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A Review on Cooling Towers of Power Plants

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Abstract: *Cooling towers are used in a variety of applications; from the 400-foot-tall towers at nuclear power plants to small 4 foot cooling boxes used by neighborhood dry cleaners. The most common use is in large building central cooling systems, but also used for refrigeration, cold storage facilities, dry cleaning, medical equipment, manufacturing and industry. Cooling towers are generally the most efficient means to remove large amounts of heat from air and equipment. Unfortunately, cooling towers use large amounts of water when properly maintained, and can waste greater amounts of water when not maintained properly through wasteful practices, inefficient equipment and leaks. Industrial cooling towers are used to remove surplus heat from water. In this study, a review study is carried out to investigate different types of cooling towers, their application, performance, usage and working principles, which can be useful in the field of nuclear plants as well as other energy stations. A number of investigations have been considered to reveal differences between the used cooling towers and finally a Fluent simulation has been carried out to examine major contours and flow field around the cooling tower.*

Keywords: Cooling tower, Heat exchanger, Nuclear Energy, Waste heat.

Introduction

Cooling towers are heat rejection devices used to transfer waste heat to the atmosphere through the cooling of a water stream. Cooling towers are mostly employed for cooling the circulating water used in power plants. A number of numerical and experimental studies have been done on the cooling towers. In this section, a summary of some valuable works is presented.

A P Chandra Shekhar et al [2022] The automotive, chemical and other plants employs use of cooling tower dissipating heat from water in to the atmosphere. The performance of cooling tower can be enhanced by various water modelling and energy consumption analysis. The current research reviews previous studies conducted in determination of effectiveness of cooling tower subjected to different operating conditions. The analytical equations are presented along with experimental data on evaluation and improvement of cooling tower performance.[1]

Ahmed Aboulmagd et al [2022] Cooling towers play a vital role in many large-scale process applications, and any decline in their performance has a considerable effect on the underlying process. It is known that the efficiency of a power plant is greatly affected by the temperature difference of the condenser. The objective of this paper was to produce cooling tower design recommendations and considerations that would prevent negative impacts and ensure stable and efficient operation. Computational fluid dynamics (CFD) was used to examine the components that contribute to cooling tower performance, using steady-state simulations and average weather data from the Egyptian Meteorological Authority. Air flow patterns in and around cooling towers were predicted using computational fluid dynamics. The current study includes a numerical analysis of the performance of the cooling tower at different wind speeds and heights of the cooling tower above the ground.

This study found that some wind speeds have a negative effect and others have a positive effect, and the height of the cooling tower above the ground has a positive effect on the performance of the tower.[2]

Guangjun Yang, et al [2020] Some previous studies show that the effect of wind speed has a negative impact on the cooling towers performance, while others say it is positive. Under poor working conditions, gas from a dry-cooling tower could not be released smoothly. As a result, the cooling tower's inner shell may have been severely corroded as a result. They created a simulation analysis for a natural-draught dry-cooling tower (NDDCT) with gas injection to evaluate contaminant transport and scatter [3].

A. Jahangiri et al [2019] The researchers discovered that injecting flue gas from steam generators into a natural draught dry cooling tower improves performance and suction capabilities. Injecting hot gas (at 130 °C) into the towers also increased air intake and improved the towers' thermal performance, according to the research [4].

A numerical analysis of closed wet cooling tower has been performed by Jiang et al. [2013]. They concluded that plate fin heat exchanger HMT coefficient and cooling Efficiency is a function of flow rate of air, process water temperature, spray water and process water. The results derived from numerical method are validated with experimental data. [5] Asvapoositkul et al. [2012] predicted cooling tower performance by specification of mass evaporation rate equation and also Evaluate acceptance test for new tower and monitor change in tower performance.[6]

heat and mass transfer has been analyzed by Lemouari et al. [2009] observed, two regimes during air/water contact inside the tower, a Pellicular Regime (PR) and Bubble and Dispersion Regime (BDR) in this investigated that BDR to be more efficient than PR as it enables to achieve more Evaporation rate and higher HMT coefficient using experimental method.[7]

Muangnoi et al. [2008] identify HMT properties of water and air and calculate Energy based on mathematical model to result shows that Energy supplied by water in larger than absorbed by air because of producing entropy by system. According to second law, Energy analysis, thermodynamic ambient temperature and humidity influence the performance of counter flow cooling tower founded by Muangnoi et al. [8].

