

Modeling the cycle of a power plant gas turbine to improve performance by additional components

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Graduation Project – I

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Research Title:

‘Modeling the cycle of a power plant to improve performance of gas turbine and enhance production of electricity by additional components’

Company:

GAS TURBINE POWER PLANT BERROUGHIA ALGERIA / 500 MW
SIEMENS TURBINE HEAVY DUTY



1. Introduction

Energy, and in particular electricity, is a crucial resource for economic and human development. The availability of electricity underpins the provision of essential services such as education, bringing light into schools and homes, food safety through refrigeration, access to communication technologies and the improvement of the productivity of agricultural and economic activities. However, the United Nations Development Program (UNDP) estimated in 2005 that 1.6 billion people still had no access to a source of electricity – the majority of this population living in the least developed countries advances. Africa is particularly concerned: in around twenty countries, more than 75% of inhabitants do not have access to electricity, a difficult situation shared by Burma, Afghanistan, North Korea, Papua New - Guinea or Cambodia.

The gas turbine is a rotating engine that transforms heat energy into mechanical energy through a continuous process that compresses, heats and exhausts a gas. The first gas turbine was patented in 1791 in England by John Barber. In 1930, still in England, Frank Whittle filed the first of many patents for aviation jet engines, which were essentially gas turbines.

A gas turbine is a continuous flow, internal combustion machine which transforms the energy contained in the fuel into mechanical energy usable on the turbine shaft (industrial machines) or in the form of propulsive energy in a jet (turbojets). In its simplest architecture, the gas turbine, which draws in ambient air and releases burnt gases into the atmosphere, operates in an open circuit. It comprises a compressor and a turbine mechanically coupled on a shaft, and a combustion chamber inserted between these two bodies.

Gas turbines are power units whose use in the hydrocarbon industry is very widespread, given the high unit powers developed, easy adaptations, variable regimes of the operating processes and modes of operation disassembly in blocks which allow increasingly extended periods of operation between repairs.

To become electricity, energy must undergo a series of transformations before being transported and distributed in our homes.



There are several sources of energy. Some renewable energies have been known for a very long time, such as solar and wind.

Other, more recent energies such as marine energy.

1.1 Electricity produced in thermal power plants



Figure 1-1: thermal power plant.

The production of electricity based on fuel (gas, coal and uranium) consists of recovering thermal energy in the form of water vapor or hot gas, then using it to turn turbines, the latter the element driving force of electricity-producing turbo-alternators. In the end, the transmission of electrical energy will be done by high voltage transformers (220 KV to 1000 KV), this is to avoid joule losses at the transmission line level.



1.2 Electricity produced by wind turbines



Figure 1- 2: Electricity produced by wind turbines.

Wind turbines installed on land or at sea transform wind energy into electricity. A wind turbine consists of a mast and a propeller (or rotor blades). When the wind blows, the propeller turns. Like windmills, wind power depends on the strength of the wind. The energy produced then passes through a multiplier, a sort of gearbox, which accelerates the speed of the rotor. In its movement it drives a generator (a large dynamo), which, while rotating, converts the wind and produces electricity. The current produced then descends along the tower and joins the electricity distribution network.

1.3 Electricity produced by the sun

Inexhaustible and well distributed around the world, solar energy makes it possible to produce electricity through different capture processes.

1.3.1 The photovoltaic process

The production of electricity from solar energy is done using the photovoltaic process used on solar panels. The phenomenon of transforming light into electricity is what we call the “photovoltaic effect”.





Figure 0-1: Electricity production from solar energy.

A solar panel is made up of several cells. These cells are made of silicon, a semiconductor material contained in sand. The sun's rays strike the surface of the cells and set the electrons in motion. These electrons will move towards other nuclei creating electric current. The production of direct current is relayed to an inverter (converter) then converted into alternating current to be compatible with the electricity distribution network.



1.4 Electricity produced by geothermal energy



Figure 0-2 : geothermal.

