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Design and optimization of Shell and Tube Heat Exchanger

KEYWORDS

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ABSTRACT *Design Optimization of shell-and-tube heat exchanger by Differential Evolution (DE) method. For the optimal design of shell-and-tube heat exchangers improved version of Genetic Algorithm named Differential Evolution (DE) is used. Design variables: tube outer diameter, tube pitch, tube length, number of tube passes, no of shell, shell head type, shell layout, baffle spacing and baffle cut are taken for optimization. Bell's method is used to find the heat transfer area for a given design configuration. A code in C language has been developed for optimum design of shell and tube heat exchanger and it is tested and validated for analytical problems of known results. The potential of DE technique is illustrated in this dissertation by means of examples related to the optimization of shell and tube heat exchangers. It has been observed that Differential Evolution (DE) technique performs better than the genetic algorithm (GA)*

INTRODUCTION

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another. The media may be separated by a solid wall, so that they never mix, or they may be in direct contact. A heat exchanger is a device for heat transfer from one medium to another. The basic concept of a heat exchanger is based on the premise that the loss of heat on the high temperature side is exactly the same as the heat gained in the low temperature side after the heat and mass flows through the heat exchanger.

In heat exchanger design, there are three types of flow arrangements: counter-flow, parallel-flow, and cross-flow. In the counter-flow heat exchanger, both fluids entered the exchanger from opposite sides. In the parallel-flow heat exchanger, the fluids come in from the same end and move parallel to each other as they flow to the other side. The cross-flow heat exchanger moves the fluids in a perpendicular fashion. Compare to other flow arrangements counter –flow is the most efficient design because it transfers the greatest amount of heat.

Factor affecting to heat exchanger

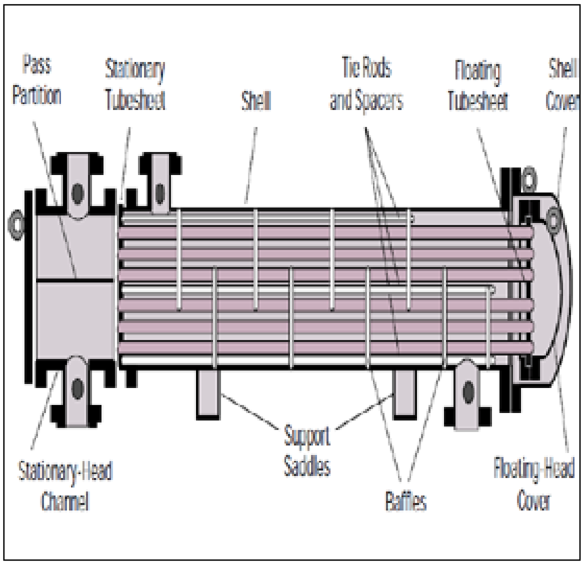
1. Flow arrangement
2. Temperature distribution
3. Heat transfer coefficient
4. Effects of fouling:

Types of heat exchangers

1. Shell and Tube Heat Exchangers
2. Double Pipe Heat Exchangers
3. Compact Heat Exchangers
4. Plate and Frame Heat Exchanger
5. Spiral Heat Exchangers
6. Regenerative Heat Exchanger
7. Scrapped Surface Heat Exchangers
8. Transverse High-Finned Exchangers

Shell and tube heat exchanger

In shell-and-tube heat exchangers, one fluid, known as the "tubeside" fluid, flows inside a set of parallel tubes known as the "tube bundle." These tubes are enclosed within a metal shell. The other fluid, known as the "shellside" fluid, flows inside the shell but over the outside of the tubes. Both the metal shell and the tubes are pressurized, and they must withstand the specified design pressures during the intended lifetime of the equipment.



They are extensively used as process heat exchangers in the petroleum-refining and chemical industries; as steam generators, condensers, boiler feed water heaters and oil coolers in power plants; as condensers and evaporators in some air-conditioning and refrigeration applications; in waste heat recovery applications with heat recovery from liquids and condensing fluids; and in environmental control.

