

1 Introduction

Nowadays, almost all countries are facing the problem of insufficient electrical energy production. An additional difficulty arises from the need for environmental protection regulations and standards defined worldwide.

Gas turbine has a high sensitivity to the influence of ambient air temperature which varies considerably between day and night, summer and winter, which affects the thermal efficiency of operation of these machines.

The cycle of a gas turbine is a very flexible cycle so that its performance parameters, i.e. efficiency and specific net work, can be improved by adding additional components to a simple cycle.

In this work, the combustion process in the combustion chamber of the gas turbine is carried out in the presence of an additional quantity of water vapor. This has been injected upstream of the combustion chamber. This method leads to an improvement in the efficiency and the available useful power of a simple cycle gas turbine. The increase in turbine efficiency and power output is a consequence of the additional mass passing through the turbine.

An attempt is made by modeling a simple cycle by recovering heat from the exhaust gases (putting an evaporator) in order to obtain superheated steam for use, considering all the factors that actually affect the performance of a real cycle. For this purpose, the physical properties of the working fluid have been taken as real (function of temperature and pressure). 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.



2 **Resume**

The use of steam for gas turbine propulsion in the Brayton cycle has been analyzed. In the considered modernization, the steam generated in the heat recovery steam generator unit is directed into the gas turbine combustion chamber, which results in an increase in the Brayton cycle power.

In this perspective, the method of injecting water vapor upstream of the combustion chamber of a gas turbine has been proposed, studied and compared with a simple cycle.

The main objective of this work is to carry out a program to calculate the influence of ambient conditions on the characteristics of the various components of the gas turbine, such as compression, combustion and expansion. Once the optimal operating parameters are known, the recalculation of the plant performance was carried out by injecting suitable quantities of water vapor upstream of the combustion chamber. The results obtained from the influence of ambient conditions on the gas turbine performance without steam injection and the influence of standard conditions on the start of injection, according to those found in the literature simulated by the thermodynamic calculation code 'Thermoptim', are in good agreement with the qualitative variation of these conditions, in the case of normal operation without steam injection. These results are represented in the form of curves.



1.1.1.1 Description of the model and formulation of the problem

Operating Principle of the Steam Injection Gas Turbine

Fig.5c shows an installation of a steam-injected cycle. Air is discharged downstream of the compressor at a pressure, combustion takes place in the combustion chamber where fuel is injected in the presence of an additional quantity of water vapor whose physical properties are calculated for injection conditions upstream of the combustion chamber.

Generally, the heat recovery steam generator is constructed in a similar way to the combined cycle, i.e. an economizer heating the pressurized water, an evaporator generating water vapor and a superheater bringing the steam to the superheated state.

- Air is compressed in the compressor.
- Fuel, steam and air are supplied into the combustion chamber forming a high temperature steam/gas mixture.
- The gas/steam mixture expands in the turbine
- Steam is generated in the HRSG, while cooling the gas/steam exhaust.
- Net power and efficiency of the steam injection gas turbine.

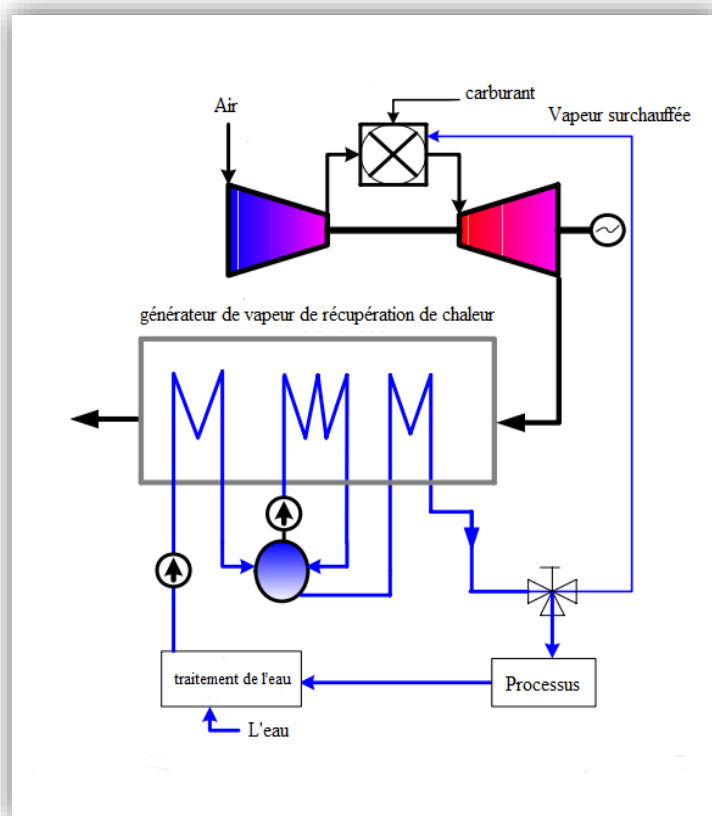


Fig.5c : represents Flow diagram of a steam injection gas turbine.