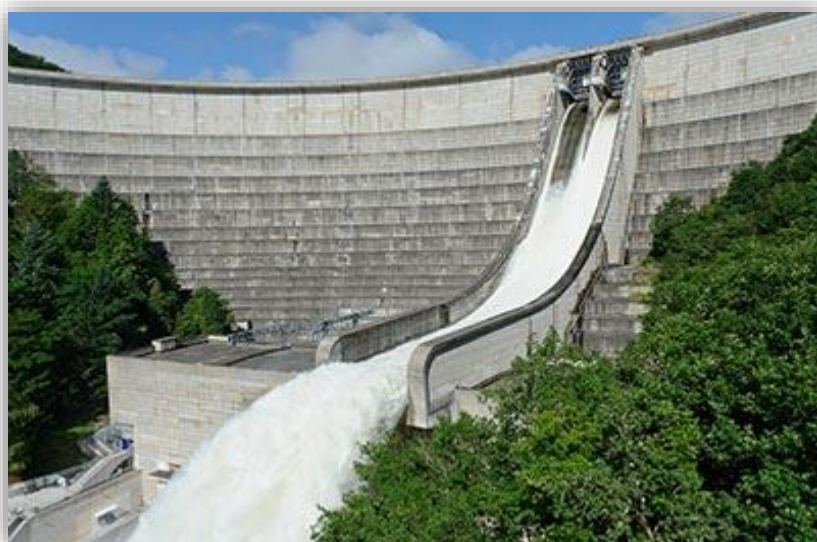
Geothermal energy refers to the recovery of heat from soils and in particular from underground hot water tables. A geothermal power plant is responsible for extracting very high temperature water contained in reservoirs in the basement. Hot water, once pumped to the surface, loses its pressure and turns into steam. At the exit from the well, the water and steam are separated. The steam will turn a turbine which, in turn, will turn an alternator and produce electric current. This current is now directed to a transformer, which will raise the voltage of the current to allow it to move easily through high voltage lines of the electricity transmission network.





1.5 Electricity produced from water in a hydraulic power plant

Electricity production through hydropower depends on the movement of water. For example, the force of water flowing in a river creates current and activates the rotation of a turbine. The force of a waterfall flowing between two height levels also causes a turbine to rotate. Water moving in a river can be retained in large quantities in a dam. When the valves open, water flows through pipes to reach the power plant. Thus, the movement of water turns a turbine, which in turn drives an alternator which produces electricity. The current is then directed to a transformer, which increases the voltage of the electricity to allow it to be distributed into the high voltage lines of the electricity distribution network..



2. Research problem:

Most electricity producing companies suffer, especially in the summer, from a large and increasing demand for electricity, which constitutes a major shortage of the population's needs, leading to many power outages.

Therefore, in-depth studies must be conducted on this company especially this kind of turbine and the factors that effect it, such as humidity, temperature, pressure, geographical location, and several other factors, so that we can find solution that are compatible with this company

The objective is to study the influence of the temperature as well as the ambient air pressure on the performance of the simple gas turbine, then for the other balances we will apply our solution to increase the electricity production efficiency and reduce toxic exhaust emissions NOX and CO at the lowest possible cost without expanding company's area.

3. References list:

- [1] Technique de l'ingénieur : *Turbine à gaz*.
- [2] SIEMENS GAS TURBINE SGT5-4000F (V94.3A).



Assignment 2

1. General description of the company

Shariket Kahraba Berrouaghia SKB Spa gas turbine power plant is part of the diversification of electricity producers on the national market. It is the 3rd independent electricity producer on the Algerian market.

It was created on October 27, 2004. Its objective is the construction, operation and maintenance of the electricity production plant, as well as the marketing of the electrical energy produced.

2.2 Site location

The site is near the town of Berrouaghia which is 130 kilometers southwest of Algiers, capital of Algeria.

Nearest major city - distance	Médéa - 30 km
Nearest port - distance	Algiers - 130 km
Nearest airport - distance	Algiers - 130 km
Nearest road	RN 18
Approach route - type and width	7 m wide asphalt road

1.5.1 Geographic data

- Average altitude above sea level: 928 m.
- Average, maximum and minimum temperature are 15.5°C, 40°C and - 4°C respectively.



