Parametric Optimization of Shell and Tube Heat Exchanger by Harmony Search Algorithm

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Abstract— Shell and Tube heat exchanger is one of the most useful heat exchanger among all the other types. Because they provide relatively large ratios of heat transfer area to volume and weight and they can be easily cleaned. It is also use in the power plants, as a feed heater or in some refrigeration system. Different parameters like Baffle angle, mass flow rate, baffle space, pressure drop and number of tubes effect on the performance of heat exchanger. In the present study these parameters are optimized to increase the heat transfer coefficient and also to reduce the operating cost.

Key words: PSO, SA, EA, TS, FA, ACO

I. INTRODUCTION

Optimization is a Procedure to make a system or design as effective, especially the mathematical techniques involved. In recent years, the word ‘meta-heuristics’ refers to modern higher-level algorithms, including Particle Swarm Optimization (PSO), Simulated Annealing (SA), Evolutionary Algorithms (EA) including Genetic Algorithms (GA), Tabu Search (TS), Ant Colony Optimization (ACO), Bee Algorithms (BA), Firefly Algorithms (FA). Among these entire meta-heuristic algorithms evolutionary algorithm known as Genetic Algorithm (GA) is well known technique for optimization problem solving. It was proposed by Holland. This technique is based on Darwin’s concept of survival of fittest. But this method has few 4 drawbacks like time of getting solution is high and the method is little bit complicated to develop.

To overcome the drawback of other algorithm , Z. W. Geem et al. in 2001 developed a New Harmony search (HS) meta-heuristic algorithm which offer many advantages, (a) HS algorithm imposes fewer mathematical requirements and does not require initial value settings of the decision variables. (b) As the HS algorithm uses stochastic random searches, derivative information is also unnecessary. (c) The HS algorithm generates a new vector, after considering all of the existing vectors, whereas the genetic algorithm (GA) only considers the two parent vectors. These features increase the flexibility of the HS algorithm and produce better solutions.

II. BASIC COMPONENTS OF SHELL AND TUBE HEAT EXCHANGER

A. Baffle

Baffles serve two important functions. First they support the tubes for structural rigidity, preventing tube vibration and sagging; and second to divert the flow across the bundle to obtain a higher heat transfer coefficient. The diameter of the baffle must be slightly less than the shell inside diameter to allow assembly, but must be close enough to avoid the substantial performance penalty caused by fluid bypass around the baffles. Shell roundness is important to achieve effective sealing against excessive bypass. Baffles can be made from a variety of materials compatible with the shell side fluid. They can be punched or machined. Some baffles are made by a punch which provides a lip around the tube hole to provide more surfaces against the tube and eliminate tube wall cutting from the baffle edge. The tube holes must be precise enough to allow easy assembly and field tube replacement, yet minimize the chance of fluid flowing between the tube wall and baffle hole, resulting in reduced thermal performance and increased potential for tube wall cutting from vibration. Baffles do not extend edge to edge, but have a cut that allows shell side fluid to flow to the next...
This optimum is achieved within the tubes. It is conceptualized using musical process of improvisation, in music improvisation, the maximum baffle spacing is the shell inside diameter. Higher baffle spacing will lead to predominantly longitudinal flow, which is less efficient than cross-flow, and large unsupported tube spans, which will make the exchanger prone to tube failure due to flow-induced vibration. Optimum baffles pacing. For turbulent flow on the shell side (Re > 1,000), the heat-transfer coefficient varies to the 0.6–0.7 power of velocity; however, pressure drop varies to the 1.7–2.0 power. For laminar flow (Re < 100), the exponents are 0.33 for the heat transfer coefficient and 1.0 for pressure drop. Thus, as baffle spacing is reduced, pressure drop increases at a much faster rate than does the heat-transfer coefficient. This means that there will be an optimum ratio of baffle spacing to shell inside diameter that will result in the highest efficiency of conversion of pressure drop to heat transfer. This optimum ratio is normally between 0.3 and 0.6.

C. Tubes
The tubes are the basic component of the shell and tube heat exchanger, providing the heat transfer surface between one fluid flowing inside the tube and the other fluid flowing across the outside of the tubes. The tubes may be seamless or welded and most commonly made of copper or steel alloys.