- Steam generated by heat recovery is injected into the combustion chamber of a gas turbine increasing the flow through the turbine.
- Steam injection increases the power output of a gas turbine and the electrical efficiency.
- Steam injection reduces the NOX emission in a gas turbine.
- The steam injection gas turbine has a lower investment cost than a common combined cycle and is suitable for process industries, due to the flexible operating conditions.
- There are limits to the amount of steam that can be injected.
- The steam entering the combustion chamber is in a superheated state, being an energy carrier of the heat recovered by the hot exhaust gases.
- The pressure of the injected steam must be slightly higher than the pressure of the air coming from the combustion chamber.
- To maintain the turbine inlet temperature, more fuel is added in a steam injection gas turbine to compensate for the increased mass in the combustion chamber.
- When steam is injected before the turbine, the mass flow rate at will be higher than without steam injection.
- The specific heat of superheated steam is about twice as large as the specific heat of the flue gas; therefore, the average for the gas mixture and C_p passing through the turbine will be higher than without steam injection.
- The compressor work, is practically not affected by steam injection.
- The turbine inlet temperature is the same as without injection and the turbine outlet temperature will remain at a similar value.
- The conclusion is therefore that the output power of the steam-injected gas turbine will be higher than for the same gas turbine without injection.
- For a steam-injected gas turbine, the power gain is relatively large, but it depends on the steam injection temperature as well as the amount of steam injected.



The superheated steam, which is injected into the combustion chamber, contains a significant amount of energy that has been recovered from the hot gas turbine exhaust in the HRSG.

A steam injection gas turbine can achieve an electrical efficiency of 40% to 45% (maximum steam injection).

However, the steam injection gas turbine cannot achieve the high electrical efficiency of a combined cycle since the water in the form of steam goes into the stack and thus the (latent) heat of vaporization of water in the gas/steam flow is lost.

For a steam injection gas turbine, there is no need for a steam turbine or a condenser system, but the efficiency is relatively high, which reduces the investment cost.

In the investment of a steam injection gas turbine, it is necessary to consider the cost of the water treatment plant.

To keep the investment cost low, it is assumed that there is no shortage of water, if there is not enough water available, the HRSG flue gases may need to be condensed to recover the water content, and the installation cost of this piece of equipment can be expensive.

The quality of the water to be used for injection is very important.

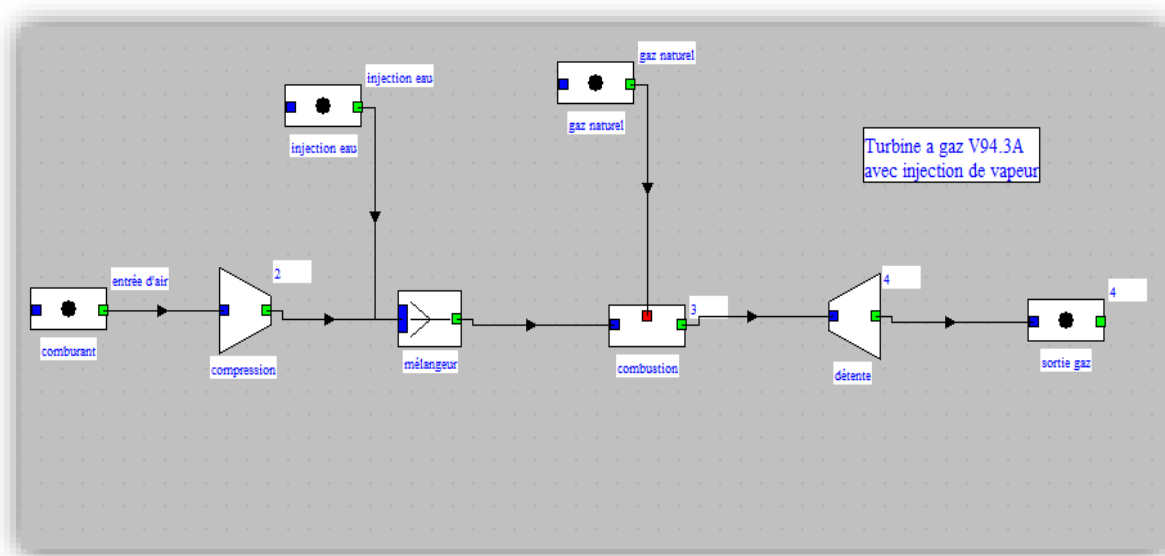
For the turbine parameters, new calculations are made. To keep the combustion chamber outlet temperature constant, in the presence of water vapor (including injection parameters T_{inj} , P_{inj}), we need to add even more fuel. So to calculate these ratios (fuel flow and the amount of injected steam), we need to make a thermal balance at the combustion chamber level.