Figure 0-1 : site location

1.5.2 Installation technique

The Berrouaghia Power Plant was commissioned in July 2007 and is equipped with two (02) gas turbines totaling a total plant power of 489.3 MW at nominal site conditions (Altitude: 928 m NGA, Average temperature + 15.5° C, Average humidity 67%)

The power plant is equipped with two (02) SIEMENS gas turbines of type V94.3A(4) SGT5-4000(E) and two SIEMENS alternators (WESTING HOUSE-USA) of type sGen5-1000A with a power of 308 MVA and a voltage of 16.5KV per group.

The turbines and alternators of the production units are installed in the engine room and the two units are operated from a control room.

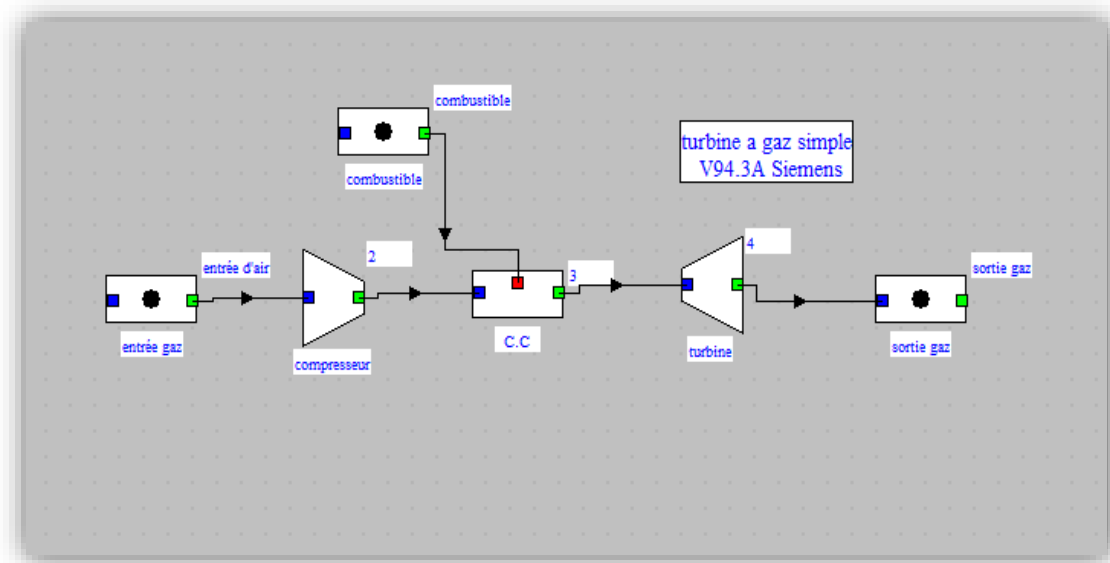
Research question?

How we can to increase the electricity production efficiency and reduce toxic exhaust emissions NOX and CO at the lowest possible cost without expanding company's area? in all seasons not only in summer, so that there is a stable and sufficient production, the important thing is to adopt the same setting so the turbine are not affected?



2. Representation of the Simple gas turbine on THERMOPTIM and calculate its efficiency

Création du schéma



This gas turbine burning natural gas without dissociation draws in air at 10°C and 0.9966 bar and compresses it to 14.949 bar with a flow rate of 650 Kg/s in a compressor with a poly-tropic efficiency of 0.8976, then the burned gases are expanded in a turbine with poly-tropic efficiency 0.8654, The turbine inlet temperature is 1166.74 °C.

The cycle was modeled using thermodynamic analysis for the simple gas turbine. For entry conditions “ambient temperature and pressure”

- Enter the state of the body at the “air inlet” point. We know its pressure (0.9966 bar) and its temperature (10°C)
- For point (2), its pressure is ‘ $p = 14.949$ ’ bar and its temperature 386.41°C, poly-tropic efficiency equals 89.76%



transfo: type:

type énergie: ☐ débit imposé

point amont: m ΔH: ☐ système fermé ☐ observée

entrée d'air: T (°C) P (bar) h (kJ/kg) titre

point aval: ☐ système ouvert

rend. polytropique: ☐ adiabatique ☐ non adiabatique

exposant polytropique: ☐ référence isentropique ☒ référence polytropique

rapport de pression (>= 1): ☐ calculé ☒ imposé

☒ Imposer le rendement et calculer la transfo ☐ Calculer le rendement, le point aval étant connu

The thermal efficiency of the TAG of the simple cycle obtained is 38.73% with a useful energy equal to 246,555 MW.

