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ENERGETIC AND EXERGETIC ANALYSIS OF STEAM TURBINE POWER PLANT IN AN EXISTING PHOSPHORIC ACID FACTORY

KHIR Tahar , HAFDHI Fathia
National Engineering School of Gabes – Tunisia
E.mail: taherkhir@Yahoo.fr - hafdhi.fathia@gmail.com

UNIVERSITÉ DE GABÈS University of Gabes جامعة قابس ENIG

1 Problematic and study object

The phosphate mineral is one of the important key vectors for the Tunisian economy balance. This mineral is used to produce several chemical products and fertilizers. Globally, the Tunisian phosphate industry occupies the 5th place in the world among the largest international operators in these activities.

Phosphate and its derivatives (Phosphoric Acid, Di-Ammonium Phosphate, etc…) are exported to about fifty countries in the five continents.
The annual production of Phosphoric Acid is about 500 000 tons.

Several Chemical Industrial Factories are implanted in different region of the country.
That constitutes an important factor for the national economic balance and employment rate.

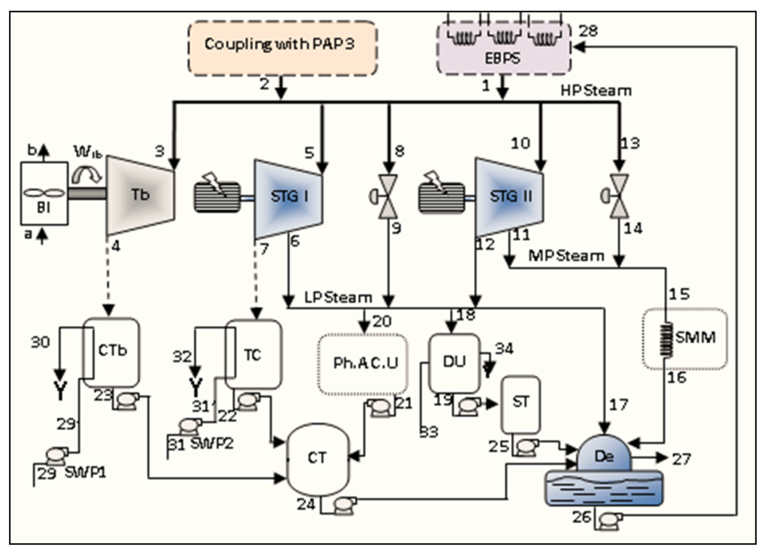
Despite the economic importance of the phosphate industry, it is considered among the largest energy consumers. In fact, the total annual cost of the energy production is very substantial.

To overcome this problem, the Tunisian Chemical Group (TCG) established programs in the purpose to improve the quality of production and increase the performance of the different plants.

In the frame of this program an optimization study on a thermal power plant used in a phosphoric acid factory is conducted. The obtained results will be presented as follows

2 Operating mode of the analyzed power plant

Diagram of the Phosphoric Acid Factory Power Plant



EBPS: Steam Generator Group
Tb: Turbo Blower
STG: Steam Turbine Generators
SMM: Sulfur Melting Unit
Ph A: Phosphoric Acid Concentration Unit
DU: Distillation Unit
De: Deaerator
Ctb, TC: Seawater Cooled Condensers

The STGI is with extraction and condensation,
while the STGII is with extraction and back pressure turbine

The Turbine Tb is used to drive the Blower Bl in the purpose to provide the required air flow rate used in the sulfur combustion furnace after drying

This Power Plant is used to provide
- Electrical Power (14 MW as net output power)
- Steam at MP and LP is used to supply the different utilities

Operating parameter ranges

Operating Parameters	Temperature Ranges (°C)	Pressure Ranges (Bar)	Mass Flow Rate
HP steam	386-395	39-41	179 (t/h)
MP steam	190	12	18 (t/h)
LP steam	165	5.7	135 (t/h)
Seawater	15-35	Input: 1 Output: 4	45 – 90 m^3/h for each pump
Seawater salinity	0.039 kg/kg		
Air Relative Humidity	0.45 – 0.8		

HP: High pressure used to feed STGI, STGII and Turbo Blower
MP: Medium pressure used to feed Sulfur Melting Unit
LP: Low pressure used to feed the other different utilities

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The main object of this study is to define the optimum operating conditions of the power plant leading to the maximum overall performance and the minimum exergy destruction rate.

