

1.1 Analysis cycle of a regenerative gas turbine for efficiency evaluation

1.2 Summary

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.



CHOICE OF A REGENERATOR

PAL-TEX
REGENERATOR



A gas turbine regenerator is a heat exchanger that uses the gas turbine regeneration cycle to transfer heat from the turbine exhaust gas to the compressor discharge air.



2 Generality

A need was seen for a more efficient and durable regenerator and in 2005 the Pal-Tex Regenerator was launched by Pal-Con, Ltd. To satisfy this request. Pal-Tex is the most efficient and durable rejuvenator ever built. A testament to the quality of the product design is the soul-sourcing of Pal Tex by many Pal-Con, Ltd. customers.

Regenerators have traditionally been built using basic pulse tube construction. This can cause uneven flow distribution which raises thermal stress levels and prematurely ages the unit. Pal-Con has designed and patented a unique innovation that addresses these concerns: Pal-Tex. The inclusion of nickel alloy helps the Pal-Tex regenerator withstand abnormally high operating temperatures, with the added benefit of protecting against oxidation. Due to the brazed cores being suspended in the regenerator to accommodate thermal growth, the Pal-Tex regenerator has an estimated life of 25 to 30 years. The brazed cores are free to expand and contract in response to the heat generated throughout the process; They are designed to withstand temperatures up to 1,200 degrees Fahrenheit. In comparison, unsprang cores are very susceptible to cracking, which can lead to significant financial losses related to:

- Damage to equipment.
- Product contamination.
- Unplanned downtime.
- Emergency repair costs, etc.

Pressure drops in a gas turbine reduce engine performance because the compressor requires increased pumping power to drive flows through the resistors with associated pressure losses.

Pal-Tex is designed to allow a maximum combined pressure drop of 3.5%.



2.1.1 PAL-TEX Design

A regenerator must offer greater than 80% efficiency in a compact package and be able to withstand cyclic operation and high exhaust temperatures to reduce the operating costs of today's gas turbine engines. To achieve these goals, PAL-CON, Ltd. Emphasizes design simplicity and high-quality materials. Important design features of PAL-TEX include: Contraintes thermiques contrôlées avec un noyau flottant

- Compact modular design to accommodate various size and installation requirements
- Operational life of 320,000 hours
- High-performance heat transfer surfaces in the core provide up to 91% efficiency
- Stainless steel core allows operation at high temperatures
- Gas fins spaced to accommodate heavy fuels

3 Basic design:

The core is the building block of the regenerator. It compresses alternating layers of gas and air-side fins separated by formed tube sheets. Finned and tube plates have the same thickness; This uniformity, coupled with expansion joints between the core and housing, controls thermal stresses and increases operational life.

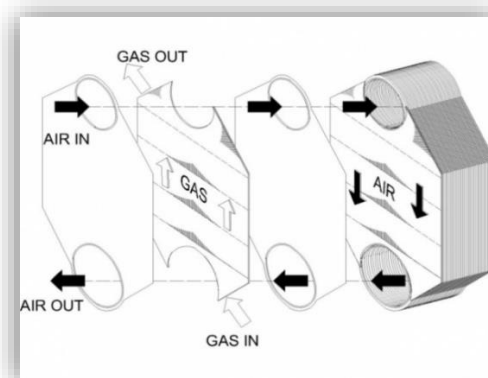


Fig 8 : represents the nucleus.



4 Modular design

An assembly of core sections constitutes a module of the regenerator. The number of core sections and modules can be easily adjusted to accommodate any turbine size. This allows for many configurations capable of working with the most difficult sites. This also makes it easier to transport by plane, train, boat or truck to the most difficult locations.