Qi et al. [2008] have derived HMT characteristics of Shower Cooling Tower (SCT) without any assumptions without assumption but many authors have taken assumptions in literature to reduce complexity and computational time. The optimization of heat transfer rate and CT packing through proper water distribution of plane area has been done by Smrekar et al. [6] to improve the efficiency of NDCT. They found that it is possible by reduction of entropy generation and minimizing the exergy destruction.[9]

Kloppers et al. [2005] have derived HMT equation for CT. Various governing equations are derived from different methods such as poppe method, merkel method and effectives-NTU method and results compared together and also given its suitable application for different CT.[10]

Fisenko et al. [2004] have calculated HMT between water droplet and damp air, design parameter and ambient condition influence on efficiency of CT and describe boundary value problem of a system by ordinary differential equation using mathematical model.[11]

Facao et al. [2004] has Developed correlation between mass transfer coefficient and spray heat transfer coefficient and also evaluates error in CT efficiency. [12]

Ch.Indira Priyadarsini et al [2017] This paper deals with a natural draft wet-cooling tower with various inlet conditions. A commercial code FLUENT has been used to simulate the transport phenomena inside the tower. In this a 50 tons cooling capacity model has been taken as reference model. The developed model is analyzed with two air flow rates in vertical direction and by combining air inlet temperature and water inlet temperature. The developed model has been updated and the height of the water inlet is increased from the basin height and the same analysis is done by using the two flowrates of air and water into the system. It is observed that the temperature and humidity inside the tower are the main influence factors on the performance of cooling tower. It is also observed that due to increase in height to an optimum condition the performance of the cooling tower is increased and further increase in the height decreased its performance. Analysis shown that due to temperature of fluid inlet, cooling capacity of the tower has been improved with increase in air airflow rate when compared with natural aspirated air. A turbulence model of k-ε with energy equation is used for simulation. [13]

Power Plant

A thermal power plant is a power station where thermal energy is converted to electric power. In most of the places in the world the turbine is steam-driven. Generally, in the process water is heated, evaporated and spins a steam turbine and finally mechanical energy converted to the electric power by an electrical generator. This process can be well defined by on a Rankine cycle as shown in the Fig. 1.

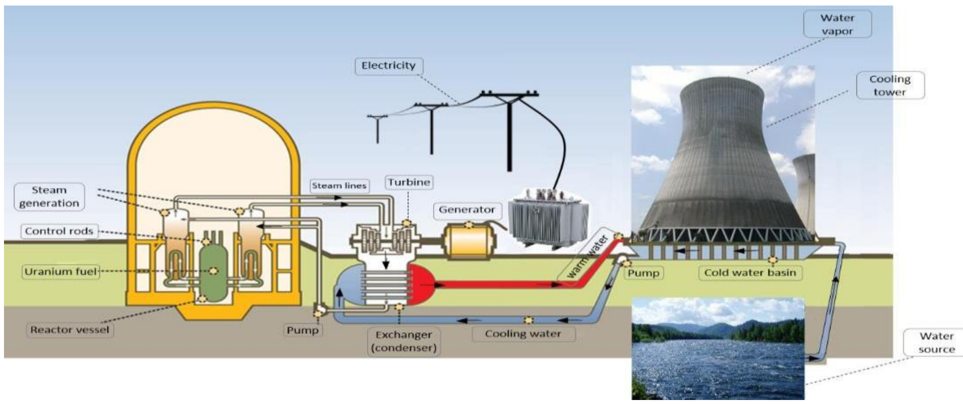

Figure 1: A schematic view of nuclear power plant with cooling tower and main components.

Heat Sources

The greatest variation in the design of thermal power stations is due to the different heat sources, which includes fossil fuel, solar thermal electric, nuclear, geothermal, waste incineration plants, and natural gas power stations (Fig. 2).

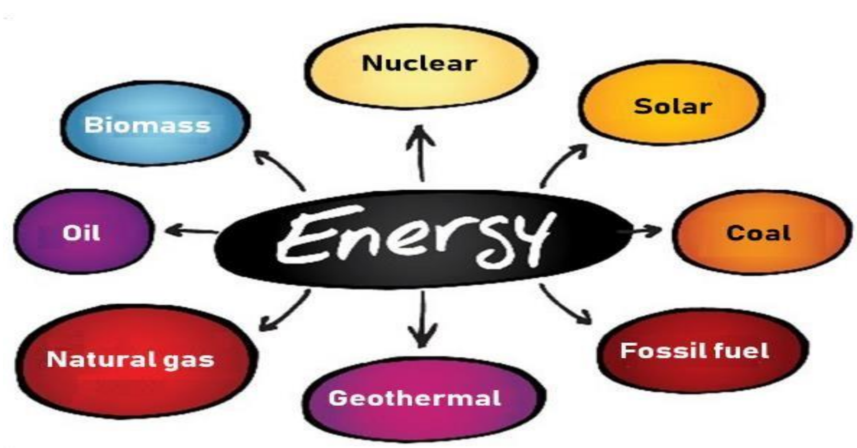

Figure 2: Heat sources to convert in thermal plants.