Nom du projet : turbine a gaz

6 POINTS

nom du point	corps	P (bar)	T (°C)
entrée d'air	air	0,9966	10
2	air	14,949	386,40811
combustible	gaz_de_Montoir	28,5	30
3	gaz_brulés	14,949	1 166,74
4	gaz_brulés	1,0128	550,69033
sortie gaz	gaz_brulés	1	550,69

6 TRANSFOS

nom transfo	point amont	point aval	type transfo
sortie gaz	4	sortie gaz	échange
combustible	combustible	combustible	échange
entrée gaz	entrée d'air	entrée d'air	échange
compresseur	entrée d'air	2	compression
turbine	3	4	détente
C.C	2	3	combustion

0 NOEUDS

nom	type	veine principale
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Schéma associé : **0 PRESSIONS IMPOSEES**

nom	valeur
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Turbine a gaz V94.3A cycle simple

Bilan

efficacité:
 énergie utile:
 énergie payante:

☒ débit auto verrouillé

types invalidés:
 types calculables:

0 ECHANGEURS DE CHALEUR

nom	type	fluide chaud	fluide froid
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Figure 0-2: final of TAG.



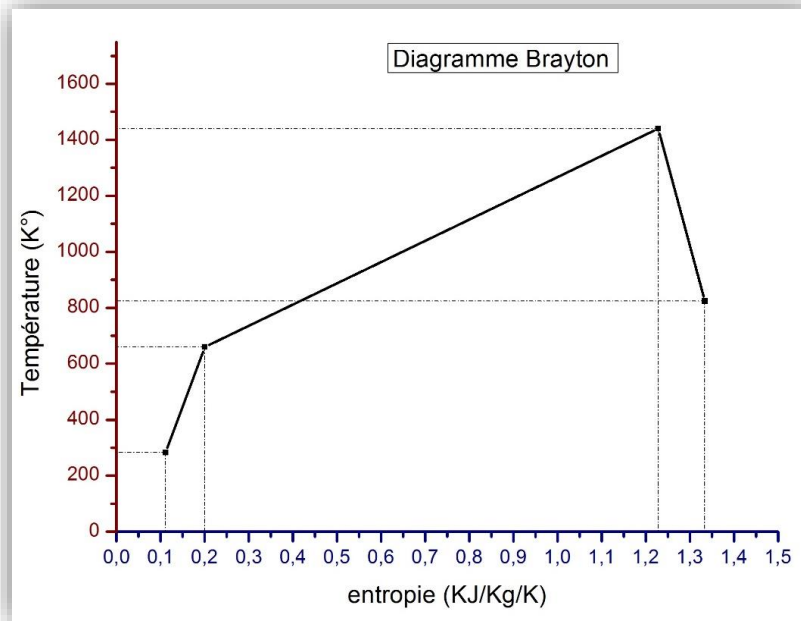


Figure 0-3: cycle simple brayton of TAG with « ORIGIN 8 ».

3. Discussion

Pressure losses are assumed in this study. The effect of thermal efficiency, power and specific fuel consumption on operating conditions is analyzed in the following section.

Effect of ambient temperature:

Simple gas turbine at different times, PCI = 48713.22						
%	°C	MW	MW	kg/s	KJ/KWH	Kg/KWH
Yield	Temps	useful energy	paid energy	gas flow	CS	CSC
39,36	-5	260,4065	661,5952	13,5784	9146,2485	0,1877
39,15	0	255,7817	653,2539	13,4072	9194,2280	0,1887
38,94	5	251,1647	644,9210	13,2361	9243,8053	0,1897
38,73	10	246,5559	636,5965	13,0653	9295,0480	0,1908
38,28	20	237,3358	619,9736	12,7241	9403,9956	0,1930
37,81	30	228,1804	603,3871	12,3837	9519,6289	0,1954
37,32	40	219,0643	586,8388	12,0441	9643,8215	0,1979

Table-1: shows effect of ambient temperature on the efficiency and useful energy of the TAG.



