Optimisation of Shell and Tube Heat Exchangers Using ANT Colony Principles

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ABSTRACT
In the present work, a shell and tube heat exchanger design and optimization approach is developed. The main objective in any heat exchanger design is to maximize the overall heat transfer coefficient for a given heat duty. Several configurations are possible with various design variables such as outer diameter, pitch, and length of the tubes; tube passes; baffle spacing; etc. Hence the design engineer needs an efficient strategy in searching for the optimum design. In the present study it is shown that, for the case when allowable pressures drops on tube and shell side are given, one can estimate optimum value of number of tubes, number of baffles, baffle spacing, velocity of tube side fluid. Ant Colony Algorithms has been successfully applied with different strategies which yield the global optimum for a wide range of the key parameters. An attempt has been made to optimize design of shell and tube heat exchanger using Ant Colony Principles.

Keywords---- Shell and Tube Heat Exchanger, Optimization, Overall Heat Transfer Coefficient, baffles, Number of tubes, Ant Colony Algorithm

I.  INTRODUCTION
Shell-and-tube heat exchangers are the most common type of thermal equipment employed in chemical process industries. This widespread use can be justified by its versatility, robustness and reliability [1, 2]. Shell and tube heat exchangers are the most widely used heat exchangers in process industries because of their relatively simple manufacturing and their adaptability to different operating conditions. The design of Shell and tube heat exchangers, including thermodynamic and fluid dynamic design, cost estimation and optimization, represents a complex process containing an integrated whole of design rules and empirical knowledge of various fields. There are many previous studies on the optimization of heat exchangers. Several investigators have used different strategies based on simulated annealing genetic algorithm and traditional mathematical optimization algorithms [10,11] for various objectives like minimum entropy generation [3,4] and minimum cost of the Shell and tube heat exchangers [7,9]. Some of these studies focuses mainly on a single geometrical parameter like optimum baffle spacing [12,13] and some others try to optimize a variety of geometrical and operational parameters of the Shell and tube heat exchangers and overall heat transfer coefficient. The process of exchanging heat between two different fluid streams is one of the most important and frequently encountered processes found in engineering practice, in which heat is exchanged between a ‘HOT fluid’ and ‘COLD fluid’. In the usual commercial fluid to fluid Heat exchangers, there is an obvious economic incentive to reduce equipment size[14,15]. The modern petro chemical industry, energy generating plants etc., are based on innumerable processes involving the use of devices to exchange heat between two fluid streams without physically mixing them, such devices are generally termed as ‘HEAT EXCHANGERS’. Ant Colony Optimization (ACO) is a paradigm for designing metaheuristic algorithms for combinatorial optimization problems. The main underlying idea, loosely inspired by the behaviour of real ants, is that of a parallel search over several constructive computational threads based on local problem data and on a dynamic memory structure containing information on the quality of previously obtained result. The collective behaviour emerging from the interaction of the different search threads has proved effective in solving combinatorial optimization (CO) problems[6,8]. The software program has been designed in ‘C’ language using Ant Colony Optimisation so that even inexperienced users should have no problem in utilising it.

II.  PROBLEM FORMULATION
For any optimization problem, the problem formul-
tion is the first and the foremost step. In the case of design optimization of shell and tube heat exchangers the problem is formulated as follows.

2.1 Objective function

\[ U = \frac{1}{h_s} + \frac{d_{to}}{d_t \times h_t} + \frac{d_{to}}{2k_m} \times \log\left(\frac{d_{to}}{d_t}\right) + r_d \]

Where

- \( h_s \) = heat transfer coefficient of shell side fluid.
- \( h_t \) = heat transfer coefficient of tube side fluid.
- \( d_{to} \) = tube outer diameter.
- \( d_t \) = tube inner diameter.
- \( k_m \) = thermal conductivity of the material.
- \( r_d \) = dirt resistance factor.