History of Cooling Towers

Development of steam engine was a first step in developing cooling towers originated in the 19th century, when condensers were used in the power generation systems. Condensers were used to condense the steam coming out of the turbines or cylinders.

In some areas with available large land, cooling ponds was used, but in big cities with limited land, the system took the form of cooling towers. Early towers were placed either on the rooftops or as free- standing structures. In 1901, an American engineer proposed a special design as a rectangular or circular shell which was similar to a chimney stack shortened vertically, but laterally enlarged very much. At the top is a set of distributing troughs, water from the condenser is pumped to top and then trickles down over wooden slats or woven wire screens, which fill the space within the tower. A hyperboloid forms of cooling tower was firstly patented by the Dutch engineers Gerard Kuypers and Frederik van Iterson in 1918 and were built in the same year near Heerlen (Gerard 1920).

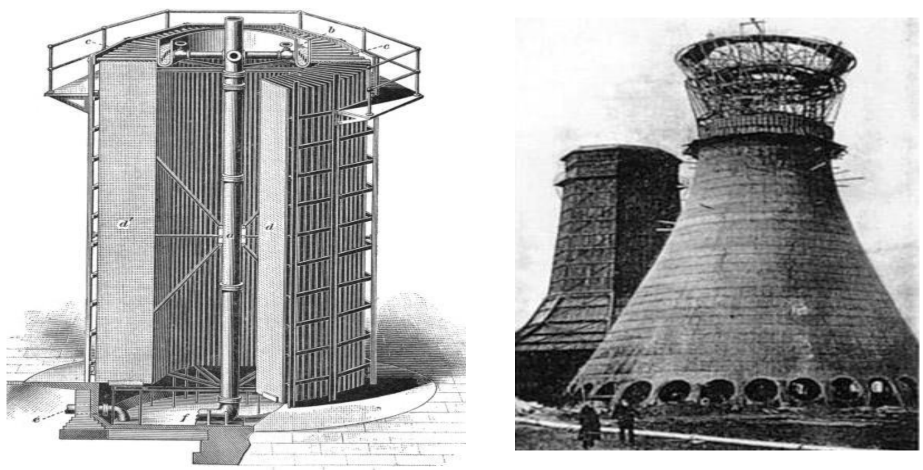

Figure 3: Barnard's fanless self-cooling tower (1902) relied on natural draft.

Classification by Use

Cooling towers are classified by use into either air-conditioning or industrial duty.

1. Air-conditioning (HVAC)

An HVAC cooling tower is a subcategory rejecting heat from a chiller. Water-cooled chillers are normally more energy efficient than air-cooled chillers. Large office buildings, hospitals, and schools typically use one or more cooling towers as part of their air conditioning systems.

2. Industrial cooling towers

Generally, industrial cooling towers are much larger than HVAC towers. Industrial cooling towers (shown in Fig. 4) are employed to remove heat from a thermodynamic process in the industrial power plants using circulating cooling water. Cooling towers are also used in petroleum refineries, petrochemical plants, food processing plants and semi-conductor plants.

Figure 4: Industrial cooling tower at a power station.

Air Flow Generation Methods

Generally, air flow through the tower is applied in two major methods;

Natural draft

In this type of cooling towers, heat transfer is completely occurred by natural convection via air circulating inside the cooling tower and warm, moist air naturally goes up due to the density difference with respect to the outside air, which produces an air flow through the cooling tower as displayed in Fig. 5.

Mechanical draft

Air fans are used in this method to circulate air through the cooling tower and generally are applied in two methods;

Induced draft: in this type, a mechanical fan at the discharge placed on top of the cooling tower is used to pull air through the tower. Axial fans are often employed in this kind of draft (Fig. 6 left).

Forced draft: in forced draft, a blower type fan is placed at the intake to force air into the cooling tower, which creates high entering and low exiting air velocities. Typically, forced draft consumes more power than that of induced types that is a disadvantage of this kind of drafts. Centrifugal and axial fans are used in this method (Fig 6. right).