Dusccusion:

Thermal efficiency with different combustion chamber outlet temperatures for different compression ratios. By increasing the turbine inlet temperature, the thermal efficiency increases. On the other hand, the increase in compression ratio leads to an increase in the thermal efficiency of the gas turbine cycle.

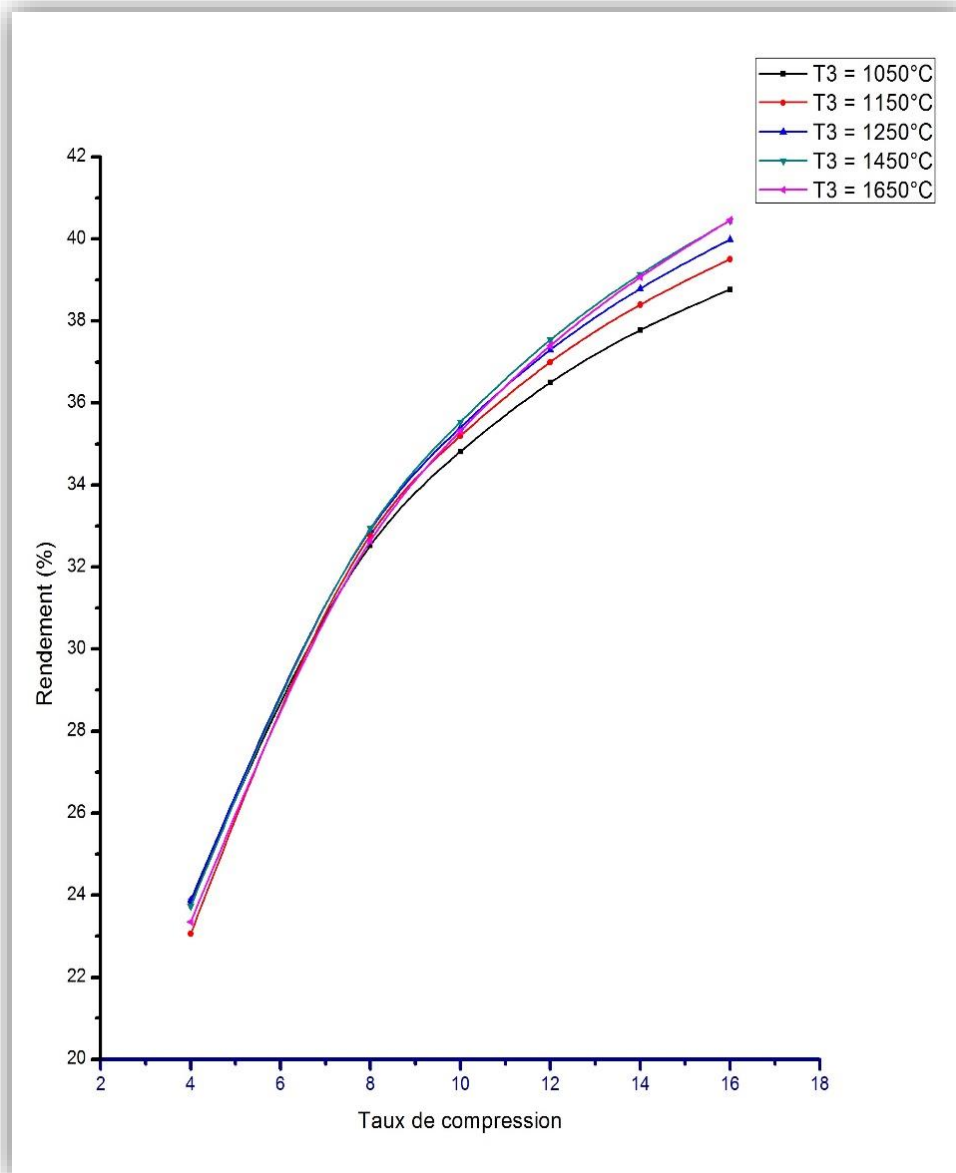


Fig 0-4: variation of efficiency as a function of different turbine inlet temperature.



