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Energy, Exergy analysis and optimization of solar thermal power plant with adding heat and water recovery system

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ABSTRACT

Water scarcity and environmental impacts of the steam power plants blow down, is one of the growing concerns. During the evaporation of water in the steam cycle of the power plant, most of the impurities of water and vapor do not evaporate and remain in the boiler. By increasing the concentration of these impurities, boiler tubes are corroded. To adjust the concentration of these impurities, some of the water in the cycle is drained, which is called blowdown. Blowdown water has a high exergy content that is going to be wasted. In this study, by recovering a great amount of contained water and heat of power plant blow down, the entering wastewater to the environment is decreased and the total power of power plant is increased. This recovery system includes Evaporator and Vacuum pump. In this system a vacuum is created in the vaccum tank by vacuum pump which causes the water to evaporate and is injected into the steam cycle. The results show that by adding the recovery system, the amount of drained wastewater from the plant to the surrounding environment decreases from 3.118 kg/s to 1.799 kg/s. After Energy and Exergy analysis, it is shown that the output power increases by 0.53%, and the exergy returns from 20.73% to 20.84%. Also, the effect of the Evaporator vacuum on the output power and the amount of recovered water indicates that with the reduction of the Evaporator vaccum pressure, the amount of the output power is reduced, but instead due to further evaporation of the water, the amount of recovered water in the Evaporator will increase. After Energy and Exergy analysis, the results are optimized by the Genetic Algorithm. The inlet temperature of HPT1, inlet pressure of HPT1, outlet pressure from each turbine, and pinch point for the first heat exchanger are considered as decision variables. Optimization results show that by obtaining suitable decisions variable amounts, output power is increased from 34.01 MW to 34.92 MW. For evaluating the results on the power plant operation, SEGS VI power plant in the US (California) is used.

1. Introduction

In solar steam power plant to prevent corrosion in boiler tubes, some water in the boiler drum is drained, which is called blowdown. The blowdown has a high energy and exergy content that is going to be wasted. Because the concentration of total dissolved solids (TDS) in blowdown is very high, it is considered to be a wastewater that has harmful effects on the environment around the plant. So it is very beneficial to create a method that can recover a large amount of heat and water in the blowdown and increase the output power of power plant with recovered water. Many researchers have studied to optimize output power of power plants and their environmental impacts. One of the ways to increase the efficiency of the power plant is the simultaneous production of heat and power. Bade and Bandyopadhyay [1] proposed a new method to add a regenerator to gas turbine using a pinch analysis. Chacartegui et. al [2] investigated the effect of turbine inlet air cooling on the power plant performance. Urosevic et al. [3] calculated the power loss coefficients of a steam turbine in a combined cycle power plant. Can et al [4] studied the energy and exergy analysis on a combined cycle power plant. The other way to increase the plant's efficiency is to use new methods to reduce fuel consumption. Bidabadi et al. [5] increased the combustion efficiency in the boiler using a special scheme. They concluded that using counterflow schematic, in addition to increasing the boiler efficiency, the amount of pollutants produced would also decrease. Raval and Patel [6] provided suitable methods to reduce the auxiliary power in power plants, especially in compressors and pumps. Kotowicz and Michalski [7] analyzed the efficiency of the supercritical power plant as a function of the oxygen recovery rate. Barma et al. [8] investigated all of waste heat that occurred in the power plant. They concluded that blowdown losses account for about 1–3% of the fuel consumption. Also, they showed boiler feed water can be preheated by recovering waste heat from blowdown

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Nomenclature

T	temperature(°C)
s	entropy
C_p	specific heat capacity (J/kg K)
K	thermal conductivity
N	number of day
A	area
k	thermal conductivity
T_s	storage tank temperature (k)
T_p	average temperature of absorber tube
E_t	equation of time
h	convective heat transfer coefficient() specific enthalpy(kJ/kg)
W_a	Collector width (m)
m	mass(kg)
L	collector length(m)

