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Research Paper

Power production limitations due to the environmental effects on the thermal effectiveness of NDDCT in an operating powerplant

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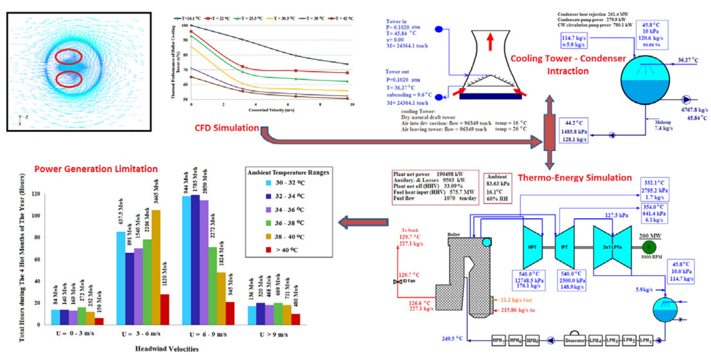
HIGHLIGHTS

- Headwind and air temperature effects on Heller cooling tower are CFD simulated.
- The thermodynamic cycle of shahid montazeri's powerplant is numerically modeled.
- The results are compared with the recorded data of shahid montazeri's powerplant.
- Heller tower behavior on the condenser's vacuum and net power are examined.
- Up to 50 MW (25%) of net power can reduce with highest headwind and temperature.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, the recorded operational data regarding one of the Heller towers in Shahid Montazeri powerplant has been analyzed by a 3-dimensional numerical study on its thermal effectiveness under different headwind and air temperature conditions.

The detailed thermodynamic cycle of this powerplant unit was simulated which has corroborated that the net power generation in this unit has been affected considerably by wind speed and air temperature. The results indicate that in conditions of increasing wind speed and ambient temperature, the Heller tower effectiveness decreases and consequently power generation in this powerplant unit is diminished. The negative effects resulting from the increased temperature is more beyond than that of the wind speed. However, both temperature and wind speed increase simultaneously will result in significant effects on the cycle thermal efficiency. Therefore, as the ambient temperature reaches as much as 25 °C higher than the designed temperature of the tower and wind speed is about 5 m/s, the limitation of power generation in this powerplant will be 50 MW. The average amount of power lost was calculated 24221.5 Mwh for 4 hot months of a typical year. This amount of power lost rated about 11% of the total energy that could be produced at this period of time in the design condition which is significant.

1. Introduction

In steam powerplants, any improvement in thermal performance of cooling towers will result in reduced temperature of condenser which in turn causes the powerplant efficiency to increase. Many powerplants around the world rely on NDDCT (Heller type) [1–4] due to lack of

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Nomenclature

A_c	surface area of the condenser (m^2)
C	specific heat capacity (J/kg·K)
D	bottom diameter of tower (m)
d	top diameter of tower (m)
g	gravitational acceleration (m/s^2)
G	turbulence kinetic energy generation (1/m^{2}s^2)
G_b	turbulence generation buoyancy (m^2/s^3)
$\vec{F}$	body force weight vector (N/m^3)
h	radiators height (m)
H	tower height (J/kg)
HPH	High Pressure Feed Water Heater (–)
HPT	High Pressure Turbine (–)
$\bar{h}$	convective heat transfer coefficient of heat exchanger (W/m^2·K)
IPT	intermediate pressure turbine (–)
k	turbulence kinetic energy (m^2/s^2)
K	thermal conductivity (W/m·K)
K_t	turbulent thermal conductivity (W/m·K)
LPH	low pressure feed water heater (–)
LPT	low pressure turbine (–)
$\dot{m}$	mass flow rate (kg/s)
P	pressure(Pa)
P_k	turbulence generation kinetic energy (m^2/s^3)
Pr	Prandtl number (–)
Pr_t	turbulent Prandtl number (–)
$\dot{Q}$	heat transfer source term (W/m^3)
$Q_{radiator}$	dissipated heat from Heller tower (W)
$Q_{radiator}^{act}$	dissipated heat from Heller tower at actual condition (W)
$Q_{radiator}^{max}$	dissipated heat from Heller tower at design condition (W)
$q"$	heat flux (W/m^2)
r	spherical radial coordinate (m)
t	time(s)
S_h	momentum source (kg/m^{2}s^2)
T	temperature(K)
T_{wi}	heat exchanger inlet water temperature(K)
T_{wo}	heat exchanger outlet water temperature(K)
T_{he}	mean temperature of the hot water (K)
T_{ai}	temperature of the air at the heat exchanger inlet(K)
T_{ao}	temperature of the air at the heat exchanger outlet (K)
$\vec{V}$	velocity vector (m/s)
U	wind velocity (m/s)
x	thermodynamics quality (–)

