Energy 154 (2018) 157–167

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Comparison and evaluation of air cooling and water cooling in resource consumption and economic performance

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ARTICLE INFO

*Article history:*
Available online 18 April 2018

*Keywords:*
Cooling type
Comparison
Price ratio
Economic analysis

ABSTRACT

Cooling systems have been widely applied in the process industry, which generally falls into two categories: air cooling and water cooling. Despite that both of these cooling types has their own specific advantages, resource consumption, especially energy and water, is inevitable to maintain system operation. Facing with overwhelming challenges in the industry field such as energy and water conservation, given selection of cooling type, it is imperative to take resource consumption and economy effect into account.

In this paper, comparison among four different cooling types is carried out, including dry air coolers, spray type air coolers, evaporative air coolers, and circulating cooling water systems, for energy and water consumption and economy performance. Considering the cooling range from 95 °C to 40 °C, under circumstance of different dry bulb temperature and relative humidity, energy and water consumption can be calculated, while annual total cost, as a measure index of economic indication, is compared in the condition of different price ratio of fresh water and industrial electricity likewise. This work contributes to the determination of optimal cooling method, which has instructive significance in actual industrial processes.



## 1. Introduction

Heat recovery systems play an important role in energy conservation of the whole industrial process. Subsequently, its remaining heat needs cooling treatment by coolers. In accordance with the cooling medium, the cooling method can usually be categorized into two sections: water cooling and air cooling.

During the last several decades, in literature, a considerable number of available studies have concerned with performance of air cooling and water cooling, since a series of global concerns such as impending climate changes, reliance on fossil fuels, acute water scarcity, highlight the importance of the excessive energy and water consumption [1]. Furthermore, stringent environment regulations, soaring resource demand and other elements oblige industrial agglomeration to enhance resource utilization efficiency as much as possible [2]. Therefore, it is of vital significance to make contrastive studies on air cooling and water cooling on energy and water consumption, as well as economic performance.

### 1.1. Different types of air coolers

Air coolers, as the name indicates, have process streams cooled when ambient air is regarded as cooling medium instead of water, which in general, has a higher capital cost but a lower operating cost in comparison with water-cooled heat exchanger [3]. There are diverse taxonomic approaches with regard to the classification of air coolers. For instance, air coolers can be divided into dry type air coolers and wet type air coolers, while the latter comes in quite a few varieties such as spray type air coolers and evaporative air coolers, according to jetting modes. For wet style air coolers, there are numerous means contributing to the intensification of heat transfer, counting humidification and mist spray. The following three types of air coolers are discussed in this paper.

a) Dry type air cooler (DAC). In a dry type air cooler, air flows blow over the smooth or finned tubes while hot streams through the tubes. Heat transfer between hot streams and ambient air leads to temperature rise of air flows and temperature fall of hot streams [4].

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https://doi.org/10.1016/j.energy.2018.04.095
0360-5442/

b) Spray type air cooler (SAC). The primary characteristic of a spray type air cooler is that the spray water is sprinkled onto the surface of heat transfer tubes, which results in sufficient surface wettability of tubes and evaporative heat dissipation, inducing the enhancement of heat transfer efficiency. The heat transfer mechanism of spray type cooling can be associated with kinds of phenomena including direct evaporation from the interface of liquid membrane [5], and convection heat transfer [6].
c) Evaporative air cooler (EAC). For an evaporative air cooler (EAC), the evaporation of water in the surface of heat transfer tubes is able to exert an influence on cooling effects, causing the decrease of inlet air temperature [7]. By dint of the latent heat of evaporative water, the water evaporation can not only cool down the air flows but also improve its humidity [8].

The previous researches were performed for the sake of further exploration of issues on air coolers in various ways. As far back as late 1960s, Schulenberg [9] discussed the theory of the finned elliptical tube and its application, comparing with the circumstance of finned circular tube on the part of air-cooled heat exchangers. In the last few years, given thermal economic optimization, Kashani et al. [10] developed a thermodynamic model as well as its optimal design of an air-cooled heat exchanger plant, with the evaluation of pressure drops and outlet temperatures of streams both in air and tube sides. Du et al. [11] studied two types of finned tube heat exchangers in an indirect air-cooling tower experimentally, providing a contrast in comprehensive heat transfer performance. Manassaldi et al. [12] introduced a disjunctive mathematical model of air coolers targeting the optimal design pertaining to optimization criteria including the minimization of the total annual total cost and operating cost. Shirazi et al. [13] focused on a mathematical model for a gas turbine cycle with inlet air cooling by thermal, economic and environmental analysis, taking the thermodynamic and economic objectives into account. Lu et al. [14] performed an investigation into cooling issues on a practical operating cooler in a coal seam gas industry, showing cooling performance under different operating conditions.