Mass, Energy and Exergy balances are established for different components, that permits to define their exergy destruction rates and the exergy efficiencies.
The concept Fuel and Product is used to express the exergy efficiency

A code is established using EES software to perform the different calculations

3 Energy and Exergy Balances

STG I

$$\begin{cases} \dot{E}_{D,STGI} = \dot{m}_5(\varepsilon_5-\varepsilon_6)+(\dot{m}_5-\dot{m}_6)(\varepsilon_6-\varepsilon_7)-\dot{W}_{STGI} \\ \eta_{ex,STGI} = \dfrac{\dot{W}_{STGI}}{\dot{m}_5(\varepsilon_5-\varepsilon_6)+(\dot{m}_5-\dot{m}_6)(\varepsilon_6-\varepsilon_7)} \end{cases}$$

STG II

$$\begin{cases} \dot{E}_{D,STGII} = \dot{m}_{10}(\varepsilon_{10}-\varepsilon_{11})+(\dot{m}_{10}-\dot{m}_{11})(\varepsilon_{11}-\varepsilon_{12})-\dot{W}_{STGII} \\ \eta_{ex,STGII} = \dfrac{\dot{W}_{STGII}}{\dot{m}_{10}(\varepsilon_{10}-\varepsilon_{11})+(\dot{m}_{10}-\dot{m}_{11})(\varepsilon_{11}-\varepsilon_{12})} \end{cases}$$

Turbine Condenser TC

$$\begin{cases} \dot{E}_{D,TC} = \dot{m}_7(\varepsilon_7-\varepsilon_{22})+\dot{m}_{31'}(\varepsilon_{31'}-\varepsilon_{32}) \\ \eta_{ex,TC} = \dfrac{\dot{m}_{31'}(\varepsilon_{32}-\varepsilon_{31'})}{\dot{m}_7(\varepsilon_7-\varepsilon_{22})} \end{cases}$$

Tb Condenser

$$\begin{cases} \dot{E}_{D,CTb} = \dot{m}_4(\varepsilon_4-\varepsilon_{23})+\dot{m}_{29'}(\varepsilon_{29'}-\varepsilon_{30}) \\ \eta_{ex,CTb} = \dfrac{\dot{m}_{29'}(\varepsilon_{30}-\varepsilon_{29'})}{\dot{m}_4(\varepsilon_4-\varepsilon_{23})} \end{cases}$$

Steam Turbine

$$\begin{cases} \dot{E}_{D,Tb} = \dot{m}_3(\varepsilon_3-\varepsilon_4)-\dot{W}_{Tb} \\ \eta_{ex,Tb} = \dfrac{\dot{W}_{Tb}}{\dot{m}_3(\varepsilon_3-\varepsilon_4)} \end{cases}$$