THERMOPTIM

TURBINE A GAZ A INJECTION DE VAPEUR
V94.3A (SGT5-4000F)
SIEMENS.

Representation of a gas turbine by injection of water vapor upstream of the combustion chamber on THERMOPTIM



Steam injected gas turbine cycle

For normal operation of a gas turbine, we previously noted that when the ambient temperature is increased, the performance of the machine decreases. This reduction becomes significant when the ambient temperature is maximum. So in order to maintain the performance of this turbine, a method of injecting water vapor upstream of the combustion chamber is proposed.

Point settings

For the entry conditions “ambient temperature and pressure” of the TAG with steam injection is the same as the TAG without steam injection (single TAG).

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

Air entry and compression

- 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 interface for thermodynamic analysis of a gas turbine cycle. The main window is titled 'transfo' and 'type' is set to 'compression'. The 'type énergie' is 'utile'. The 'point amont' (inlet) is 'entrée d'air' with the following properties: T (°C) = 10, P (bar) = 0.9966, h (kJ/kg) = -14.88, and titre = 1. The 'point aval' (outlet) is '2' with properties: T (°C) = 386.41, P (bar) = 14.949, h (kJ/kg) = 372.48, and titre = 1. The 'débit' (mass flow rate) is 650 kg/s. The 'm ΔH' is 251 781,24 kJ/s and 'Q' is 0 kJ/s. The 'rend. polytropique' is 0.8976 and the 'exposant polytropique' is 1.45402. The 'rapport de pression (>= 1)' is 15. The 'système' is 'ouvert' (open) and 'observée' (observed). The 'liens' (links) are 'adiabatique' (adiabatic) and 'référence isentropique' (isentropic reference). The 'calculer' (calculate) button is visible. The 'Sauver' (save) button is also present. The 'Supprimer' (delete) button is visible. The 'Fermer' (close) button is visible. The 'Imposer le rendement et calculer la transfo' (impose efficiency and calculate transfo) button is selected.



Combustion chamber and turbine expansion

- Point 3 is at 14,949 bar and 1,120.37°C corresponding to the end of combustion. (we notice a drop in the temperature in the combustion chamber compared to simple TAG '1166.74°C).
- Point 4 is at 1.0128bar and 526.04°C with poly-tropic efficiency equal to 86.54%. (we also notice that the temperature of the exhaust gases is reduced).