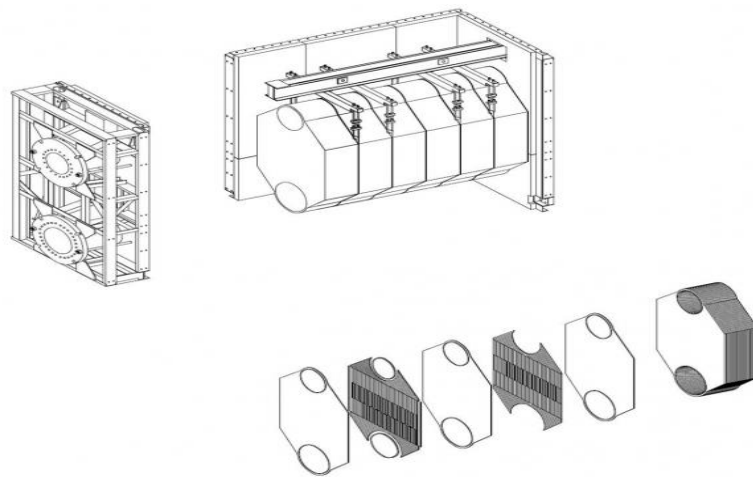


Fig 5: PAL-TEX DESIGN.

5 Design compact

The image below illustrates the size difference between Pal-TEX and an older shell and tube regenerator [1]. Even though the Pal-TEX regenerator is much smaller than older shell and tube types, it has more surface area for heat transfer, resulting in greater efficiency. In many open configurations, the entire Pal-TEX system will be less than half the size of older shell and tube designs.





Fig : size comparison between PAL-TEX and another regenerator [1].

6 Thermal fatigue

Thermal fatigue is inherent in conventional heat exchangers. This condition is caused by the difference in heating rates between the bonded materials inside the heat exchanger.

The PAL-TEX regenerator uses fins in the air passage to evenly distribute high pressure air coming from the compressor. Since the air pressure is balanced, the core no longer needs to be rigidly attached to the housing. This allows expansion joints to be used between the cores and the housing, allowing both parts to heat independently. These seals eliminate most of the stresses that lead to thermal fatigue.

Bellows expansion joints connecting the air plenums of each unit configuration of the air piping flanges, which are rigidly attached to the housing. The weight of the core assembly is transmitted to the casing through a flexible suspension system, allowing the cores to grow unconstrained from the casing during operation, minimizing thermal fatigue.





Fig: transfer surface technology.

Pal-Tex uses aerospace technology to control thermal stresses and produce a more efficient regenerator.

Pal-Tex uses brazed cores to achieve a large surface area, this surface area allows maximum heat transfer from the turbine exhaust gas and turbine compressor outlet air, while minimizing pressure drop. The product also uses a floating core design, allowing control of thermal stresses caused by operating in a high temperature environment.

Moreover,

Regenerator tube diameter

$$D_T = 300 \text{ mm}$$

Section of a single tube

$$S_{\text{tube}} = 3,14 \times \left(\frac{0,3}{2}\right)^2 = 0,70 \text{ m}^2$$

Total section of the four tubes

$$S_{\text{TOT}} = S_{\text{tube}} \times 4 = 0,28 \text{ m}^2$$

Compressor outlet section

$$S_C = 1,47 \text{ m}^2$$

$$N = \frac{1,47}{0,28} = 5,25 ; N \text{ real number, so we take } N = 5$$

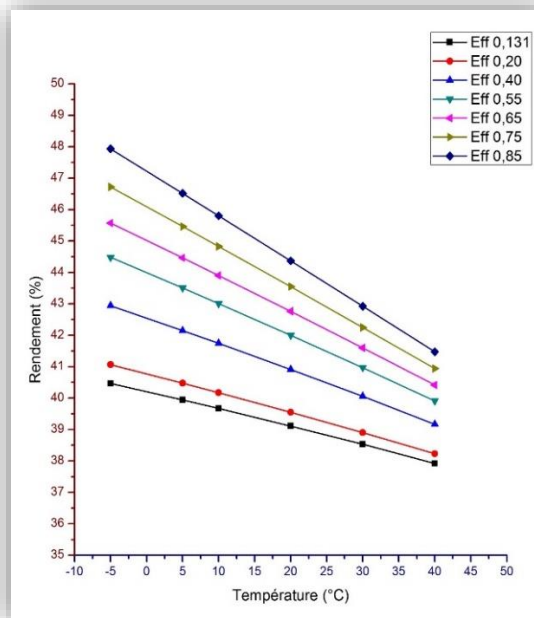
« So ape pre one-fifth (1/5) quantity of air will regenerate».