4. Conclusion

This work describes an exegetical and theoretical analysis of the influence of ambient conditions on the performance of a gas turbine. Detailed research was done to predict the performance of a real gas turbine cycle.

In simple cycle, thermal efficiency always increases with increasing compression ratio, increasing ambient temperature caused a decrease in thermal efficiency, but increasing turbine inlet temperature increases the thermal efficiency.

Power output and thermal efficiency increase with compressor and turbine efficiency, also with increasing the compression ratio to 16.



5. Researche Hypotheses and model

Analysis of a cycle of a regenerative gas turbine for efficiency evaluation

The effect of a regenerative heat exchanger in a gas turbine is analyzed using a regenerative 'Brayton' cycle model, where all global irreversibilities in the heat exchanger are taken into account by means of an efficiency effective. The regenerative gas turbine cycle has higher cycle efficiencies than the simple cycle operating under the same conditions. Power output, efficiency and specific fuel consumption are simulated based on operating conditions.

Analytical formulas on the relationship for determining thermal efficiency are derived taking into account the operating conditions (ambient temperature, compression ratio, regenerator efficiency and turbine inlet temperature).

Model calculations for a wide range of parameters are presented, as well as comparisons with a simple gas turbine cycle. Power output and thermal efficiency increase with regeneration efficiency and compressor efficiency.

Efficiency increases with increasing compression ratio to 16, then efficiency decreases with increasing compression ratio, but in simple cycle, thermal efficiency always increases with increasing compression ratio.

Increasing the ambient temperature results in a decrease in thermal efficiency, but increasing the turbine inlet temperature increases the thermal efficiency.



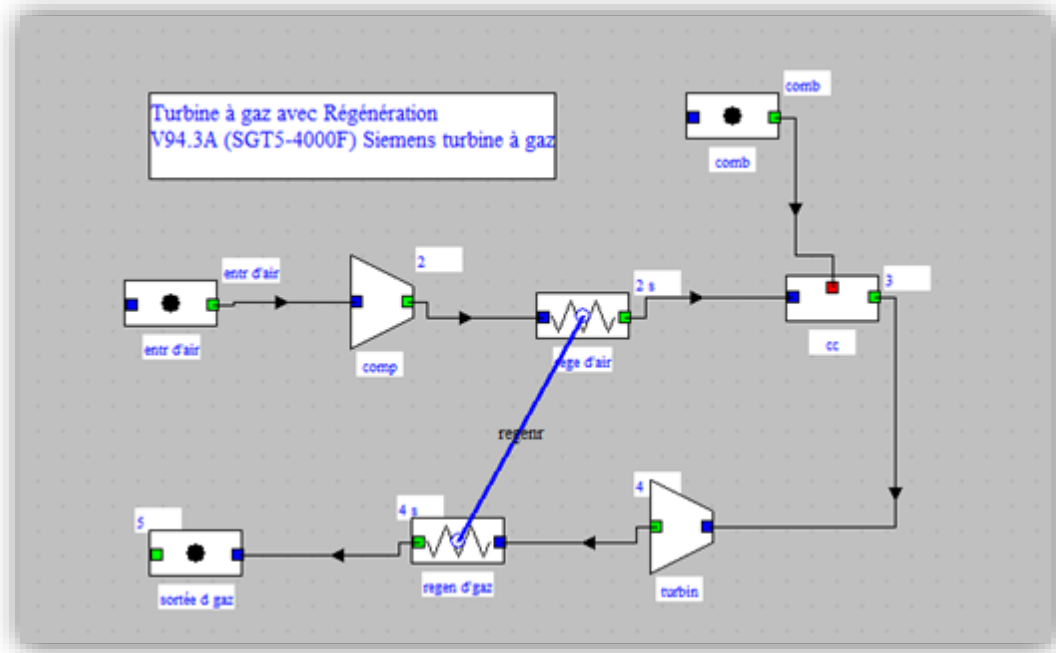
Suggested structure:

The idea is to find a gas turbine regenerator that uses the gas turbine regeneration cycle to transfer heat from the turbine exhaust gas to the compressor discharge air.