Greek

ϵ	emissivity
η	energy efficiency
θ	incident angle
ν	viscosity
ρ	density

Subscripts

BD	blow down
HP	high pressure
LP	low pressure
dis	discharge
f	liquid phase
g	gas phase
HE	heat exchanger
tot	total
D_o	outlet diameter(m)
D_i	input diameter(m)
Y_D	irreversibility ratio
E_D	exergy loss
E_{sun}	sun exergy
U_L	overall heat transfer coefficient
$\dot{m}$	mass flow rate
t	Time(h)
F_R	heat transfer ratio
δ_c	declination angle
C_p	heat capacity
S_b	heat absorbtion
I_b	beam radiation

Abbreviations

Conv	convection
Cond	conduction
Kn	kinetic
OFWH	open feed water heater
CFWH	close feed water heater
CP	condense pump
PH	preheater
SG	steam generator
SH	super heater
FWP	feed water pump
RH	reheat
HPT	high pressure turbine
LPT	low pressure turbine
VP	vaccum pump

water with a heat exchanger and approximately 1% improvement on system's efficiency could be achieved. In [9], the rate of blowdown has been calculated according to the boiler pressure and the amount of heat that can be obtained from blowdown and used to preheating feed water is studied. A great volume of water that is used by industry all over the world is drained as wastewater to the environment. Many researchers have tried to minimize the drained wastewater of industries. Dexin Wang et al. [10] in 2012 recovered contained water and heat in the exhaust gas. The recovered water can be used directly for water makeup in the power plant boiler and increase its efficiency. Onishi et al. [11] distillated shale gas produced water by single and multi-effect evaporation and obtained the contained pure water in the wastewater. They concluded that, by using this system, a great amount of the contained water in the wastewater can be recovered. DePaepe and Dick [12] recovered injected water in combustion chamber with several condensers and compared them in terms of energy and economics. Wang et al [13] studied Using a nanoceramic membrane, the ability to recover the steam and its hidden heat from flue gas at a coal power plant. They concluded this method not only recover water, but also increase the efficiency of the power plant. Zhang et al. [14] recovered contained water in wastewater of a cooling tower of a power plant in the North of China by using ultrafiltration membrane. They used two membranes, A and B, for recovering water and concluded that in module A greater amount of Fe and Cu is omitted, while module B can omit more Phosphate and Silica. Ifaei et al. [15] analyzed a steam power plant by a new layout and low water consumption economically. They compared the new lay out with a typical one and concluded that in the new layout water losses are lower and the new one is a better alternative. In the other research [16], they investigated the new lay out of steam power plant as environmentally and concluded in regions that environmental-economic value of water is greater than 1.081 $/l, the new lay out of steam power plant is better. Frinjs et al. [17] studied the potential energy in domestic and urban wastewaters. They concluded that by recovering contained organic carbon in municipal wastewater, biogas can be generated and also by absorbing the contained heat in domestic wastewater, some amount of needed energy for houses can be supplied. Wang et al. [18] used combined method of Electro dialysis and Crystallizer to reduce the wastewater in the Vanadium extraction process. Farahbod et al. [19] minimized the drained wastewater of a petrochemical unit by adding a solar reservoir. For different wastewater purification systems in different scales life cycle assessment was done by Garcia et al. [20] and Piao et al [21]. Right now lots of countries, like Switzerland, South Africa, Egypt, Qatar, Australia, Tunisia, and Singapore are working on some projects for wastewater reuse in full scale mode [22].

Salgado et al. [23] reduced water consumption in rankine cycle by adding an absorption refrigeration system. They concluded water consumption is reduced from 1.12 m3/MWh to 5.58 m3/MWh. Although output power of power plant is reduced by 10% because in the new proposed layout two pumps are added. Davood Abadi Farahani et al. [24] recovered output wastewater from cooling tower in a steam power plant. To do this, they used two methods of coagulation-filtration (NF) and ultrafiltration (UF).

In this study, simulation and exergy analysis of a power plant with adding heat and water recovery system are performed. By recovering a much portion of blowdown with heat and water recovery system, not only reduces the harmful environmental impacts but also recover a great amount of energy to the steam cycle of the power plant. To the