transfo: détente type: détente

type énergie: utile ☐ débit imposé

point amont: 3

T (°C): 1 120,37261
P (bar): 14,949
h (kJ/kg): 1 305,35
titre: 1

point aval: 4

T (°C): 526,04
P (bar): 1,0128
h (kJ/kg): 561,19
titre: 1

débit: 670

m ΔH: -498 582,98
Q: 0

☒ système fermé ☒ observée

☒ système ouvert

☒ adiabatique ☐ non adiabatique

☐ référence isentropique ☒ référence polytropique

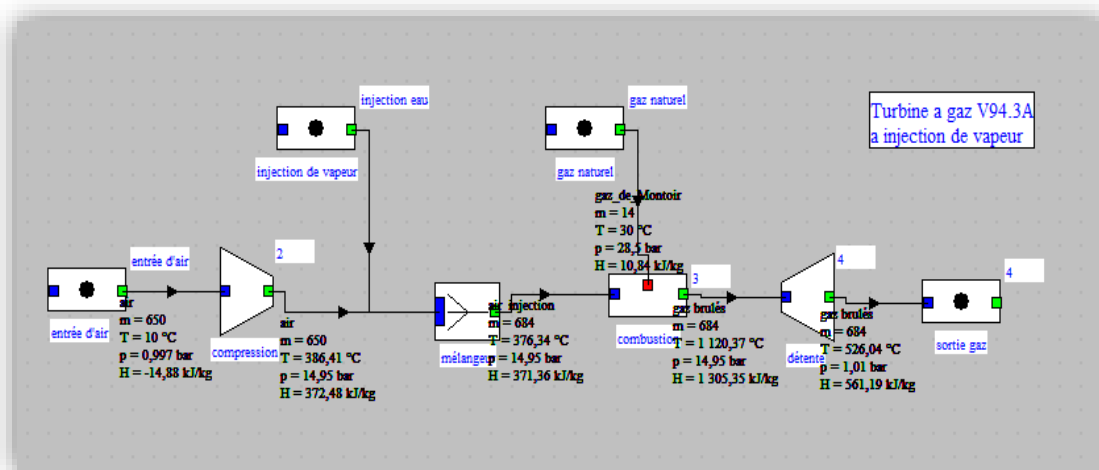
rend. polytropique: 0,8654
exposant polytropique: 1,2603

rapport de détente (>= 1): 14,76 ☐ calculé ☒ imposé

☒ Imposer le rendement et calculer la transfo

☐ Calculer le rendement, le point aval étant connu

☐ mécaniquement équilibrée avec



Thermal efficiency and result

The thermal efficiency of the TAG with steam injection obtained is 39.93% with a useful energy equal to 257.221MW.

Fichiers de projet Fichiers de résultats Spécial Aide

Nom du projet : STIG Schéma associé : STIG

7 POINTS

nom du point	corps	P (bar)	T (°C)
2inj	air_injection	14,949	376,34328
gaz naturel	gaz_de_Mont..	28,5	30
2	air	14,949	386,40811
injection eau	eau	14,949	201,265
3	gaz brûlés	14,949	1 120,37261
4	gaz brûlés	1,0128	526,04434

0 PRESSIONS IMPOSEES

nom	valeur
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turbine à gaz V94.3A à injection de vapeur

7 TRANSFOS

nom transfo	point amont	point aval	type transfo
sortie gaz	4	4	échange
gaz naturel	gaz naturel	gaz naturel	échange
combustion	2inj	3	combustion
compression	entrée d'air	2	compression
détente	3	4	détente
comburant	entrée d'air	entrée d'air	échange

1 NOEUDS

nom	type	veine principale
mélangeur	mélangeur	combustion

0 ECHANGEURS DE CHALEUR

nom	type	fluide chaud	fluide froid
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efficacité 0,399382

énergie utile 257 221,84

énergie payante 644 050,07

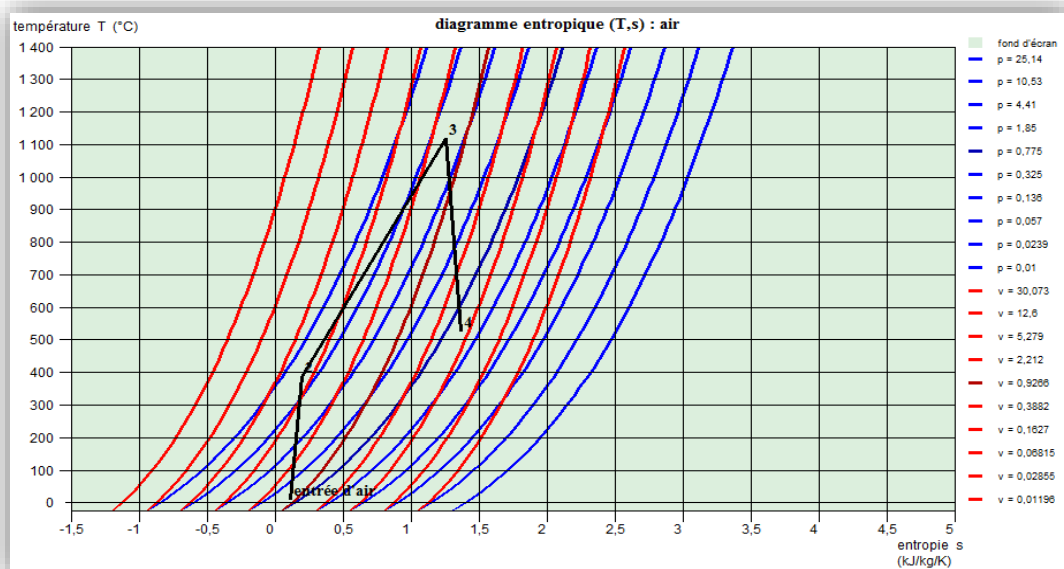
Recalculer ☒ débit auto ☐ verrouillé

types invalidés 0

types calculables 0

Bilan

Figure: shows the thermal efficiency, useful and paid energy obtained.