CHOICE OF A REGENERATOR



6. Representation of the gas turbine with regeneration on THERMOPTIM and calculate its efficiency



1.5.3 Setting points

For the inlet conditions “ambient temperature and pressure” of the TAG regenerate is the same as the TAG without regeneration.

The cycle was modeled using thermodynamic analysis for the simple gas turbine and the regenerative gas turbine.

1.5.4 Air entry and compression

Figure 4.5-1 represents

- Enter the state of the body at the “air inlet” point. We know its pressure (0.9966 bar) and its temperature (10°C)
- For point (2), its pressure is ‘ $p = 14.949$ ’ bar and its temperature 386.41°C, poly-tropic efficiency equals 89.76%



The screenshot shows a software window for configuring a compression process. It includes the following elements:

- transfo:** Set to 'compression'.
- type:** Set to 'compression'.
- type énergie:** Set to 'utile'.
- point amont:**
 - entr d'air: Set to 'affichage'.
 - T (°C): 10
 - P (bar): 0.9966
 - h (kJ/kg): -14.88
 - titre: 1
- point aval:**
 - Set to 'affichage'.
 - T (°C): 386.41
 - P (bar): 14.949
 - h (kJ/kg): 372.48
 - titre: 1
- débit:** 650
- m ΔH:** 251.781,24
- Q:** 0
- liens:** Buttons for '<', '>', 'Sauver', 'Supprimer', and 'Fermer'.
- système fermé / système ouvert:** Radio buttons, with 'système ouvert' selected.
- adiabatique / non adiabatique:** Radio buttons, with 'adiabatique' selected.
- référence isentropique / référence polytropique:** Radio buttons, with 'référence polytropique' selected.
- rend. polytropique:** 0.8976
- exposant polytropique:** 1.45402
- rapport de pression (>= 1):** 15
- calculé / imposé:** Radio buttons, with 'imposé' selected.
- Imposer le rendement et calculer la transfo:** Selected.
- Calculer le rendement, le point aval étant connu:** Not selected.
- Calculer:** Button to perform calculations.

Fig 1.5-5 : air entry and compression

1.5.5 Configuration and some notions about the regenerator

As we have indicated, the new model uses a new component, the regeneration exchanger, called “regenerator” and placed between the exhaust gases and the compressed air.

The coupling between two exchange transformers called “air regeneration” and “gas regeneration” is ensured.

We need five constraints to parameterize the regenerator and the quantities are:

The four fluid temperatures $T_{(fe/fs)}$ and $T_{(ce/cs)}$, as well as the air flow entering the exchanger, making a total of five constraints.

The two temperatures T_{fs} and T_{cs} are obtained through several manipulations on the ‘THERMOPTIM’ to set the temperature T_3 and the exhaust temperature.



nom type

fluide chaud

Tce (°C) ☒ imposé ☐ calculé

Tcs (°C) ☒ imposé ☐ calculé

mc ☐ imposé ☒ calculé

Cpc

m ΔHc

☒ non contraint

☐ pincement minimum DTmin

☐ efficacité imposée epsilon

fluide froid

Tfe (°C) ☒ imposé ☐ calculé

Tfs (°C) ☒ imposé ☐ calculé

mf ☒ imposé ☐ calculé

Cpf

m ΔHf

UA

R

NUT

DTML

☒ dimensionnement ☐ non nominal

The thermal efficiency of the TAG with regeneration obtained is 39.67% with a useful energy equal to 246,014 MW.

