NATIONAL UNIVERSITY OF ENGINEERING

COLLEGE OF MECHANICAL ENGINEERING

THERMOELECTRIC CENTERS- MN163

Energy Efficiency Analysis and Economic Valuation of Ventanilla Thermal Power Plant - EDEGEL Plant

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CHAPTER 1

INTRODUCTION

Energy is an essential resource for the life and economic development of countries, seeking energy development.

However, at present, society seeks energy sustainability through a balance between three important aspects: Energy, Economy and Ecology that make up the fundamental pillars of the Rational Use of Energy; therefore, the goal is to achieve an accessible, available and acceptable energy. Accessibility is closely linked to an appropriate price policy (Economy). Availability is linked in short-term to energy quality and in long-term to supply security (energy). Acceptability is linked to environmental objectives and public sensitivities (Ecology).

These objectives are the main lines of the energy policies of the countries that are enunciated as guarantee of supply and diversification of energy sources; Protection of the environment and economic competitiveness.

The use of fossil fuels (coal, natural gas or petroleum products) for electricity generation are questioned from the environmental point of view for their "pollutant emissions", "consumption of non-renewable resources" and the threat of " climate change".

The solution to these problems is the use of renewable energies that have less impact on the environment, but by their very nature have very high specific costs and are less secure, so fossil fuel technologies have more acceptance than renewable energies.

Therefore, our current society needs an adaptation period, possibly of several years, until reaching the energetic sustainability.

During this period of adaptation fossil energies will continue to play a major role in the generation of electricity, especially natural gas in the short term and probably coal in the medium term, for which it is necessary of great technological development effort to improve their environmental performance while allowing a reasonable energy cost to sustain economic growth.

In the long term the use of renewable energy, nuclear fusion and hydrogen as an energy vector will be the energies that will be used in the future

OBJECTIVES

• Conduct the Energy Evaluation of the Ventanilla Thermoelectric Plant, finding the efficiency of the plant.

• Conduct the Economic Evaluation of the Ventanilla Thermoelectric Plant, finding the US $ / Kw- h

GENERALITIES

The combined cycle power plant is one where electricity is generated by the joint use of two turbines:

- • A gas turbine
- • A steam turbine

That is to say, for the transformation of the fuel energy into electricity, two cycles are superimposed:

- • **The Brayton cycle** (gas turbine): takes the air directly from the atmosphere and undergoes a heating and compression to take advantage of it as mechanical or electrical energy.
- • **The Rankine cycle** (steam turbine): where the heat consumption is related to the production of work or the creation of energy from water vapor.

ADVANTAGES OF THE COMBINED CYCLE

The main characteristics of combined cycle thermal power plants are:

• **Flexibility**. The control unit can operate at full load or partial loads, up to a minimum of approximately 45% of the maximum power.

• **High efficiency**. The combined cycle provides greater efficiency over a wider power range.

• **Their emissions are lower** than in conventional thermal power plants.

• **Low investment cost** per installed MW.

• **Short construction periods**.

• **Lower surface area per MW installed** when compared to conventional thermoelectric power plants (which reduces visual impact).

• **Low consumption of cooling water**.

• **Energy saving** in the form of fuel

FUNDAMENTAL PARTS OF A COMBINED CYCLE PLANT

In order to understand the operation of a combined cycle thermal power station, it is necessary to know first the parts that form it:

Gas turbine. Which consists of:

- **Compressor**, whose function is to inject the air under pressure for the combustion of the gas and the cooling of the hot zones.
- **Combustion chamber**, where the natural gas (fuel) is mixed with the air under pressure, producing combustion.
- **Gas turbine**, where the expansion of gases coming from the combustion chamber takes place.

It consists of three or four expansion stages and the temperature of the gases at the inlet is around 1,400 ° C leaving the turbine at temperatures above 600 ° C.