Discussion

To keep the exit temperature of the combustion chamber constant, in the presence of water vapor (including the injection parameters T_{inj}, P_{inj}), we must add even more fuel.

So to calculate these ratios (fuel flow and the quantity of steam injected), we must create a thermal equilibrium at the level of the combustion chamber, i.e. to increase our useful energy we must first raise the compressor outlet temperature a $T_3 = 1166.74^\circ\text{C}$ (like T_3 in simple TAG) and keep this temperature constant; the same thing, for the exhaust temperature.

Effect of ambient temperature

Turbine à gaz avec injection de vapeur T3 fixe à 1166.74°C, PCI = 48713,22								
%	°C	MW	MW	kg/s	KJ/KWH	Kg/KWH	°C	Kg/s
Rend-ements	temps	énergie utile	énergie payante	Débit gaz	CS	CSC	temps de mélange	débit d'air
40,72	-5	269,1335	660,9260	14,3695	8840,7124	0,1814	344,47	597
40,53	00	267,2386	659,2833	14,3338	8881,2794	0,1823	354,94	603
40,34	05	265,6768	658,4926	14,3166	8922,7733	0,1831	365,4	610
40,15	10	263,2151	655,5565	14,2527	8966,0634	0,1840	375,8	615
39,95	15	261,4850	654,4467	14,2286	9010,1138	0,1849	386,22	622
39,74	20	259,9974	654,1257	14,2216	9057,2189	0,1859	396,62	630
39,33	30	255,6975	650,0887	14,1339	9152,6897	0,1878	417,31	643
38,90	40	248,9806	639,9667	13,9138	9253,2617	0,1899	437,79	650
38,69	45	244,3937	631,6200	13,7323	9303,9844	0,1909	447,94	650