D. Tube Sheets
The tubes are held in place by being inserted into holes in the tube sheets and there either expanded into grooves cut into the holes or welded to the tube sheet. The tube sheet is usually a single round plate of metal that has been suitably drilled and grooved to takes the tubes however where the mixing between two fluids must be avoided, a double tube sheet such as shown in fig. may be provided.

The space between the tube sheets is open to the atmosphere so any leakage of either fluid should be quickly detected. The tube sheet must withstand to corrosion. The tube sheets are made from low carbon steel with a thin layer of corrosion resisting alloy metallurgically bonded to one side.

E. Shell and Shell-Side Nozzles:
The shell is simply the container for the shell side fluid, and the nozzle are the inlet and exit ports. The shell normally has a circular cross section and is commonly made by rolling the metal plate of appropriate dimensions in to cylinder and welding the longitudinal joint. In large exchanger, the shell is made out of low carbon steel wherever possible for the reason of economy, though other alloys can be and are used when corrosion or to high temperature strength demand must be met.

III. HARMONY SEARCH ALGORITHM
Harmony Search Algorithm is developed by Z. W. Geem et al. 2001. It is conceptualized using musical process of searching for a perfect state of harmony. Music harmony is a combination of sounds considered pleasing from an aesthetic point of view. Harmony in nature is a special relationship between several sound waves that have different frequencies. Musical performances seek a best state (fantastic harmony) determined by aesthetic estimation, as the optimization algorithms seek a best state (global optimum— minimum cost or maximum benefit or efficiency) [1] determined by objective function evaluation. Aesthetic estimation is determined by the set of the sounds played by joined instruments, just as objective function evaluation is determined by the set of the values produced by component variables; the sounds for better aesthetic estimation can be improved through practice after practice, just as the values for better objective function evaluation can be improved iteration by iteration. The concept is explained in following figure 3.

As shown in above fig.3, in music improvisation, each player sounds any pitch within the possible range, together making one harmony vector. If all the pitches make a good harmony, that experience is stored in each player’s memory, and the possibility to make a good harmony is increased next time. Similarly in engineering optimization, each decision variable initially chooses any value within the possible range, together making one solution vector. If all the values of decision variables make a good solution, that experience is stored in each variable’s memory, and the possibility to make a good solution is also increased next time. So by above discussion we can compare the terms which are used in music and in optimization.
A. Basic Harmony Search Algorithm (BHSA)

Harmony Search was inspired by the improvisation of Jazz musicians. Specifically, the process by which the musicians (who have never played together before) rapidly refine their individual improvisation through variation resulting in an aesthetic harmony.

Now let us understand above method by a small example [1].

The structure of Harmony Memory (HM) is shown in Figure 3. Consider a jazz trio composed of fiddle, saxophone and keyboard. Initially, the memory is stuffed with random harmonies: (C, E, and G), (C, F, A), and (B, D, G) that are sorted by aesthetic estimation. In the improvising procedure, three instruments produce a new harmony; for example, (C, D, A); fiddle sounds {C} out of {C, C, B}; saxophone sounds {D} out of {E, F, D}; and keyboard sounds {A} out of {G, A, G}. Every note in HM has the same opportunity to be selected, for example, each of the notes E, F, or D of the saxophone in HM has a selection probability of 33.3%. If the newly made harmony (C, D, A) is better than any of the existing harmonies in the HM, the New Harmony is included in HM and the worst harmony (in this example, (B, D, G)) is excluded from the HM. This process is repeated until satisfying results (near optimum) are obtained.

![Fig. 4: Structure of Harmony Memory](image)

1) Steps of harmony search algorithm

Step 1: Initialize the problem and algorithm parameters

In Step 1, the optimization problem is specified as follows:

Minimize, the function $f(x)$ Subjected to

$x_i \in X_i, i = 1, 2, 3, ..., n$

Algorithm Parameters:

- Harmony Memory Size (HMS), or the number of solution vectors in the harmony memory
- Harmony Memory Considering Rate (HMCR), $HMCR \in [0,1]$;
- Pitch Adjusting Rate (PAR), $PAR \in [0,1]$;
- Bandwidth
- Number of improvisations (NI), or stopping criterion;

Step 2: Initialize the harmony memory

In this Step, the HM matrix is filled with as many randomly generated solution vectors as the HMS and sorted by corresponding objective function values of each random vector, $f(x)$.