Nom du projet : turb a gaz avec rege

Schéma associé :

8 POINTS

nom du point	corps	P (bar)	T (°C)
entr d'air	air	0,9966	10
2	air	14,949	386,40811
2 s	air	14,5	408
3	gaz brûlés	14,5	1 166,74
comb	gaz de Mont...	28,5	30
4	gaz brûlés	0,982385	550,25088

8 TRANSFOS

nom transfo	point amont	point aval	type transfo
sortée d gaz	4 s	5	échange
regen d'gaz	4	4 s	échange
comb	comb	comb	échange
rege d'air	2	2 s	échange
entr d'air	entr d'air	entr d'air	échange
comp	entr d'air	2	compression

0 NOEUDS

nom	type	veine principale
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0 PRESSIONS IMPOSEES

nom	valeur
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Bilan

efficacité

énergie utile

énergie payante

☒ débit auto verrouillé

types invalidés

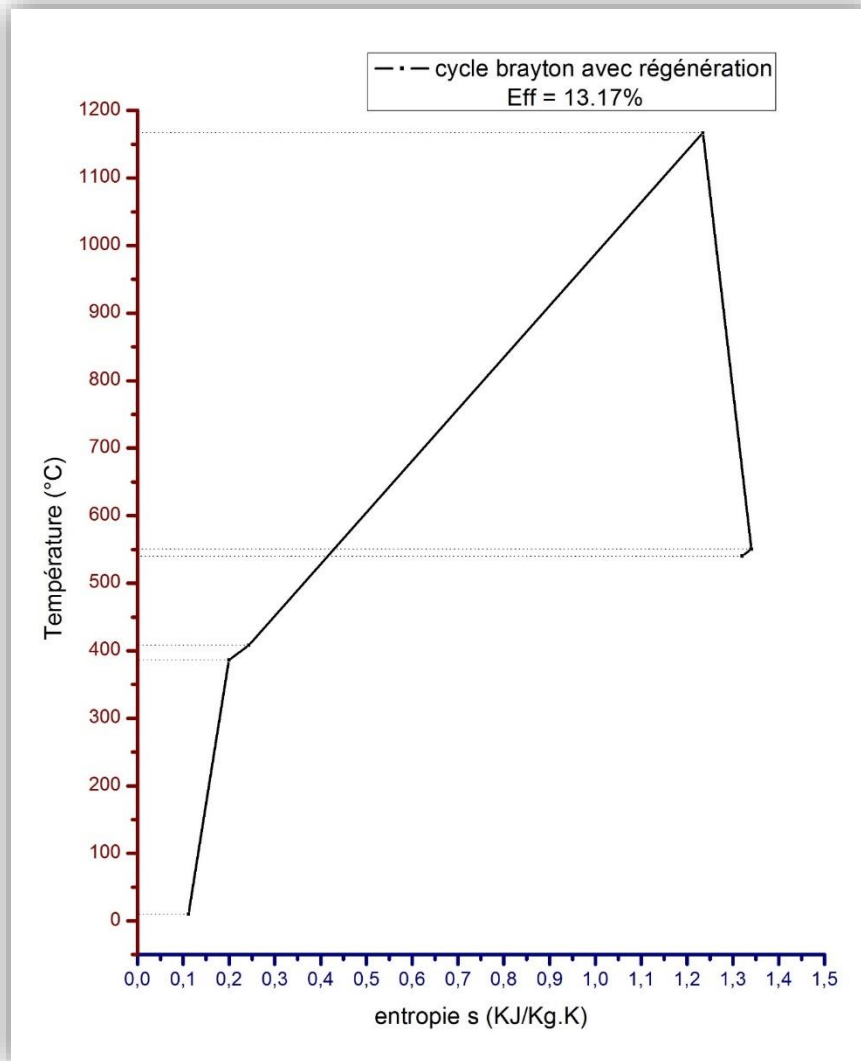
types calculables

1 ECHANGEURS DE CHALEUR

nom	type	fluide chaud	fluide froid
regenert	contre-cou...	regen d'gaz	rege d'air

TAG V94.3A avec Régénération





1.6 Discussion

The cycle was modeled using thermodynamic analysis for the simple gas turbine and the regenerative gas turbine. Pressure losses are assumed in this study. The effect of thermal efficiency, power and specific fuel consumption on operating conditions is analyzed in the following section.

1.6.1 Effet de la température ambiante

Picture shows the effect of ambient temperature and regeneration efficiency on the thermal efficiency of the gas turbine cycle. The turbine inlet temperature T_p and its efficiency are 1166.74°C, 15 and 0.85 respectively.