### 1.2. Cooling water systems

The cooling water system (CWS) could fairly claim to be one of the major portions of industrial energy systems in the field of chemical processes, which can be classified into the once-through cooling water system and the circulating water cooling system [15]. Relatively speaking, heat recovery for energy synthesis and conservation of fresh water contributes to the preference of circulating water cooling systems, in contrast to once-through cooling water systems [16]. In consequence, among assorted kinds of water cooling systems, the open type circulating cooling water system is selected to evaluate in this work.

In recent years, none the less, most of studies in this field have obtained certain achievements to some extent. Panjeshahi and Ataei [17] extended the integrated ozone treatment cooling system design, intending to minimize cost and to maximize resource conservation. Souza et al. [18] studied the optimization of the hydraulic debottlenecking of cooling water systems through a MINLP problem, with comparison showing economic performance. Muller and Craig [19] explored the control of hybrid non-linear model predictive control (HNMPC) and economic HNMPC with the regard to the reduction of energy consumption and total cost for a dual circuit induced draft cooling water system.

### 1.3. Comparison among different kinds of cooling methods

Since different cooling methods have their own merits respectively, for the reasonable lectotype, comparison and evaluation deserve great attention. Alhazmy et al. [20] compared water spray cooling process with direct mechanical air-cooling systems in terms of energy analysis, with presentation of performance between two kinds of coolers, drawing a conclusion that the former is able to gain the maximum power and the latter is more appropriate for drier air conditions. Bolotin et al. [21] showed a comparative study of two types of evaporative air coolers: typical cross-flow evaporative air cooler and regenerative cross-flow evaporative air cooler, with the key target of analysis on the basis of numerical methods, coming to a decision that the typical cross-flow evaporative air cooler is more favourable with higher air flowrates, and the regenerative cross-flow evaporative air cooler is supposed to be operated under the condition of lower air flowrates. Jeng et al. [22] conducted a comparative study experimentally on the heat transfer characteristics and pressure drops of cross-runner heat exchangers with different configurations using air cooling and water cooling respectively, arriving at a conclusion that, the heat exchanger with rectangular punched holes forming cross-runners has the greatest commercial potential in both air cooling and water cooling.

### 1.4. The work in this paper

Although there have been a considerable number of researches on different cooling methods, rare studies have made a general analysis among these different cooling types, in the way of resource consumption and economic performance.

In this work, different types of cooling methods including DAC, SAC, EAC, and CWS are taken as candidates for cooler selection. When selecting a suitable cooling method, it is extremely necessary to consider not only environmental conditions corresponding to different seasons, such as dry bulb temperature and relative humidity, but also price factors consistent with different regions, which have large influence on economic performance of coolers. In this paper, the price ratio of fresh water to industrial electricity is regarded as the price factor of economic analysis, in order to choose the cost-optimal cooling type. Such work is not reported before. It can contribute to the reduction of both resource consumption and overall cost implementation, which is of vital importance to resource conservation and sustainable development of the process industry.

## 2. Mathematical model

In this section, the mathematical model for cooling methods will be introduced. The design of DAC and CWS can be built up by Aspen EDR, while the determination of parameters related to the calculation is based upon measures of heat transfer enhancement on referring to series of formulas.

### 2.1. Energy and water consumption of DAC

The module of air cooler is chosen in Aspen Exchanger Design and Rating (EDR), with the set of parameters including the flowrates of streams, physical property data concerned and so on, while air is selected as cooling medium under different relative humidity, bringing about data through simulation process, such as number of tube rows.

The film heat transfer coefficient outside surface ($h_o$) of the DAC is calculated as follows [23]:

$$h_o = 0.1378 \cdot \frac{\lambda_a}{d_r} \cdot \mathrm{Re}_a^{0.718} \cdot \mathrm{Pr}_a^{0.333} \cdot \frac{s_i}{h} \cdot \frac{A_i}{A_o} \tag{1}$$

where $\lambda_a$ refers to the thermal conductivity of air; $Re_a$ and $Pr_a$ are