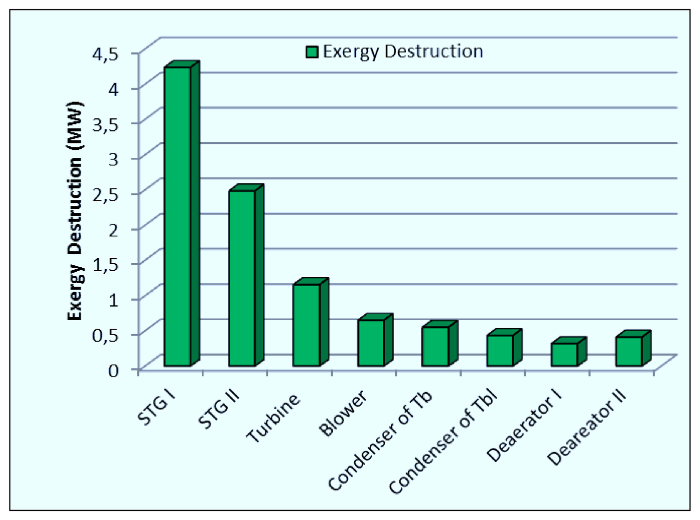
Blower

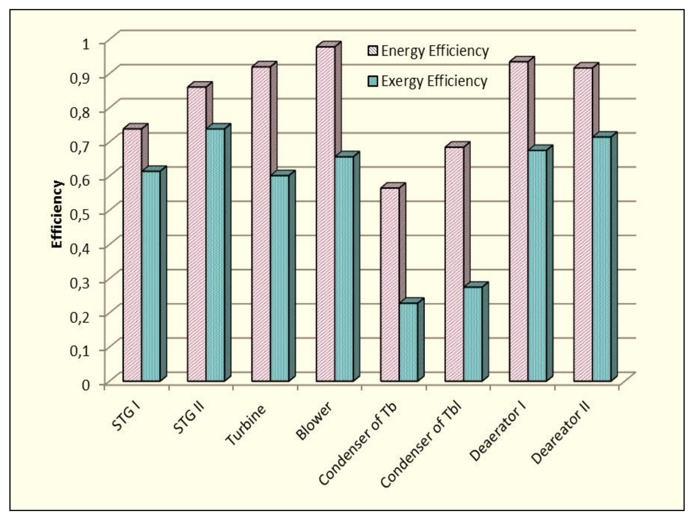
$$\begin{cases} \dot{E}_{D,Bl} = \dot{m}_{air}(\varepsilon_a-\varepsilon_b)-\dot{W}_{Bl} \\ \eta_{ex,Bl} = \dfrac{\dot{m}_{air}(\varepsilon_a-\varepsilon_b)}{\dot{W}_{Bl}} \end{cases}$$

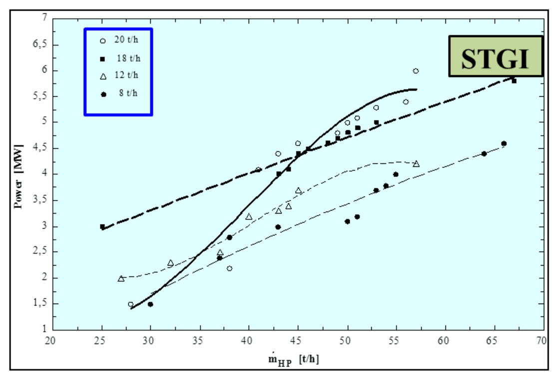
Deaerator

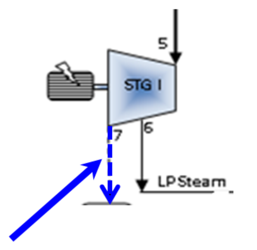
$$\begin{cases} \dot{E}_{D,TC} = \dot{m}_7(\varepsilon_7-\varepsilon_{22})+\dot{m}_{31'}(\varepsilon_{31'}-\varepsilon_{32}) \\ \eta_{ex,TC} = \dfrac{\dot{m}_{31'}(\varepsilon_{32}-\varepsilon_{31'})}{\dot{m}_7(\varepsilon_7-\varepsilon_{22})} \end{cases}$$