Thus, the thermal efficiency for the regenerative gas turbine cycles is reduced. It can be noted that the gain in thermal efficiency increases by 7.5% with increases in regenerative efficiency from (0.131 to 0.85).

Température	Rendement						
°C	%						
	Eff = 0,131	Eff = 0,20	Eff = 0,40	Eff = 0,55	Eff = 0,65	Eff = 0,75	Eff = 0,85
-5	40,4671	41,0661	42,9457	44,4803	45,5721	46,7229	47,9375
05	39,9438	40,4796	42,1507	43,5077	44,4651	45,4646	46,5169
10	39,6718	40,1777	41,746	43,0089	43,9022	44,8279	45,8032
20	39,1107	39,5517	40,9138	42,0018	42,7613	43,55	44,3696
30	38,5302	38,9052	40,0601	40,9713	41,6003	42,2498	42,9244
40	37,9203	38,2327	39,1714	39,9132	40,4192	40,9423	41,4752

Tabl: Effect of ambient temperature and effectiveness



6.1.1.1 Comparaison des résultats obtenus

	Simple gas turbine		TAG with regeneration	
°C	MW	MW	MW	MW
temps ambiante	Useful energy	paid energy	Useful energy	paid energy
-5	260,4065	661,5952	259,7502	641,8797
05	251,1647	644,921	250,5943	627,3680
10	246,5559	636,5965	246,0145	620,1248
20	237,3358	619,9736	236,8809	605,6684
30	228,1804	603,3871	227,8126	591,2568
40	219,0643	586,8388	218,7561	576,8840

The variation of thermal efficiency at the inlet temperature of the simple cycle and the regenerative cycle is shown in Figure. It is observed that the thermal efficiency is higher for the regenerative cycle than for the simple cycle.

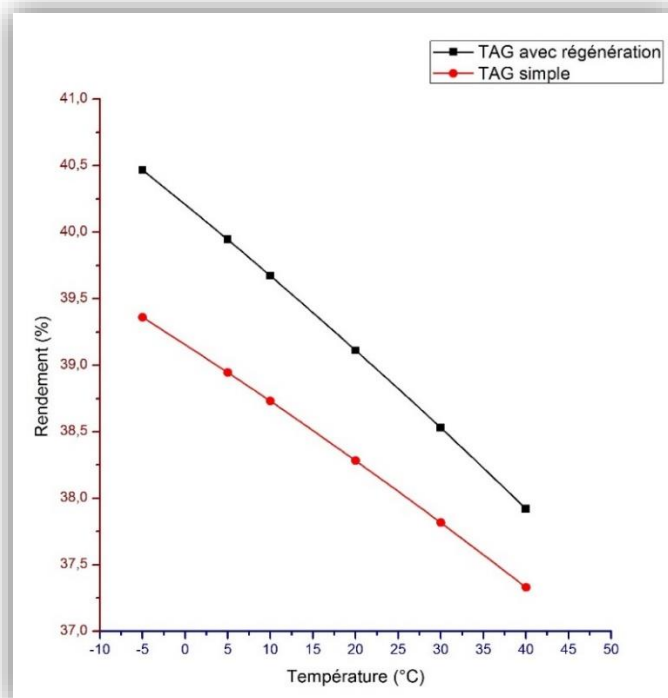


Fig: Effect of ambient temperature on thermal efficiency for
a simple cycle and the regenerative cycle



Comment

We maintain almost the same useful power in both cases (single TAG and with regeneration) for the purpose of minimizing the consumption of natural gas and reducing paid energy.