- **Recovery boiler**. In this conventional boiler, the heat from the gases that come from the gas turbine is used in a water-steam cycle.
- **Steam turbine**. This turbine usually has three bodies and is based on conventional technology.
- **Pumps**

It is very common for the gas turbine and the steam turbine to be coupled to the same axis so as to actuate the same electric generator.

OPERATION OF A COMBINED CYCLE PLANT

First the air is compressed at high pressure in the **compressor**, passing to the combustion chamber where it is mixed with the fuel.

Then the combustion gases pass through the gas turbine where they expand and their heat energy is transformed into mechanical energy, transmitting it to the axis.

The gases leaving the gas turbine are brought to a heat recovery boiler to produce steam, as of this moment we have a conventional water-vapor cycle.

At the outlet of the turbine, the steam condenses (turning back into water) and returns to the boiler to start a new steam production cycle.

Currently the tendency is to couple the gas turbine and the steam turbine to the same axis, so that they jointly drive the same electric generator.

ENVIRONMENTAL IMPACTS OF COMBINED CYCLE PLANTS

The use of natural gas for the generation of electricity through the combined cycle technology is within the environmental policy of a large number of countries, as it offers a large number of advantages compared to other electrical production technologies.

In particular, CO_2 emissions in relation to kWh produced **are less than half of the emissions** from a conventional coal plant.

CHAPTER 2

DESCRIPTION OF THE PLANT

2.1. General description

The plant, which has been under construction for two years, is the first combined cycle plant in Peru and the first to use natural gas from the Camisea reservoirs.

It is the largest and most modern and efficient thermoelectric power plant in the country. Its construction demanded an investment of 135 million dollars.

The Ventanilla Thermoelectric Plant was using natural gas from Camisea under the simple cycle system; That is to say, natural gas entered its two turbines, where a combustion originated whose force moved an axis acting on a generator that produced electric energy.

As a result of this process, there were hot gases that were expelled to the environment through two chimneys. With the combined cycle, those hot gases that maintain a temperature of 540 ° C recover and pass to two cauldrons that contain pipes with water that, when receiving the heat of the gases, is transformed into steam.

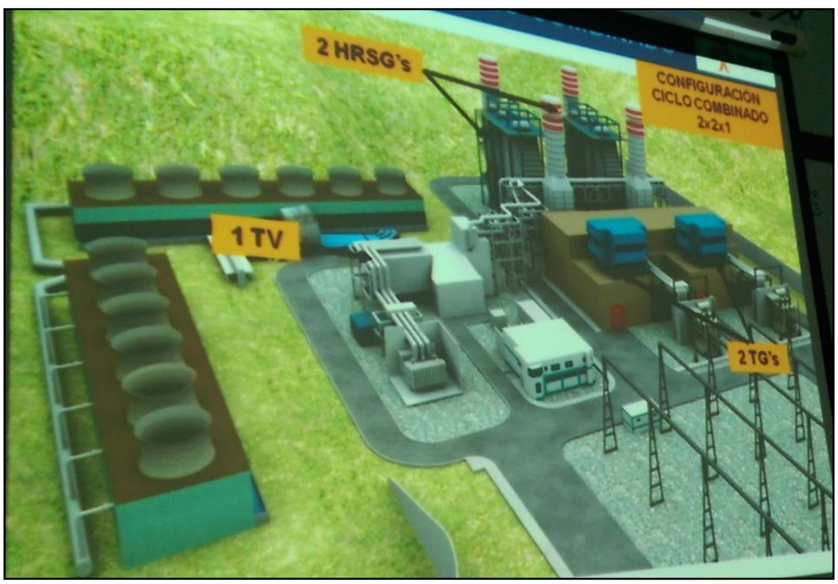
Finally, the steam is transferred to a third turbine coupled to a generator where electrical energy is produced. Thus, the same amount of gas is used to produce energy in two ways: through two gas turbines and a steam turbine.

In this way, the plant increased its efficiency because it now generates more energy using the same amount of natural gas.

