be easily generalized and applied to any thermal-fluid system whose behavior is reproducible through CAE simulation.

REFERENCES

[1] Ranganayakulu, Herres 2006 Heat transfer from horizontal tubes in pool boiling: influence of three-dimensional heat conduction in the wall of the evaporator tube—a finite element analysis Springer Heat Mass Transfer 42: 271–278
[2] Bart, Brozio, Herbsthofer 2000 Heat Transfer and Hydrodynamics in Annular Chromatography: CFDSimulation and Experiments Springer J. of Thermal Science Vol.9, No.2
[3] Kamali, Binesh 2008 The importance of rib shape effects on the local heat transfer and flow friction characteristics of square ducts with ribbed internal surfaces Science Direct International Communications in Heat and Mass Transfer
[4] Jeong ,Haa, Kwon , 2006 Evaluation of the conduction shape factor with a CFD code for a liquid–metal heat transfer
[5] Fard 2009 CFD modeling of heat transfer of CO2 at supercritical pressures flowing vertically in porous tubes Sciencedirect International Communications in Heat and Mass Transfer
[6] Arularasan & Velraj, 2008, modeling and simulation of a parallel plate heat sink using computational fluid dynamics, springer, Int J Adv Manuf Technol DOI 10.1007/s00170-008-1867-9
[7] Copiello, Fabbri 2009 Multi-objective genetic optimization of the heat transfer from longitudinal wavy fins Science direct International Journal of Heat and Mass Transfer 52
[8] Samad Lee 2008 Multi-objective optimization of a dimpled channel for heat transfer augmentation Springer Heat Mass Transfer
[9] Moon 2009 Optimization of a stepped circular pin-fin array to enhance heat transfer performance Springer Heat Mass Transfer

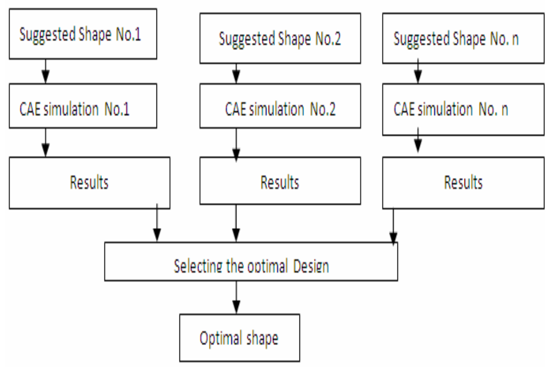

Fig. 1. the workflow of a traditional optimization method which the optimal design is selected manually by engineer

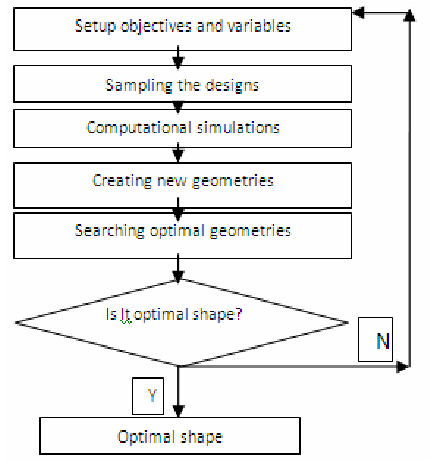

Fig. 2. the optimization procedure utilizing the evolutionary algorithms

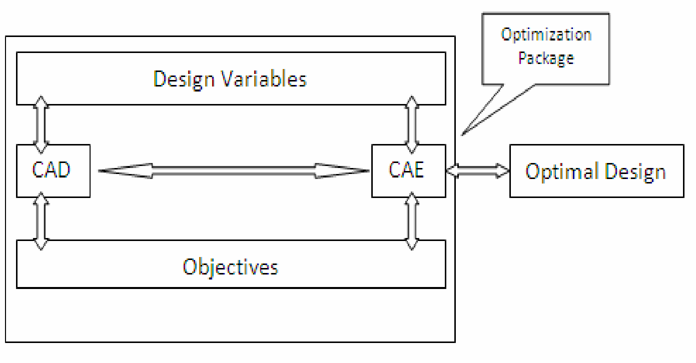

Fig. 3. the workflow of the automatic multi-objective optimization design process, utilizing optimizer packages

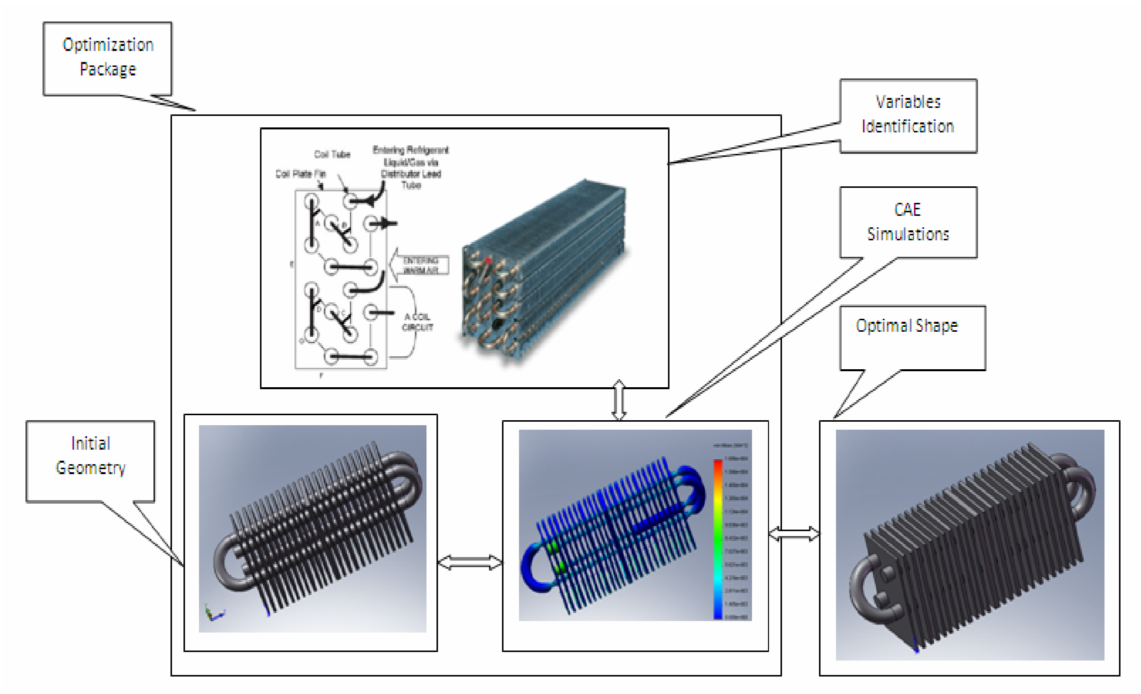

Fig. 4. Workflow of the automatic multi-objective optimization design process, utilizing optimizer package of modeFRONTIER