4 Results and Discussions





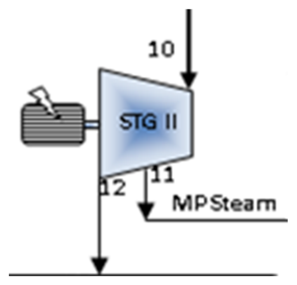


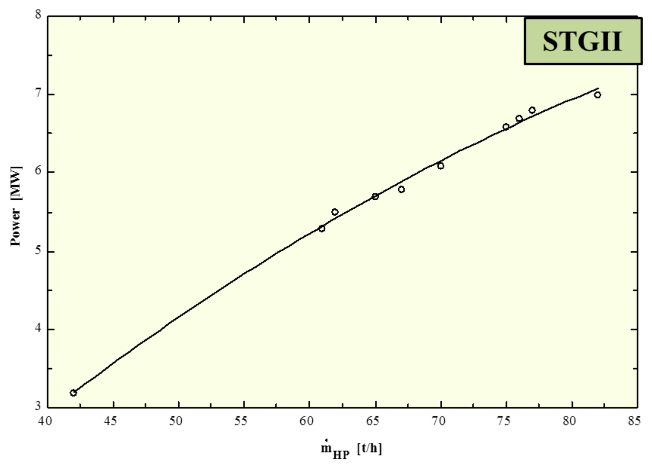


Condensation rate : Mass flow rate transferred to the seawater condenser (Point 7)

The generated power increases gradually with HP steam mass flow rate. For HP steam flow rate less than 35 t/h the generated power in not significantly affected by the condensation rate.

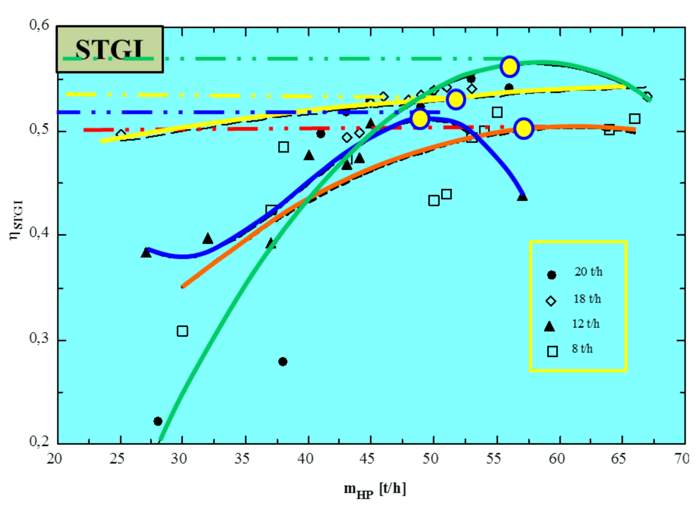
For HP mass flow rate above 40 t/h, increasing the condensate rate leads to the enhancement of the generated power. A maximum net power of about 6 MW is obtained for a condensation rate of 20 t/h .

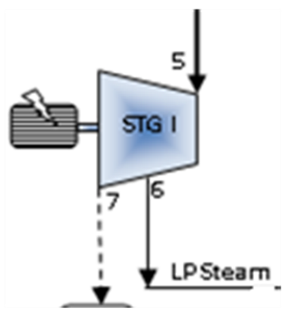




For the back pressure steam turbine STGII, The generated power increases linearly to achieve about 7 MW for a HP steam mass flow rate of about 82 t/h.

The total power generated by the two Steam turbines is widely sufficient for the plant requirements.





The exergy efficiency increases with HP mass flow rate to reach maximum values as follows:
50 % for condensation flow rates of 8t/h
51% for condensation flow rates of 12t/h
52% for condensation flow rates of 18t/h
56 % for condensation flow rates of 20 t/h

The optimum values of steam mass flow rate leading to the indicated maximum exergy efficiencies are:
55, 46, 52 and 54 t/h.

