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Energetic and exergetic analysis of a steam turbine power plant in an existing phosphoric acid factory

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ABSTRACT

An energetic and exergetic analysis is conducted on a Steam Turbine Power Plant of an existing Phosphoric Acid Factory. The heat recovery systems used in the different parts of the plant are also considered in the study. Mass, energy and exergy balances are established on the main compounds of the plant. A numerical code is established using EES software to perform the calculations required for the thermal and exergy plant analysis considering real variation ranges of the main operating parameters such as pressure, temperature and mass flow rate. The effects of theses parameters on the system performances are investigated.

The main sources of irreversibility are the melters, followed by the heat exchangers, the steam turbine generator and the pumps. The maximum energy efficiency is obtained for the blower followed by the heat exchangers, the deaerator and the steam turbine generator. The exergy efficiency obtained for the heat exchanger, the steam turbine generator, the deaerator and the blower are 88%, 74%, 72% and 66% respectively.

The effects of High Pressure steam temperature and pressure on the steam turbine generator energy and exergy efficiencies are investigated.

1. Introduction

The phosphate sector is one of the important key vectors for the Tunisian economy balance, both in terms of employment and in terms of the trade balance. The annual production of Phosphoric Acid is about 500,000 tonnes. Globally, the Tunisian phosphate industry occupies the 5th place among the largest international operators in this activity. Indeed, phosphate and its derivatives (phosphoric acid, DAP, TSP, DCP, etc.) are currently exported to about fifty countries in the five continents. While the industry is very important for the economy, it is considered among the largest energy consumers.

Many national programs are conducted in Tunisia in the purpose to improve the energy efficiency of the industrial sector, especially in the heavy industry factories such as the chemical industry field.

This study focuses on the analysis of a Steam Turbine Power Plant with heat recovery systems used in Phosphoric Acid Factory.

Energy and exergy analysis may be constituted as a key methodology for thermal system design and optimization. It is used to locate and determine the magnitude of irreversibility rates occurring in the streams and components of any energy system.

Many works were developed on energy and exergy optimization of industrial plants.

Vučković et al. [1] established an exergy analysis and exergoeconomic investigation of a real industrial plant constituting a part of a rubber factory. This plant is used to supply production unites, services and working spaces by steam, compressed air and cooling and hot water. The exergy efficiency and the exergy destruction rate of the main components of the plant are determined. The possibilities of plant performance improvement are suggested.

Kaushik et al. [2] presented a review on energy and exergy analysis of thermal power plant. A comparison between thermal power plant stimulated by coal and gas was made. For coal based thermal power plant, obtained results show that the highest energy loss is located in the boiler. While for gas fired combined cycle thermal power plant the maximum losses are located in the combustion chamber.

Ray et al. [3] developed an exergy analysis for proper operating and maintenance decisions in a 500 MW steam power plant. The study is conducted considering design and off-design conditions

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Nomenclature

AC	additional condenser
Bl	blower
cp	specific heat at constant pressure (kJ/kg K)
CU	concentration phosphoric acid unit
De	deaerator
DU	distillation unit
$\dot{E}$	exergy (kW)
h	specific enthalpy (kJ/kg)
HP	high pressure steam
LP	low pressure steam
MP	medium pressure steam
$\dot{m}$	mass flow rate (kg/s)
PAP	unit of phosphoric acid
Ph. A	phosphoric acid
R	gas constant (kJ/kmol K)
SMM	Sulfur melting and maintenance
STGI	Steam Turbine Generator I
STGII	Steam Turbine Generator II
T	temperature (°C)
Tb	turbine
TC	turbine condenser

Subscripts

0	reference state
CT	condenser of turbine
D	destruction
De	deaerator
da	dry air
e	energy
ex	exergy
Ge	gear
ha	humid air
in	inlet
out	outlet
Pm	pump
sw	seawater
v	water vapor
val	valve

Greek letters

ε	specific exergy (kW/kg)
η	efficiency
ω	air humidity ratio

for various values of superheat and reheats sprays. Obtain results constitute guide procedures for exergy, economy and maintenance scheduling similar power plants.

Aljundi [4] performed an exergy and energy analysis of a steam power plant with a capacity of 396 MW. The effect of the reference environment temperature variation on the exergy analysis of the consider power plant has been studied. The results showed that the exergy efficiency of the power cycle was about 25%. The rate of exergy destruction and the exergy efficiency, of each component, changed with reference environment temperature. The main conclusion indicates that the boiler is the major source of irreversibility in the system. Indeed the exergy destruction in the boiler system is about 77% of the fuel exergy input. The exergy destruction in the turbine, condenser and all heaters and pumps are respectively about 13%, 9% and 2%.

An exergy analysis for thermal power plant is conducted by Hou et al. [5] using Aspen plus software. The effects of main operating parameters such as combustion exes air coefficient, steam temperature and pressure and combustion temperature on the exergy efficiency are analyzed. The obtained results reveal that the boiler engenders the maximum irreversibility rates followed by the turbine. Furthermore the authors suggest that the increase of the combustion temperature as well as the steam pressure and temperature leads to improvement of exergy efficiency.

Regulagadda et al. [6] performed a thermodynamic analysis of a subcritical boiler–turbine generator for a 32 MW coal-fired power plant. Energy and exergy equation governing the cycle are established. A parametric study is conducted for a range of operating variables. That permits to define the optimum parameters leading to the best plant performances. The boiler and turbine engender the maximum exergy destruction rates in the power plant. The identification of the exergy losses in the different cycles has permitted to develop an environmental impact and sustainability analysis.

In the purpose to analyze the opportunities to improve the energy efficiency of existing lignite thermoelectric power plant of 300 MW, Koroneos et al. [7] was performed a comparative study between the indicated plant and three proposed combined heat and power systems CHP, working according to Rankine cogeneration cycle and using the same fuel mass flow rate. Therefore, different arrangements of recovery and cogeneration systems are adopted for the investigated CHP power plants. The main comparison criteria are based on the power production. According to analytic study, the authors confirm that it is possible to improve the efficiency of the existing power of about 8.5% by using the most efficient prosed CHP system.

A comparison between nine coal-fired power plants in Turkey is conducted by Erdem et al. [8]. For each plant a calculation model is proposed and the mass, energy and exergy balances are established. That permits to determine the energy and exergy efficiency as well the exergy destruction rate of each component. A comparison is then accomplished between the considered power plants. The obtained results may constitute helpful tools for further investigations in the field of energetic and exergetic industrial power plant analysis.

Ghannadzadeh et al. [9] developed a general methodology for exergy balance in chemical and thermal process integrated in the ProSimPlus code. In order to fully automate exergy analysis, the whole exergy balance of the system is presented under the form of single software. The essential elements for exergy analysis are provided that can be applied for every process or utility system.

An energy and exergy investigation of a cement plant was carried out by Atmaca et al. [10]. In order to assess the performance of the whole factory and their components, the authors are applied a mass, thermal as well as the exergy balances taking into account the variation of operating parameters. A set of performance criteria are defined in the aim to conduct this analysis.

Molés et al. [11] conducted a thermodynamic analysis of a combined organic Rankine cycle and vapor compression cycle system using two different fluids with low Global Warming Potentials GWP for each cycle. System performances are determined for ranges of operating conditions variations. Results show that the combined cycle COP varied between 0.30 and 1.10 while the computed electrical COP is varied between 15 and 110. Furthermore, for vapor compression system the selection of working fluid does not affect significantly the thermal and electrical efficiencies. Whereas, for ORC the working fluid has an important effect, especially on electrical efficiency.