2.2 Design variables and their bounds:

1. Velocity of tube side fluid (m/s) 
   \[ 1 \leq v_t \leq 2.5 \]
2. Baffle spacing 
   \[ 0.1 \leq l_{bc} \leq 0.5 \]
3. Number of baffles 
   \[ 6 \leq N_b \leq 33 \]

2.3 Design parameters:

1. Shell side pressure drop.
2. Tube side pressure drop.

2.4 Design constraints:

1. Shell side pressure drop \( d_{ps} \leq 83631 \text{N/m}^2 \)

\[ d_{ps} = \frac{2f_e G_e^2 D_e (N_b + 1)(N_s)}{D_e \times \rho_s \times \left(\frac{\mu_s}{\mu_{sw}}\right)^{0.14}} \]

- \( d_{ps} \) = shell side pressure drop.
- \( f_e \) = fanning friction factor of shell side fluid.
- \( G_e \) = flow throughput on shell side.
- \( D_e \) = shell diameter.
- \( N_b \) = number of baffles.
- \( N_s \) = number of shell passes.
- \( D_e \) = equivalent diameter.
- \( \mu_s \) = viscosity of shell side fluid.
- \( \mu_{sw} \) = viscosity of shell side fluid at wall temperature.
- \( \rho_s \) = density of shell side fluid.

2. Tube side pressure drop \( d_{pt} \leq 78805 \text{N/m}^2 \)

\[ d_{pt} = \frac{2f_t G_t^2 D_t (N_t)(N_s)}{d_t \times \rho_st \times \left(\frac{\mu_t}{\mu_{tw}}\right)^{0.14}} + \frac{1.25G_t^2 (N_t)(N_s)}{\rho_st} \]

Where,

- \( d_{pt} \) = tube side pressure drop.
- \( f_t \) = fanning friction factor on tube side.
- \( G_t \) = flow throughput on tube side.
- \( L \) = equivalent length.
- \( N_t \) = number of tube passes.
- \( N_s \) = number of shell passes.
- \( d_t \) = inner tube diameter.

\( \rho_{st} \) = density of tube side fluid.
\( \mu_t \) = viscosity of tube side fluid.
\( \mu_{tw} \) = viscosity of tube side fluid at wall temperature.

2.5 Input parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Shell side</th>
<th>Tube side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow rate (kg/s)</td>
<td>75.22</td>
<td>19.15</td>
</tr>
<tr>
<td>Density (kg/m³)</td>
<td>820.12</td>
<td>789.72</td>
</tr>
<tr>
<td>Heat capacity (J/kg.K)</td>
<td>2135.3</td>
<td>2428.34</td>
</tr>
<tr>
<td>Viscosity (cP)</td>
<td>2.885</td>
<td>1.2</td>
</tr>
<tr>
<td>Viscosity at the wall tube temperature (cP)</td>
<td>1.813</td>
<td>3.1</td>
</tr>
<tr>
<td>Thermal conductivity (W/m.K)</td>
<td>.123</td>
<td>.1056</td>
</tr>
<tr>
<td>Inlet temperature (C)</td>
<td>51.66</td>
<td>210</td>
</tr>
<tr>
<td>Outlet temperature (C)</td>
<td>83.631</td>
<td>104.44</td>
</tr>
<tr>
<td>Allowable pressure drop (kPa)</td>
<td>83.631</td>
<td>78.805</td>
</tr>
<tr>
<td>Fouling factor (K.m²/W)</td>
<td>.00035</td>
<td>.00035</td>
</tr>
</tbody>
</table>

Table 1: Input design parameters

III. RESULTS AND DISCUSSIONS

The shell and tube heat exchanger is designed with the given input parameters using ant colony algorithm. Allowable pressure drops on shell side and tube side, tube inner and outer diameters, tube layout, heat duty, temperatures on shell side and tube side are used to design the shell and tube heat exchanger and to determine the optimum value of tube side velocity, baffle spacing, number of baffles, overall heat transfer coefficient. Here in this ant colony optimization we are going to find the optimum value of overall heat transfer coefficient by studying the effect of number of ants and number of iterations. The design is done for the following six cases.

CASE: 1

When Number of Ants (Na) = 500, Number of Iterations (Ni) = 1000 the optimum values of overall heat transfer coefficient (U opt), velocity of tube side fluid (v_t), baffle spacing (l_{bc}), number of baffles (N_b) are obtained by the ant colony method are shown in Table 2.
CASE: 2
When Number of Ants (Na) = 500, Number of Iterations (Ni) = 2000 the optimum values of overall heat transfer coefficient (U_{opt}), velocity of tube side fluid (v_t), baffles spacing (lbc), number of baffles (Nob) are obtained by the ant colony method are shown in Table 3.