Greek symbols

β	volume expansion coefficient (1/K)
ε	turbulence dissipation rate (m^2/s^3)
ε_{th}	thermal performance of tower (%) (–)
μ	dynamic viscosity (kg/m·s)
ϑ	kinematic viscosity (m^2/s)
ρ	density (kg/m^3)
σ	stress tensor (Pa)
$\vec{\nabla}$	gradient operator (–)
ΔP	pressure drop a across the tower (Pa)
$\Delta P_{radiator}$	pressure drop through radiators(Pa)
$\Delta P_{louvers}$	pressure drop in the louvers (Pa)
ΔP_{skin}	friction drop due to the cooling tower skin (Pa)

Subscripts

a	air
act	actual
c	condenser
hw	headwind
max	maximum
ref	reference point
t	turbulence
w	circulating cooling water

water resources. According to Fig. 1, in these cooling towers, condenser's exit hot water is pumped into finned radiators (delta forgo type) arranged around the tower. Thereby, tower can cool down the circulating water to the condenser's temperature. Conversely these radiators suck the ambient air due to heat gain from the hot water. The heated air is then discharged to the environment through the tower top exit [3]. It was in 1961 when this system was first used in an Iron Fusion plant in Hungary and since then it has been popular in other countries where this cooling system used in plants [5]. In Iran, this indirect dry cooling system (Heller) started to be operationalized in 1979 in Shahid Montazeri thermal plant. Recently, some plants initiated to build Heller towers, too [6,7].

Several researchers have conducted studies on NDDCT both experimentally and numerically [8–14]. Environmental situations severely have an effect on Heller cooling tower's overall effectiveness. Temperature, density and the air flow sucked into the Heller tower will drastically affect its operation [13–18].

Recent research studies have focused on the thermal effectiveness of NDDCT. By increasing computing power of computers, methods based on computational fluid dynamics (CFD), could handle more detailed study on the flow and temperature field around the towers [16–18]. Demuren and Rodi [19], considered tower as a hollow cylinder and studied its temperature and velocity profiles numerically. Because of this simplification and ignoring the Boussinesq approximation, their work had a lot of errors and could not accurately predict the heat and flow fields.

Radosavljevic and Spalding [20] numerically modeled a 3-D wet cooling tower under head wind using CFD software. Leene [21] studied the physical function of a Heller tower. It was concluded that unequally distribution of inlet air flow around tower under strong head wind results exacerbated cooling towers static pressure dispersion.

Bergstrom et al. [22] developed a 2-D computer program for modeling inside of the cooling tower.

In Wei et al.'s [23] experimentation, adverse effects of wind condition on the efficiency of the cooling tower was tested.

They found the reasons of reduced cooling effectiveness under headwind as:

– Undesired pressure distribution at bottom of tower

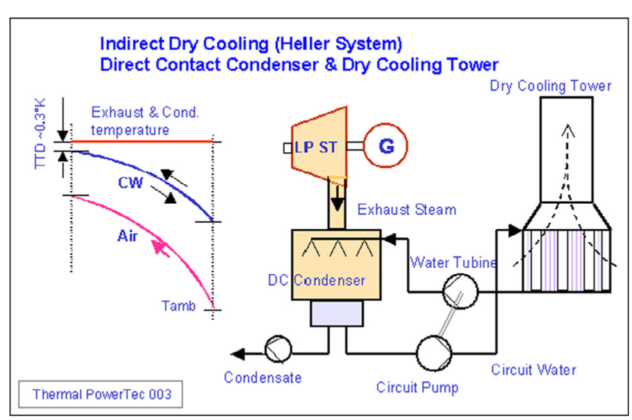

Fig. 1. Basic layout scheme of the dry cooling system [3].