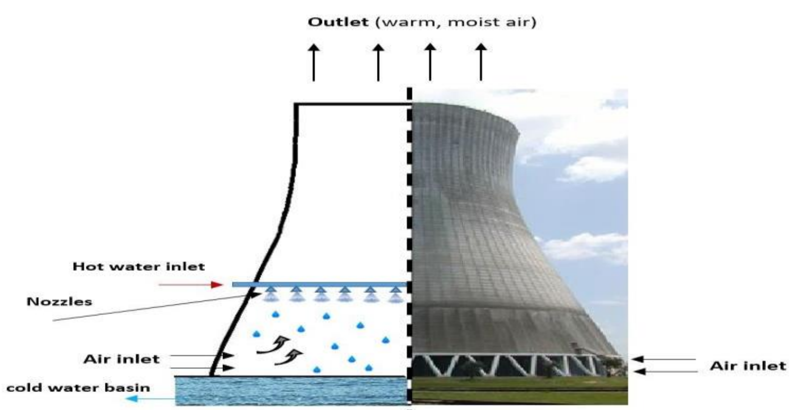

Figure 5: Natural draft cooling tower (wet type).

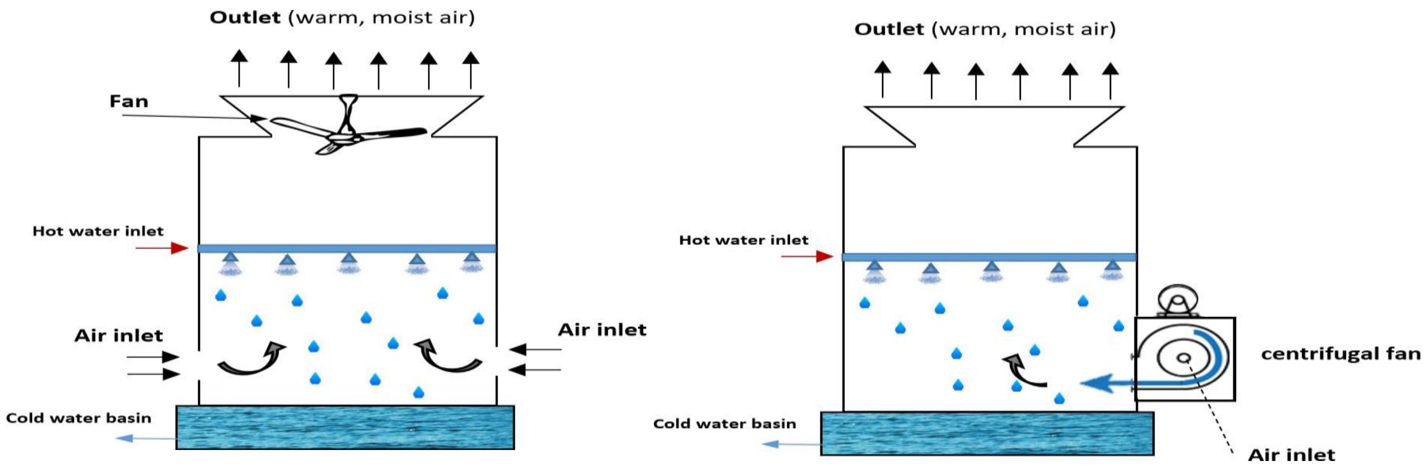

Figure 6: Mechanical draft induced type (left) and forced type (right).

Heat Transfer Methods

The main types of the heat transfer methods used in cooling towers can be classified as shown in Fig. 7 and described in following,

Dry cooling towers;

In this method, the working fluid is separated from ambient air and the process is approximately similar to tube type heat exchangers, and convective heat transfer has a major role in this method. Their shapes, are also similar to that of evaporating types except the internal construction. In general, a dry type cooling tower works at the same principles as an automobile radiator.

Wet or evaporating cooling towers;

The principle of evaporative cooling is used in this method. Direct contact of cooling water with air occurs within the cooling tower. Most of the heat is rejected by evaporating a portion of the circulating water, while a lower level of heat is also lost by heat transferring to the air.

Wet/dry type cooling tower;

This new proposed type of cooling tower as a mixed method can reduce water consumption to about 20% of the conventional wet type cooling towers (which is an undesirable issue to power plant cooling- systems). Fig. 8 shows the structure of Wet/dry cooling towers (Shen Chou1973).