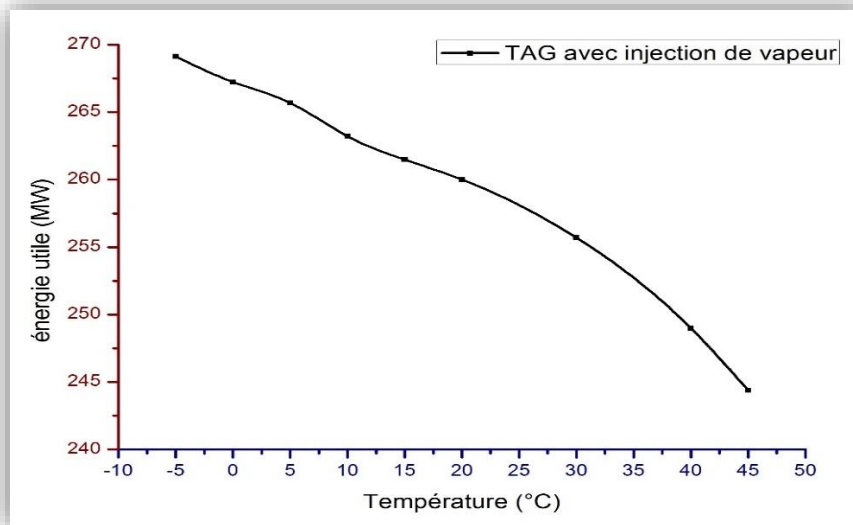
CS & CSC

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

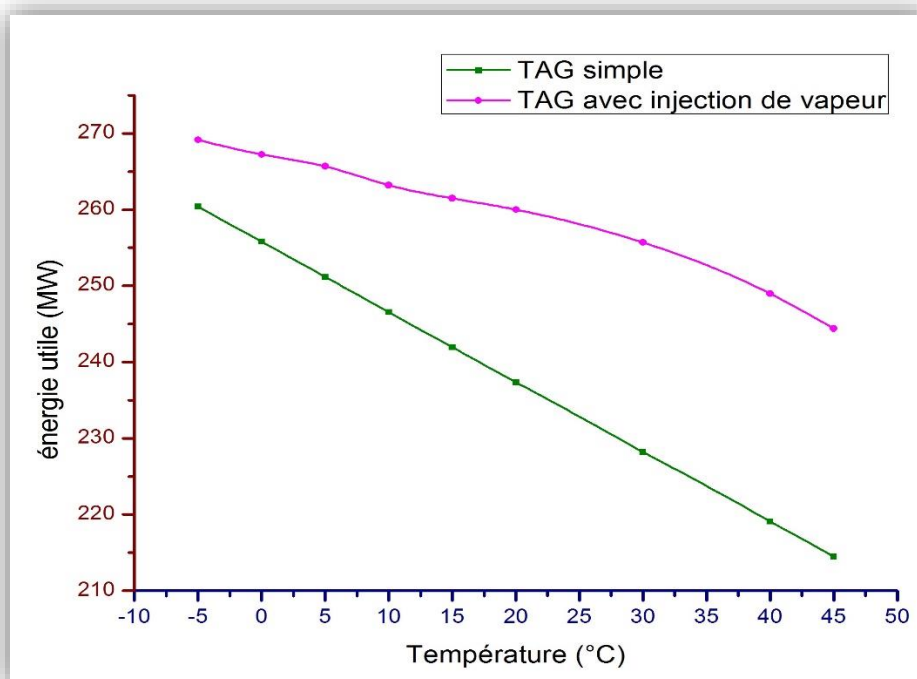
Comment

the variation in useful energy as a function of ambient temperature in the steam injection cycle, a degradation of power which is linked to the drop in ambient temperature.





It is clear from the results obtained in Figure 5.4-18w that a cycle with steam injection has a good production than in a cycle of a simple TAG, a difference of 5 to 13% of useful energy between them in different ambient temperatures.



CONCLUSION

In a steam injection gas turbine, steam is generated by recovering hot exhaust gas from the TAG and then injected into the TAG combustion chamber where it is heated to the inlet temperature of the turbine.

Steam injection leads to a greater mass flow rate through the turbine and thus increases the net power produced compared to a gas turbine without steam injection.

The efficiency of a steam injection gas turbine is also higher compared to a simple gas turbine, the hot gases recovered from the gas turbine exhaust are returned to expansion.

In reality, the increased flow rate through the turbine causes an increased pressure drop, which also leads to the compressor needing to work at a higher pressure ratio.

The use of a steam injection gas turbine as part of an industrial process has several advantages:

1. Higher efficiency than a gas turbine without steam injection.
2. The steam injection rate can vary from 0 to 20% of the air mass flow, which means the amount of process steam can also vary.
3. Takes up less space than a combined cycle and a steam cycle.



Formulaire Submit a questionnaire titled "Enhancement of performance of gas turbine power plant simple cycle by injection steam upstream of combustion chamber"

[Enhancement of performance of gas turbine power plant simple cycle by injection steam upstream of combustion chamber - Google Forms](#)

*Sans titre2 [] - IBM SPSS Statistics Editeur de données

	Nom	Type	Largeur	Décimales	Libellé	Valeurs	Manquant	Colonnes	Align	Mesure	Rôle
1	Age	Numérique	8	2		{1,00, 20 - 25}	Aucun	8	Droite	Echelle	Entrée
2	Gender	Numérique	8	2		{1,00, Male}	Aucun	8	Droite	Nominales	Entrée
3	Educational_qualification	Numérique	8	2		{1,00, High ...}	Aucun	8	Droite	Ordinales	Entrée
4	Q1	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
5	Q2	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
6	Q3	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
7	Q4	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
8	Q5	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
9	Q6	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
10	Q7	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
11	Q8	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
12	Q9	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
13	Q10	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
14	Q11	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
15	Q12	Numérique	8	2		{1,00, Stron...	Aucun	8	Droite	Ordinales	Entrée
16											

2		{1,00, Stron...	Aucun	8	Droite
2		{1,00, Stron...	Aucun	8	Droite

Libellés de valeurs

Valeur :

Libellé :

Orthographe...

Ajouter

Changer

Eliminer

1,00 = "20 - 25"

2,00 = "25 - 30"

3,00 = "30 - 35"

4,00 = "35 years and over"

OK Annuler Aide