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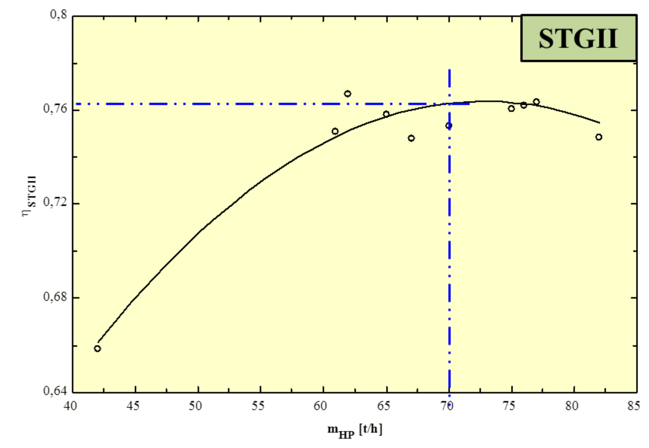
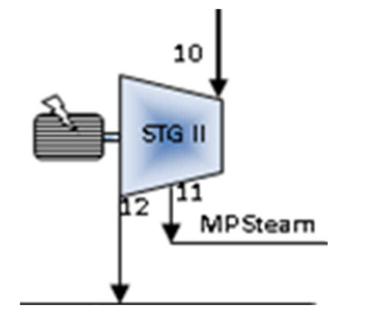
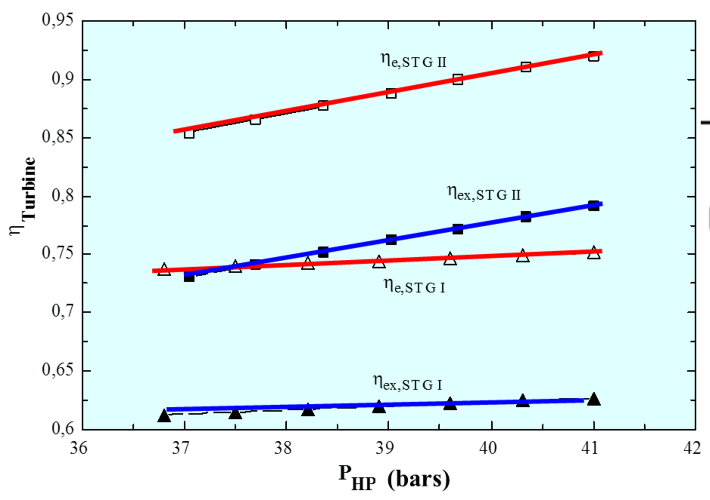
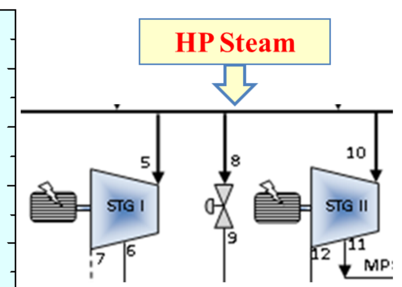




The exergetic efficiency increases sensibly with HP steam mass flow rate to reach a maximum value of about 75.5 % for a mass flow rate of about 73 t/h. That can be considered as an optimum value for the STGII supply.

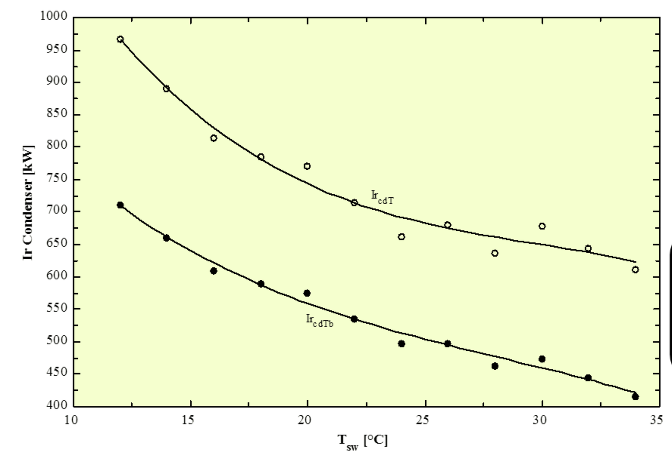


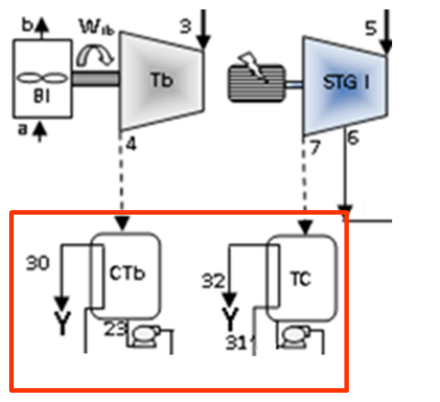


The energy and exergy efficiencies increase linearly with the pressure of steam.
For the explored ranges of pressure, the energy efficiencies increase of about 1.37 % and 8.8 % for STGI and STGII respectively.