CASE: 3
When Number of Ants (Na) = 1000, Number of Iterations (Ni) = 2000 the optimum values of overall heat transfer coefficient (U_{opt}), velocity of tube side fluid (v_t), baffles spacing (lbc), number of baffles (Nob) are obtained by the ant colony method are shown in Table 4.

CASE: 4
When Number of Ants (Na) = 1000, Number of Iterations (Ni) = 1000 the optimum values of overall heat transfer coefficient (U_{opt}), velocity of tube side fluid (v_t), baffles spacing (lbc), number of baffles (Nob) are obtained by the ant colony method are shown in Table 5.
When Number of Ants (Na) = 1000, Number of Iterations (Ni) = 2000 the optimum values of overall heat transfer coefficient ($U_{opt}$), velocity of tube side fluid ($v_t$), baffles spacing ($l_{bc}$), number of baffles ($N_{ob}$) are obtained by the ant colony method are shown in Table 6.

CASE: 5

When Number of Ants (Na) = 2000, Number of Iterations (Ni) = 1000 the optimum values of overall heat transfer coefficient ($U_{opt}$), velocity of tube side fluid ($v_t$), baffles spacing ($l_{bc}$), number of baffles ($N_{ob}$) are obtained by the ant colony method are shown in Table 7.

Table 6 $U_{opt}$ value and variables value for Na=2000, Ni=1000

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_{opt}$</td>
<td>685.153648</td>
</tr>
<tr>
<td>$v_t$</td>
<td>1.645000</td>
</tr>
<tr>
<td>$l_{bc}$</td>
<td>0.272000</td>
</tr>
<tr>
<td>$N_{ob}$</td>
<td>17.610000</td>
</tr>
</tbody>
</table>

CASE: 6

When Number of Ants (Na) = 2000, Number of Iterations (Ni) = 2000 the optimum values of overall heat transfer coefficient ($U_{opt}$), velocity of tube side fluid ($v_t$), baffles spacing ($l_{bc}$), number of baffles ($N_{ob}$) are obtained by the ant colony method are shown in Table 7.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>F&lt;sub&gt;opt&lt;/sub&gt;</td>
<td>673.538916</td>
</tr>
<tr>
<td>vt</td>
<td>1.330000</td>
</tr>
<tr>
<td>lbc</td>
<td>0.188000</td>
</tr>
<tr>
<td>nob</td>
<td>11.940000</td>
</tr>
</tbody>
</table>

Table 7 U<sub>opt</sub> value and variables value for Na=2000, Ni=2000

### IV. CONCLUSION

Ant colony optimisation has been and continues to be a fruitful paradigm for designing effective combinatorial optimization algorithms. After more than ten years of studies, both its application effectiveness and its theoretical beginnings have been demonstrated, making ACO one of the most successful paradigms in the meta-heuristic area. Maximization of overall heat transfer coefficient is achieved. By increasing number of ants and number of iterations in ACO more accurate values can be obtained. The following optimum values are obtained for the six cases by executing the “C” program are shown in below table 8

<table>
<thead>
<tr>
<th>CASE</th>
<th>U&lt;sub&gt;max&lt;/sub&gt;(W/m²K)</th>
<th>vt(m/s)</th>
<th>lbc(m)</th>
<th>Nob</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>758.050203</td>
<td>1.615000</td>
<td>0.264000</td>
<td>17.070000</td>
</tr>
<tr>
<td>2</td>
<td>706.083556</td>
<td>1.075000</td>
<td>0.120000</td>
<td>7.350000</td>
</tr>
<tr>
<td>3</td>
<td>746.869969</td>
<td>1.915000</td>
<td>0.344000</td>
<td>22.470000</td>
</tr>
<tr>
<td>4</td>
<td>693.482730</td>
<td>1.385000</td>
<td>0.256000</td>
<td>16.530000</td>
</tr>
<tr>
<td>5</td>
<td>685.153648</td>
<td>1.645000</td>
<td>0.272000</td>
<td>17.610000</td>
</tr>
<tr>
<td>6</td>
<td>673.538916</td>
<td>1.330000</td>
<td>0.188000</td>
<td>11.940000</td>
</tr>
</tbody>
</table>

Table 8 Optimum values are obtained for the six cases by executing the “C” program.

### REFERENCES