$HM = \begin{pmatrix}
1
2
3
\vdots
n
\end{pmatrix}
\begin{pmatrix}
f(x_1) \\
f(x_2) \\
f(x_3) \\
\vdots \\
f(x_n)
\end{pmatrix}
$

Step 3: Improvise a new harmony

A New Harmony vector is generated based on three rules:

1) memory consideration,

2) pitch adjustment rate

3) random selection.

Step 4: Update harmony memory

For each new value of harmony the value of objective function, is calculated. If the New Harmony vector is better than the worst harmony in the HM, the New Harmony is included in the HM and the existing worst harmony is excluded from the HM.

Step 5: Check stopping criterion

If the stopping criterion (maximum number of improvisations) is satisfied, computation is terminated. Otherwise, Steps 3 and 4 are repeated. Finally the best harmony memory vector is selected and is considered as best solution to the problem.
Fig. 5: HS Flowchart
IV. LITERATURE REVIEW

Z. W. Geem, 2001, developed a New Harmony search (HS) meta-heuristic algorithm having the purpose to produce better solution than other existing algorithm in less number of iterations. In current international literature one can find variety of applications of HSA and number of publications on HSA.

D. Manjarres, 2013, “A survey on applications of the harmony search algorithm” This paper thoroughly reviews and analyzes the main characteristics and application portfolio of the so-called Harmony Search algorithm, a meta-heuristic approach that has been shown to achieve excellent results in a wide range of optimization problems. As evidenced by a number of studies, this algorithm features several innovative aspects in its operational procedure that foster its utilization in divine fields such as construction, engineering, robotics, telecommunication, health and energy.

M. Fesanghary, 2008, “Design Optimization of Shell and Tube heat exchanger using global sensitivity analysis and harmony search algorithm” This paper demonstrates successful application of harmony search algorithm for the optimal design of shell and tube heat exchangers. The HSA is simple in concept, few in parameters and easy for implementation. Moreover, it does not require any derivative information. These features increase the applicability of the HSA, particularly in thermal systems design, where the problems are usually non-convex and have a large amount of discrete variables or discontinuity in the objective function. One of the features presented in this study is the use of global sensitivity analysis. The aim of the sensitivity analysis is to identify geometrical parameters that have the largest impact on total cost of STHXs. The GSA could successfully find the most important parameters. The algorithm ability was demonstrated using an illustrative example and the performance was compared with genetic algorithm. Results reveal that the proposed algorithm can converge to optimum solution with higher accuracy in comparison with genetic algorithm.

Sampreeti Jena, 2013 “Multi objective optimization of design parameters of shell and tube type heat exchanger using genetic algorithm” There has been ample research on the optimization of heat exchangers from economic point of view using a wide range of algorithms, there has been no work to achieve the simultaneous optimization of 2 objectives- the annual sum of capital investment and working cost as well as the length of the heat exchanger. The given work has drawn a co-relation between the minimization of length and the minimization of length.

We have clearly outlined the impact of minimization of one objective on the other. In order to achieve this we have implemented the multi-objective solver that uses genetic algorithm (gamultiobj), available in the MATLAB optimization tool-box. The multi-objective algorithm(Elitist Multi-objective Genetic Algorithm) searches for the optimal values of design variables such as outer tube diameter, outer shell diameter and baffle spacing, for two types of tube layout arrangement (triangular and square) with the number of tube passes being two or four.

V. CONCLUSION

There are different algorithms use for the optimization. But from the literature survey we can say that the result obtained by the harmony search algorithm has an optimum value compare to all the other algorithm. So, we can minimize the cost of manufacturing and increase the efficiency of heat exchanger by using the harmony search algorithm.

REFERENCES