

General Pattern Search Applied to the Optimization of the Shell and Tube Heat Exchanger

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Abstract— The literature has different implementations and results for the mono-objective and multiobjective optimization of the shell and tube heat exchanger (STHE), most of them using evolutionary computation. However, there is a gap to find the optimal solution of this problem through direct search methods (numerical optimization). So, this paper uses the Pattern Search algorithm of MATLAB toolbox applied to this case study.

Keywords— Optimization, Pattern Search algorithm, Shell and Tube Heat Exchanger.

I. INTRODUCTION

Heat exchangers are used in process industries, steam generating plants, refrigeration systems, heating systems, air conditioning, petrochemical industries, among other applications. Its function is to provide the recovery and use of thermal energy efficiently and economically. There are different models of heat exchangers, such as spiral, plates, regenerators, compacts, shell and tube heat exchanger (STHE). During its design it is possible to obtain different configurations, however, it is desirable the optimal design, which starts from the modeling of the same.

The recent literature review [1] shows the trend in the use of Evolutionary Algorithms for the mono-objective optimization of STHE. The most commonly used technique is Genetic Algorithm (GA). Other algorithms are Particle Swarm Optimization (PSO), Harmony Search Algorithm, Differential Evolution, Cuckoo Search Algorithm, Imperialist Competitive Algorithm, Biogeography Base Algorithm, Simulated Annealing, Firefly algorithm, Bat Algorithm, and Jaya algorithm. In the multiobjective optimization are the Non-Dominated Sorting Genetic Algorithm II (NSGA II) and the Multi-Objective Particle Swarm Optimizer (MOPSO).

Considering the previous discussion, the objective of this article is to solve the mono-objective optimization of the STHE by minimizing the objective function total annual cost with the use of the algorithm General Pattern Search (GPS), which is implemented in the MATLAB toolbox.

II. OPTIMIZATION OF THE SHELL AND TUBE HEAT EXCHANGER

The problem considered is the minimization of the total annual cost (TC) of the shell and tube heat exchanger.

$$\text{Min } f(\mathbf{x}), f(\mathbf{x}) = TC, \quad (1)$$

The modeling and problem of the shell and tube heat exchange used in this article are the found in [1-3]. The variables used for the multiobjective optimization are presented in Table 1.

Table 1: Variables for optimization of the Shell and Tube Heat Exchanger

Var.	Symbol	Values
		triang. (30°); square (90°); rot. square (45°)
x ₁	a _p	(45°)
x ₂	n _p	1; 2; 4
x ₃	L _t	2.438 m to 11.58 m
x ₄	esp	0.002108 m to 0.004572 m
x ₅	d _o	0.01588 m to 0.0508 m
x ₆	L _b	0.0508 m to 29.5(x ₅) ^{0.75}
x ₇	bc	15% to 45%
x ₈	d _{tb}	0.01x ₅ to 0.1x ₅
x ₉	d _{sb}	0.0032 m to 0.011 m

Follow the description of the variables: a_p is the tube layout pattern, n_p is the number of tubes passes, L_t is the tube length, esp is the tube wall thickness, d_o is the tube outer diameter, L_b is the baffle spacing, bc is the baffle cut, d_{tb} is the tube-to-baffle diametrical clearance, d_{sb} is the shell-to-baffle diametrical clearance.

Considering the material of the tube (70%Cu, 30%Ni) and of the shell (carbon steel), the total annual cost estimation (TC) that includes direct and indirect costs

(C_{BM}) and operational costs (OC), was conducted in the same manner as in [1,2]:

$$TC = C_{BM} \frac{i(1+i)^n}{(1+i)^n - 1} + OC \quad (2)$$

Where i is the fractional interest rate per year, n is the lifetime in years estimated for the heat exchanger. Being that the operational costs are in function of the pressure

drop, and direct and indirect costs are in function of the thermal exchange area.

Three constraints was considered involve the limits of the shell side pressure drop, the tube side pressure drop, and the maximum area value of the heat exchanger. The formulation was the same as the one considered in [1,3,4].

III. EXPERIMENTS AND RESULTS

The optimization of shell and tube heat exchanger was performed by direct search [5,6], through the Pattern Search algorithm of the MATLAB toolbox, and the configuration of the *Poll* and *Search* methods used was the *General Pattern Search positive basis 2N* (GPS) [7-9], the other settings were the program standards.

The result obtained by the GPS was compared to the multiobjective optimization performed by the algorithm NSGA II and transformed to the minimum annual cost criterion used in [1]. The GPS algorithm was also compared to the result found for the genetic algorithm of MATLAB toolbox. In this case, a configuration used was 50 generations, uniform stochastic selection, scattered crossover, and mutation constraint dependent.

The Table 2 and Table 3 show the best results found for algorithm GPS. In Table 4 the results for the GA algorithm are presented and in Table 5 has the results for NSGA II algorithm.

Table.2: Results for optimization, GPS algorithm, triangular tube arrangement, one tube pass

Variable	Value
a_p	Triangular
n_p	1
L_t	2,438 m
esp	0,002108 m
d_o	0,01588 m
L_b	0,9925 m
bc	17,4 %
d_{tb}	0,0001588 m
d_{sb}	0,0032 m
Function objective	Value
	\$ 3335,45

Table.3: Results for optimization, GPS algorithm, rotated square tube arrangement, one tube pass

Variable	Value
a_p	rotated square
n_p	1
L_t	2,438 m
esp	0,002352 m
d_o	0,01863 m
L_b	0,711 m
bc	15,3 %

d_{tb}	0,0001588 m
d_{sb}	0,0032 m
Function objective	Value
	\$ 3346,77

Table.4: Results for optimization, GA algorithm

Variable	Value
a_p	rotated square
n_p	1
L_t	3,658 m
esp	0,002108 m
d_o	0,01905 m
L_b	0,8588 m
bc	18,6 %
d_{tb}	0,0003921 m
d_{sb}	0,0054 m
Function objective	Value
	\$ 3362,45

Table.5: Results for optimization, NSGA II algorithm

Variable	Value
a_p	Triangular
n_p	1
L_t	2,438 m
esp	0,002108 m
d_o	0,01588 m
L_b	1,6312 m
bc	17,4 %
d_{tb}	0,0004775 m
d_{sb}	0,0042 m
Function objective	Value
	\$ 3337,12

For the triangular tube arrangement configuration and one tube pass, the result was better than the obtained by the algorithm NSGA II. And for the arrangement square rotated and one tube pass the algorithm also obtained better performance than the GA.

During the experiment, GPS algorithm was applied for all combinations of discrete variables of the STHE, so nine results were obtained. However, it was chosen to present only the best results and that could be compared to other optimization algorithms.

It is understood that the configuration of the STHE with square tube arrangement, rotated square tube arrangement with two tube passes or four tube passes, and triangular tube arrangement with two tube passes or four tube passes, does not allow good results.

IV. CONCLUSION

The GPS algorithm was a viable alternative for the mono-objective optimization of the shell and tubes heat exchanger, being that it found better results than the

popular algorithms like NSGA II and GA.

This result is important and interesting because most paper that apply optimization of the heat exchanger use heuristic methods, especially with the use of genetic algorithm (GA). However, when a competitive result is found with a direct search algorithm, one must extend the use of numerical optimization applied to other real problems. In addition, it is suggested that it encourages its use in hybrid algorithms.

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