ISSN 2395-1621

Design and Optimization of Cooling Tower using Geometry Algorithms

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ABSTRACT

Genetic algorithms (GAs) are a heuristic search and Optimization technique inspired by natural evolution. They have been successfully applied to a wide range of real-world problems of significant complexity.GA algorithms are independently valid approaches with certain strengths and weaknesses. GA is best for finding global optimum solution. GA algorithm used for design optimization of natural draft wet cooling tower. The GA problem is formulated so as to Minimizing the total annual cost and that consists of fixed charges plus operating costs. The results obtained using proposed GA is compared with those obtained by using Leap-frog Optimization Program with Constraints (LFOPC) optimization algorithm model result.

Keywords - Wet-cooling tower; Geometry optimization; Genetic Algorithm.

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

I. INTRODUCTION

A cooling tower [4] is a device that uses a combination of heat and mass transfer to cool water by direct contact between air and water. The water to be cooled is distributed in the tower by spray nozzles, splash bars, fills, etc. in a manner that exposes a very large water surface to atmospheric air. The movement of the air is accomplished by fans, natural draft or the induction effect from water sprays. A portion of the water is evaporated because the moisture content of the air is less than saturated air at the temperature of the water. Since this process of evaporation requires energy to change the water from liquid to vapor, the water is cooled. Cooling tower found in power and chemical plants throughout the world. Different shapes and types of structures exist, but their fundamental function is the same. The wet or evaporative cooling towers may be classified as natural draft and mechanical draft types. In the mechanical draft cooling tower, air is circulated through the tower by means of electrically driven fans. On the other hand, the natural draft cooling tower uses the natural buoyancy of the warmed air to circulate it through the tower. Mechanical draft towers can be either induced draft (fan located at the top of the tower) or forced draft (fan located at the bottom of the tower). In practice, large natural draft cooling towers are used in power plants for cooling the water supply to the condenser. Mechanical draft cooling towers are preferred for oil refineries and other process industries. The dimensions of a natural draft wet-cooling tower as shown in Fig. 1 are optimized to obtain the minimum combined operational and capital cost compounded over the economic life of the cooling tower. The current study only considers the geometry of a wet-cooling tower in the optimization analysis. This focused approach leads to a better understanding of the factors that influence the life-cycle cost of a wet-cooling tower. The design of cooling tower, including thermodynamic design, cost estimation and optimization, represents a complex process containing an empirical knowledge of various fields. Previously there were many studies on the performance analysis of cooling towers. Serna-González et al. [1] used GAMS software environment, using the DICOPT solver for the mixed-integer non-linear programming optimization of mechanical draft counter flow wet-cooling towers. The author had considered the minimization of total annual cost as an objective function. Six different examples were also considered for the demonstration of optimization method. Kintner-Meyer and Emery [2] described a method for the optimum sizing of cooling tower which included the cost optimal selection of cooling tower range and approach. Kloppers and Kroger [3] used Wet-Cooling Tower Performance Evaluation (WCTPE) software in conjunction with the Leap-frog Optimization Program with Constraints (LFOPC) optimization algorithm for the geometric optimization of a natural draft wet-cooling tower. The authors had considered the minimization of total cost of cooling tower as an objective function. Rao and Patel [6] used artificial bee colony (ABC) algorithm for optimization of mechanical draft counter flow wet-cooling towers. The author had considered the minimization of total annual cost as an objective function. Six different examples were also considered for the demonstration of optimization method. Ansary, Damatty, Nassef [7] develop a numerical tool that is capable of achieving an optimum shape and design of hyperbolic cooling towers . The objective function is set to be the minimum weight of the tower. In this paper, we investigate and optimization model for the economic design of dry-type natural-draft cooling towers used in dissipating the waste heat of steam electrical plants. For the complete cycle from fuel to electricity, the efficiency of a fossil-fuel plant is about 40%, while for nuclear plants the efficiency drops to nearly 30%. This means that a significant fraction of the energy in the fuel appears as waste heat. The usual method of carrying away this waste heat has been to use circulating water from a natural body of water. For ecological reasons, the resulting increase in the water temperature of the river, lake, or ocean bay may be unacceptable.

Cooling towers are often used to transfer the heat of condensation of the turbine exhaust steam to the atmosphere. Most cooling towers currently being used are evaporative-type towers that result in a considerable loss of water to the atmosphere.

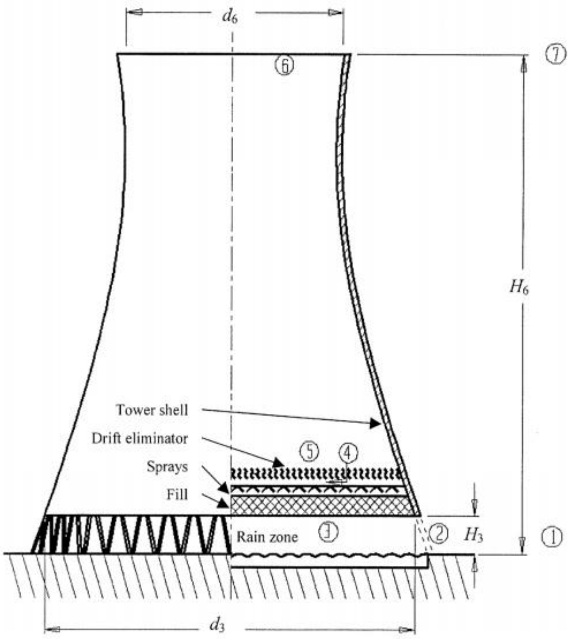

Fig. 1. Cooling tower model.