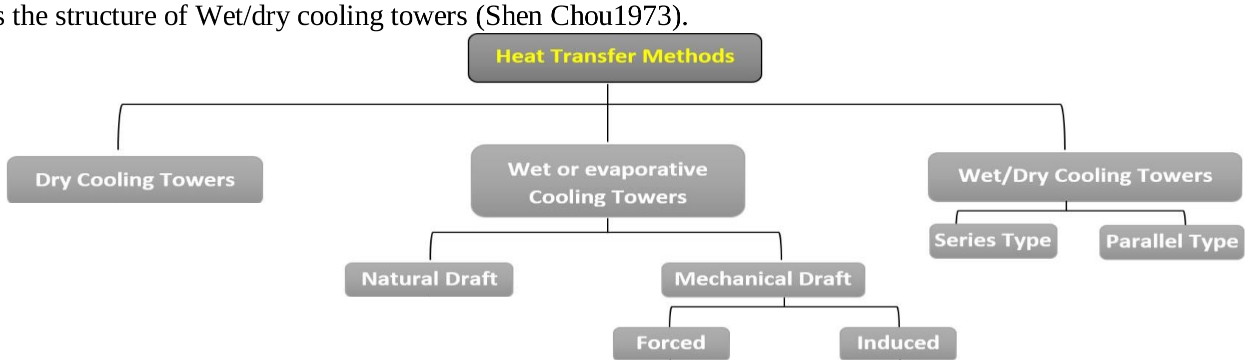

Figure 7: Heat transfer methods.

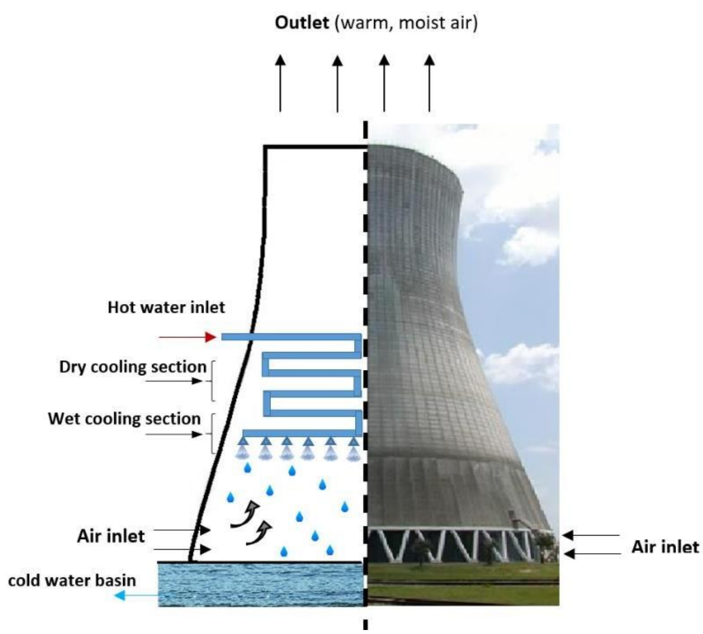

Figure 8: Wet / Dry type cooling tower.

Size of Cooling Towers

The towers size is designed regarding the required cooling performance and are either built in the site (in the case large towers) or in the factory (small towers). Towers size is different from small roof-top type to very large hyperboloid towers that are built even higher than 200 meters and 100 meters in diameter, or rectangular cases higher than 40 meters tall and 80 meters long. For increasing the efficiency of cooling tower one of tallest towers was built in Niederaussem Power Plant in Germany, which is a natural draft cooling tower and is also the largest shell structure in the world (Busch et al 2001).

Effects on Ecosystem

Without cooling tower and using once-through water for the aim of cooling, it would require huge amount of water and warmed water would have to be continuously returned to the river, lake or ocean, from which it was again obtained and resupplied to the power plant. In this regard, discharging warm water consumed in huge power plants may increase the temperature of the receiving lake or river and change the local ecosystem. The raised water temperatures can harm aquatic organisms, kill fish and other living creatures. On the other hand, cooling towers release a large amount of heat into the atmosphere instead, which spreads by wind over a much larger region than that of hot water can distribute local waters. Unfortunately, petroleum refineries also consume very large amount of water in cooling tower as well as coal-fired and nuclear power plants. Locating in coastal areas and using once-through ocean water, cooling towers should be examined for discharge water condition to avoid environmental pollution.

Conclusion

The basic characteristics of various types of cooling towers were analyzed using literature references to reveal differences of cooling towers in the term of structure, application and cooling principles. It was discussed that, cooling towers are an essential component of power plants like nuclear power stations as well as petroleum refineries, petrochemical plants and food processing plants. The working principles of natural draft and mechanical draft cooling towers were compared. Dry and wet types of cooling towers were also reviewed in this study. Finally, fluent software as a CFD program was employed to simulate a sample cooling tower and as a result major contours of the simulation were provided in this work.

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