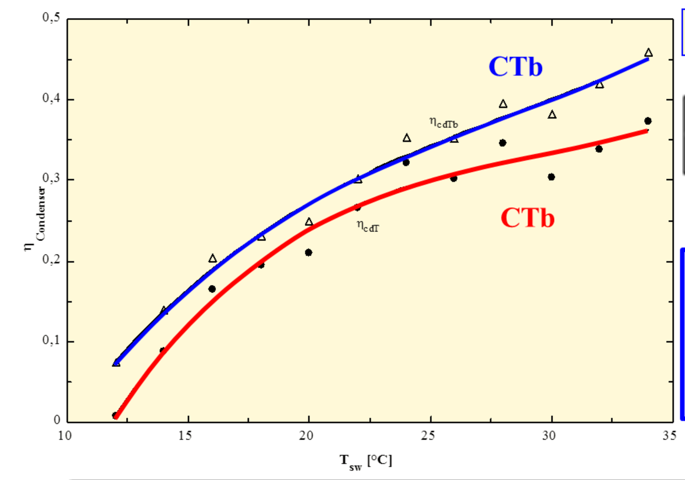
The exergy efficiencies increase of about 2.46 for STGI and 6.8 % for STGII.

The two seawater condensers of Turbo-Blower CTb and Steam Turbine TC are considered among the main components of the Power Plant. Their irreversibilty rates are affected by the seawater temperature

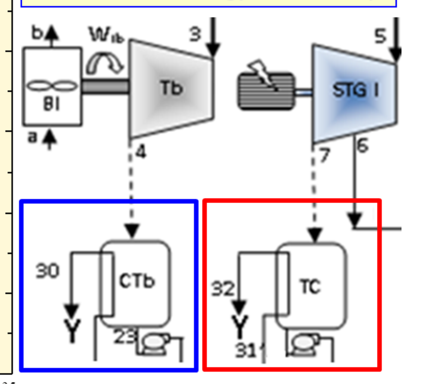




For Tsw variation from 12 to 34 °C, the irreversibility rates decrease of about 35 %.



Condenser exergy Efficiency



Increasing the seawater temperature from 12 to 24 °C leads to an increase of the exergy efficiency of about 6 times for the turbo blower condenser CTb and 14 times for the turbine condenser TC.

For T_{sw} above 25 °C the exergy efficiencies increase slightly to reach maximum values of about 35 % and 45 % for the turbine condenser and the turbo-blower condenser respectively.

5 Conclusion

The effects of the key operating parameters on the power plant performances are investigated (mass flow rate, HP pressure and temperature, seawater temperature..)

The Steam Turbine Generator STGI presents energy and exergy efficiencies of about 73 % and 57 % respectively.
While the STGII presents energy and exergy efficiencies of about 90 % and 76 % respectively.

The energy and exergy efficiencies of STGI and STGII increase slightly according to HP steam pressure

The optimum steam mass flow rates leading to the maximum net power and exergy efficiency are:
- ❑ About 55 t/h for STGI.
- ❑ About 73 t/h for STGII.

The seawater temperature affects significantly the exergy efficiency of the condensers. That should by taking into consideration for the operating conditions in cold seasons.

The obtain results constitute helpful tools to analyze the real performances of the existing power plants and permit to better undertake the future modifcations that can be carried out on the different streams in order to improve the efficiency and reduce the energetic losses.

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