This problem is proposed by Kloppers and Kroger (2004) [3]. In this problem they use the dimension of a natural draft wet cooling tower are optimized to obtain the minimum combined operational and capital cost compounded over the economic life of the cooling tower. They use Leap-frog Optimization Program with Constraints (LFOPC) optimization algorithm. The objective function to be minimized consists of the sum of the operational costs and capital costs compounded over a specified economic life of the cooling tower. The wet-cooling tower cost analysis that follows is relatively simple but it can be readily expanded to include more detailed cost approximations. It is relatively difficult to obtain accurate and reliable cooling tower costing information as costs are generally site specific and can vary significantly from country to country. The operational and capital cost components employed in the optimization analysis are presented.

II. Need of Optimization

Due to the competitive nature of the industry and the high capital cost of cooling towers. The optimizing design for given cooling capacity is justified within practical limitations. The degree of optimization ultimately achieved is usually a function of

- The sophistication of the design program.
- Computational cost.
- Quality of available input data including material, labor and energy cost structure.

In particular, the minimization of energy related expenses is critical in the objectives of energy savings and resources conservation. The design of a cooling tower involves the selection/sizing of its main mechanical components to fulfill a desired service. Each set of design parameters constitutes a possible solution to the problem and, since there are several possibilities that can execute a certain service, an optimization procedure is being applied to identify the best option, usually based on economic factors. However, the concept of a good design involves aspects that cannot be easily described in a single economic objective function: air flow, circling water flow, outlet water temperature, wet bulb temperature etc. are few of the objectives that lead to redesign of cooling tower after basic design optimization.

III. GENETIC ALGORITHM

The power of the GA to work on the solution in a global sense while allowing the SA to locally optimize each individual solution According to Anthony roach et.al [6], "it is widely recognized that GAs are not well suited to performing finely-tuned local search. Like natural systems, GAs progress by virtue of changing the distribution of high performance substructures in the overall population; individual structures are not the focus of attention. Once the high performance regions of the source space are identified by the GA, it may be useful to invoke a local search routine to optimize the members of the final population." According to [9], "GAs do not fit best for scheduling problems in order to get near optimal solutions if no improvement heuristic, such as local search, is incorporated." Reference proposed an SA for the "fine-tuning" of a quadratic assignment problem (QAP). Over the last decade, Genetic Algorithms (GA) [9] have emerged as a leading tool for optimization of arbitrary functions and for guided search problems in high dimensional spaces. GA's are typically comprised of two types of operations: mutation and crossover which are repeatedly applied to a population of chromosomes, each of which encodes a possible solution to the given problem. GA's have been successfully applied to many theoretical optimization problems and several industrial applications.

The basic concept GA is presented as follows:

1. Initialize the parameters of the GA
2. Generate the initial population

3. Use the GA to produce k good solutions (k = population size)
4. Repeat steps 3 and 4 as needed.

IV. OBJECTIVE FUNCTION.

The objective function to be minimized consists of the sum of the operational costs and capital costs compounded over a specified economic life of the cooling tower. The wet-cooling tower cost analysis that follows is relatively simple but it can be readily expanded to include more detailed cost approximations. It is relatively difficult to obtain accurate and reliable cooling tower costing information as costs are generally site specific and can vary significantly from country to country. The operational and capital cost components employed in the optimization analysis are presented below.

A. TOWER OPERATIONAL COST

The pumping power can be approximated by [2]

$$P_{pump} = m_w * g * (H3 + L_{fi} + L_{sp}), \qquad (1)$$

where L_{sp} is the height of the spray zone, which is assumed to be constant.
The operating cost of the pump for one year is given by

$$C_{pump} = P_{pump} * C_{elec}\tau \qquad (2)$$

where τ is the total hours per year that the pump is working and C_{elec} is the cost of electricity. The effect of the motor-pump efficiency can be included in C_{elec}, for example by multiplying C_{elec} by 1.1 if the motor-pump efficiency is 90%.
The operating cost of the pump compounded over the selected period, expressed in years, is given by

$$C_{pump} = \sum_{n=1}^{years} P_{pump} * C_{elec} * \tau\left(1 + \left(\frac{i}{100}\right)\right)^{n-1} \qquad (3)$$

where i is the inflation rate to account for the increase in the cost of electricity due to inflation.