	%	Kg/s	KJ/KWH	Kg/KWH	Temps
	efficiency	gas flow	CS	CSC	°C
TAG with Regeneration	40,46	13,1737	8896,116	0,1826	-5
	39,94	12,8759	9012,663	0,1850	05
	39,67	12,7272	9074,456	0,1862	10
	39,11	12,4305	9204,642	0,1889	20
	38,53	12,1348	9343,32	0,1918	30
	37,92	11,8398	9493,596	0,1948	40
Simple gas turbine	39,36	13,5784	9146,249	0,1877	-5
	38,94	13,2361	9243,805	0,1897	05
	38,73	13,0653	9295,048	0,1908	10
	38,28	12,7241	9403,996	0,1930	20
	37,81	12,3837	9519,629	0,1954	30
	37,32	12,0441	9643,822	0,1979	40

Tabl: comparison between simple TAG and TAG with regeneration.

CS specific consumption & specific fuel consumption:

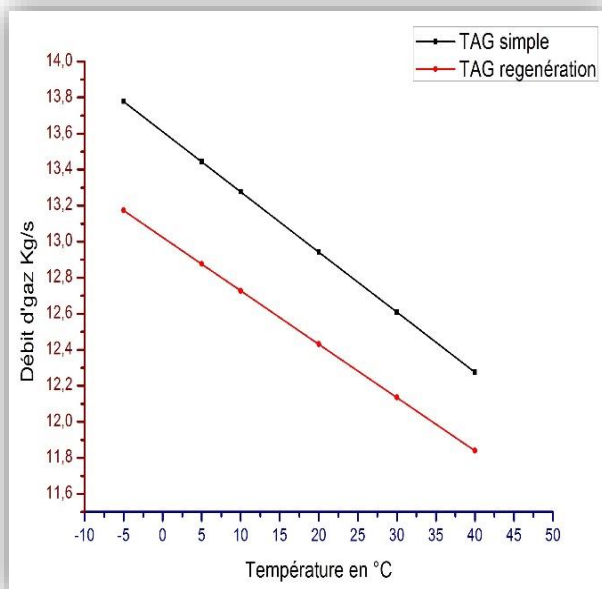


Fig shows the variation of the gas flow as a function of the ambient temperature in the simple brayton cycle and the regenerative cycle, we notice that in the simple cycle, the gas consumption is greater than the regenerative cycle.

$$CS = \frac{3600}{\eta_{globale}}, \text{ En KJ/KWh} \quad \& \quad CSC = \frac{CS}{PCI}, \text{ En Kg/KWh}$$



6.2 Étude économique

The benefit resulting from the gas turbine with regeneration is summarized in this table:

	TAG simple	TAG With Regeneration					
°C	MW	MW	%	MW	DA	DA	DA
temps	energy paid	energy paid	gain	paid energy gain	money earned per day	gain per 1 year	gain per 4 years
-5	661,5952	641,8797	2,9799	19,7155	32953,05	12027863,25	48111453
05	644,9210	627,3680	2,7217	17,5530	29338,59	10708583,79	42834335,14
10	636,5965	620,1248	2,5874	16,4717	27531,27	10048913,55	40195654,2
20	619,9736	605,6684	2,3073	14,3052	23910,12	8727193,8	34908775,2
30	603,3871	591,2568	2,0103	12,1303	20274,93	7400349,45	29601397,8
40	586,8388	576,8840	1,6963	9,9548	16638,74	6073139,057	24292556,23

Tabl: shows an economic study and a comparison between simple TAG and regenerative TAG.