Optimal design of shell and tube heat exchangers

The basic design equation

$$QT = A_0 U F_T \Delta T$$

Estimation of heat load

$$QT = M_h \ (h_{h\,in} - h_{h\,out}) = Mc\,(h_{c\,out} - h_{c\,in}$$

Estimation of the mean temperature Difference:

$$\Delta TM = \frac{(T_{h\,in} - T_{c\,out}) - (T_{h\,out} - T_{c\,in})}{\ln(T_{h\,in} - T_{c\,out}) - (T_{h\,out} - T_{c\,in})}$$

Estimation of U_O

$$\frac{1}{U_0} = \frac{1}{\alpha} + R_{fo} + t_w\, 2\lambda \ln\frac{D_t}{D_{ti}} + \frac{D_t}{D_{ti}}\,(R_{fi} + \frac{1}{\alpha})$$

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Calculation of A

$$A_i = A_0 F_1 F_2 F_3$$

Bundle diameter

$$D_{ctl}, D_{ctl} = Ds - L_{bb}$$

Number of baffles

$$N_b = (L_{to}/L_{bc}) - 1$$

Heat transfer coefficient tube and shell side

$$h = h_i J_c J_1 J_b J_s j_r$$

Pressure Drop

$$P = P_c + P_w + P_e$$

Differential Evolution Technique
DE belongs to the class of genetic algorithms (GAs) which use biology-inspired operations of crossover, mutation, and selection on a population in order to minimize an objective function over the course of successive generations (Holland, 1975). The overall structure of the DE algorithm resembles that of most other population based searches. The parallel version of DE maintains two arrays, each of which holds a population of NP, D-dimensional, real valued vectors.

Pseudo code of DE technique
Initialize the values of D, NP, CR, F and MAXGEN.
• Initialize all the vectors of the population randomly.
for i = 1 to NP
{
for j = 1 to D
, j = random number
}
calculated by a separate function cal_area () using Bell's method.

for i = 1 to NP
= cal_area ()
evaluation of the objective function for a specified number of generations.

While (gen < MAXGEN)
{
for i = 1 to NP
{
For each vector Xi randomly from the current population (primary array) other than the vector Xi

do
{
r1 = random number * NP
r2 = random number * NP
r3 = random number * NP
}
Perform crossover for each target vector Xi with its noisy vector
p = random number * 1
r = random number * D
n = 0
do
{
for binomial crossover
{
p = random number * 1
r = random number * D
for n = 1 to D
{
}
if (, i > 1), i = 1
If (, i < 0)
Perform selection for each target vector, Xi by comparing its cost with that of the trial vector, , i ; whichever has the lowest cost will survive for the next generation.

Ct, i = cal_area ()
if (Ct, i <) new Xi = , i
else new Xi = X i /* for i=1 to NP */
}
}
• **Print the results**
A generalized procedure has been developed to run the DE algorithm coupled with a function that uses Bell's method of heat exchanger design, to find the global minimum heat exchanger area

Case study: 1
As a case study the following problem for the design of a shell-and-tube heat exchanger (Sinnott, 1993) is considered: 20,000 kg/hr of kerosene leaves the base of a side-stripping column at 200 and is to be cooled to 90 with 70,000 kg/hr light crude oil coming from storage at 40. the lowest cost design meeting the above specifications is reported to be a heat transfer area of 55 based on outside diameter DE is applied for the same problem then area 34.39

Case study: 2
As a case study the following problem for the design of a shell-and-tube heat exchanger is considered: 170000 kg/hr of steam leaves the base of a side-stripping column at 145 and is to be cooled to 138 with 85607 kg/hr light Caprolectum coming from storage at 80. the lowest cost design meeting the above specifications is reported to be a heat transfer area of 52.11 based on outside diameter DE is applied for the same problem then area 33..39

Case study-3
As a case study the following problem for the design of a shell-and-tube heat exchanger is considered: 36.3 kg/s of oil leaves the base of a side-stripping column at 65.5 and is to be cooled to 63 with 18.1 kg/s water coming from storage at 32.5. the lowest cost design meeting the above specifications is reported to be a heat transfer area of 32.79 based on outside diameter DE is applied for the same problem then area 15.08

CONCLUSION
The objectives of the design optimization of a heat exchanger are to minimize the cost of its material, power to pump the fluids, cost for external heat provided by utility, cost of utility used, weight, area, pressure drop etc. and to maximize heat transfer between two fluids and heat transfer coefficient.

In the case studies, the objective functions are optimization of area of shell and tube heat exchanger Among DE's advantages are its simple structure, ease of use, speed and robustness. DE has been successfully applied for solving several complex problems and is now being identified as a potential source for accurate and faster optimization. The solution to examples taken from the literature show how previously reported designs can be improved through the use of the DE technique presented in this work.

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