B. TOWER CAPITAL COST

The volume of the concrete in the tower shell can be approximated by

$$V_s = (\pi/2)*(d3 + d6)*t_s*H6 \qquad (4)$$

where t_s is the thickness of the cooling tower shell.
The capital cost of the tower shell is approximated by

$$C_s = V_s * C_{conc} \qquad (5)$$

Where C_{conc} is the cost of concrete per unit volume, which includes the cost of construction.It must again be stressed that these equations can be readily expanded to include more detailed cost approximations. Equation (4) is generally relatively accurate when compared to accurate representations of the volume of concrete employed in cooling towers. The cost of the tower shell is also a function of the height of the shell and the thickness of the shell where the thickness varies throughout the height of the shell [3]. The actual shape and thickness of the tower shell is a function of the geometry of the cooling tower, which is not known *a priori*. To employ accurate representations of the volume of concrete a structural analysis of the tower shell must be included in the optimization analysis, which is beyond the scope of the current investigation.

The volume of the fill is given by

$$V_{fi} = A_{fr} * L_{fi} \qquad (6)$$

The cost of the fill is given by

$$C_{fi} = V_{fi} * C_{fi} \qquad (7)$$

where C_{fi} is the cost of the fill material per unit volume.
The total capital cost over the selected period is given by

$$C_{cap} = (C_s + C_{fi})\left(1 + \left(\frac{i}{100}\right)\right)^{n-1} \qquad (8)$$

where i is the inflation rate.
The Objective Function for optimization is given by

Minimize

$$Cost = C_{cap} + C_{pump} \qquad (9)$$

Only two inequality constraints are included in the current analysis, *i.e.*

$$H3 \geq c1 \qquad (10)$$

$$H6 \leq c2 \qquad (11)$$

Where $c1$ and $c2$ are constants.
The input values are,

TABLE I

Cost and optimization variables [2]

The water outlet Temp. T_{wo}	21.376 ^{o}C
The water inlet Temp. T_{win}	40 ^{o}C
Heat load, Q	972.3714MW
Heat capacity of water, C_{pw}	4.193
Cost of electricity, Celec	0.03 \$/kWh
Operating hours per year,τ	8760h/year
Inflation rate	3%
Economic life of cooling tower	35 years
Cost of concrete (including the cost of construction)	200 \$/m^3
Cost of fill	25 \$/m^3

The parameter setting for the GA to solve the optimization problem of cooling tower is given below:

- Population size =100
- Number of generations = 80
- Probability of crossover =0.7
- Probability of mutation =0.015
- Initial temperature = 320
- Decrement factor = 0.001

For the selected values of operating parameters of the GA algorithm results of optimization are shown in Table II along with those obtained by using other optimization algorithms.

V. RESULT

Table II

Cooling tower dimension with corresponding total cost

	H_6 (m)	H_3(m)	D_3(m)	A_{fr}(m)	L_{fi}(m)	D_6 (m)	*Cost (M\$)*
Kroger,1998	147	10	104.5	8300	2.054	60.85	330.459
LFPOC (Kloppers and Kroger, 2004)	139.21	4.925	99.89	7584.64	4.614	57.94	268.715
GA(2015)	133.5	4.97	95.50	7962.56	2.50	55.33	**258.6211**

Table II shows the optimal result produced by GA algorithm

Fig. 3 shows the magnitude of the normalized objective function as convergence commences for the optimization analysis.

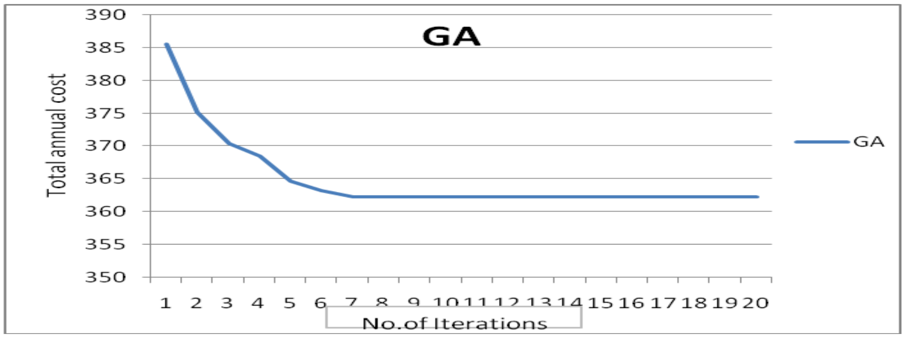

Fig 3. Effect of no. of generations on convergence rate

VI. CONCLUSIONS

It is clear from the optimization analysis that the inlet height of a cooling tower has a significant effect on the total cost of a cooling tower. It is observed that for the present application the proposed GA algorithm outperformed all other algorithms. This improvement is due to global benefits of GA selection. The present study demonstrates successful application of GA algorithm for the optimization of mechanical draft counter flow wet-cooling tower. The result obtained by using the GA is compared with and LFPOC. GA algorithms show significant improvement (≈ 07%) over the result obtained by using LFPOC [3]. The Genetic Algorithm is developed in MATLAB software.

ACKNOWLEDGMENT

I feel great pleasure to present this work on ‘Design and Optimization of Cooling Tower using Geometry algorithms’. I am very much thankful towards my respected project Guide Prof. B C Londhe for his leading guidance in this topic. Also he has been a persistent source of inspiration to me.

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