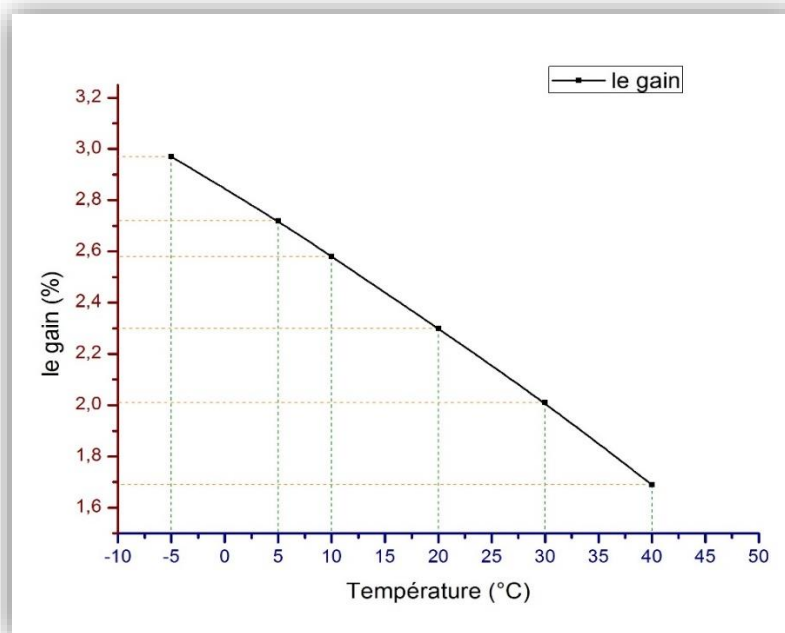


Fig: shows gain variation as a function of temperature.



6.2.1 Discussion

We note that in winter the saving or optimization of paid energy which represents natural gas has been well considered in relation to a period when the ambient temperature is high.

$$\text{Gain} = \frac{\text{énergie payante TAG simple} - \text{énergie payante TAG avec Régénération}}{\text{énergie payante TAG simple}} \times 100$$

The paid energy gain =

Paid energy TAG simple – paid energy TAG with Regeneration

Average operating time of gas turbine per 1 day is 12 hours 1 KWh $\Rightarrow$

1 Algerian Dinar of the gain

1 MWh $\Rightarrow$ 1000 Dinar algerien gain

1.56 DA $\Rightarrow$ 1m³gaz $\Rightarrow$ 11.2 KWh

1560 DA $\Rightarrow$ 11.2 MWh

Example

14 MW gain energy

14MWh*12hrs =168MWh

So, 168MWh $\Rightarrow$ 23 400 DA/day

gain per 1 an = 23 400DA*365 = 8 541 000 DA



6.3 Conclusion

This chapter has presented a consideration that should be included in determining the performance of a regenerative gas turbine power plant. A design methodology was developed for the parametric study and performance evaluation of a regenerative gas turbine. The parametric study showed that pressure ratio, ambient temperature and turbine inlet temperature played a very important role on the overall performance of a regenerative gas turbine.

The thermal efficiency of the simple gas turbine cycle undergoes small improvements at large pressure ratios compared to the regenerative gas turbine cycle.

In the regenerative gas turbine cycle, thermal efficiency increases and specific fuel consumption decreases with regenerator efficiency.

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.



Reference

[1] Technique de l'ingénieur : *Turbine à gaz*.

[2] SIEMENS GAS TURBINE SGT5-4000F (V94.3A).

[3] Rajiv Ranjan¹, Dr. Mohammad Tariq : *Analysis of a Regenerative Gas Turbine Cycle for Performance Evaluation*, « *International Journal of Engineering Research and General Science* Volume 2, Issue 4, June-July, 2014 ISSN 2091-2730 ».

[4] Lyes KADEM : *Brayton cycle with regeneration*, [Thermodynamics II] 2007.

[5] **Abdallah BOUAM, Rabah KADI & Slimane AISSANI** : *AMELIORATION DES PERFORMANCES DES TURBINES A GAZ PAR L'INJECTION DE LA VAPEUR D'EAU A L'AMONT DE LA CHAMBRE DE COMBUSTION*, 13èmes Journées Internationales de Thermique, Albi, France du 28 au 30 Août 2007.