The central is located in Bierzo avenue, in the district of Ventanilla, Callao province, department of Lima. Specifically, it is located on the right edge of the Chillón river, in the locality called "Pampa de los Perros", about 10 kilometers from the road to the window (Av. Néstor Gambeta). The project is located 50 meters above sea level, and the coordinates of the project are: 11 ° 56'14.19 " south latitude and 77 ° 07'09.07 " East longitude.

2.2. Description of main equipment and systems

The Ventanilla Thermoelectric Plant has a combined cycle configuration of 2 x 2 x 1, as can be seen in the following graph:



Source : EDEGEL

The main data of this plant is summarized below:

-(2) Gas Turbine

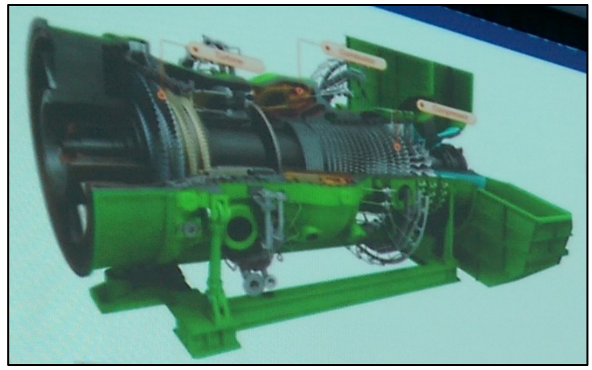
• Brand : SIEMENS

• Model : SGT6 4000F

• Burners : Low NOx Emissions

• Terminal Power : 160 MW

• Performance: 37.5%



-(2) Recovery Boiler

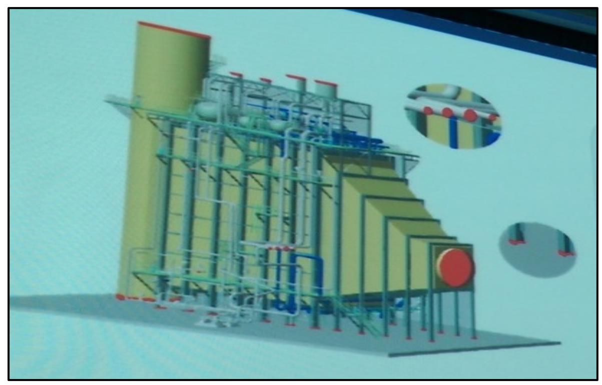
• Brand : VOGT NEM

• With additional fire and overheating

• (3) Vapor pressure : High, medium, low

• Gas inlet temperature: 560 ºC

• Gas outlet temperature: 100 ° C



-(1) Steam Turbine

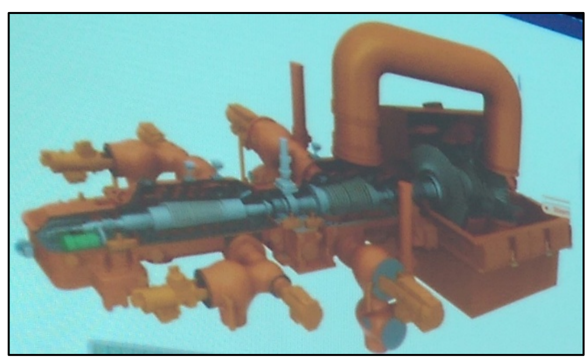
• Brand : SIEMENS

• Model : SGT6 5000

• Terminal Power : 185 MW

• (3) Vapor pressure : High, medium , low

• Vacuum Pressure : 0.070 Bara



-(3) Generators

• Brand: SIEMENS

• Model: SGEN6 - 3000W

• Voltage: 16.6 Kv.

• Terminal Power: 200 MVA - TG, 240 MVA - TV

• Power Factor: 0.85 - TG, 0.80 - TV

• Cooling: By Air

- Transformers

• Voltage: 16.6 / 220 Kv.

• Terminal Power: 200 MVA

Main Cooling System

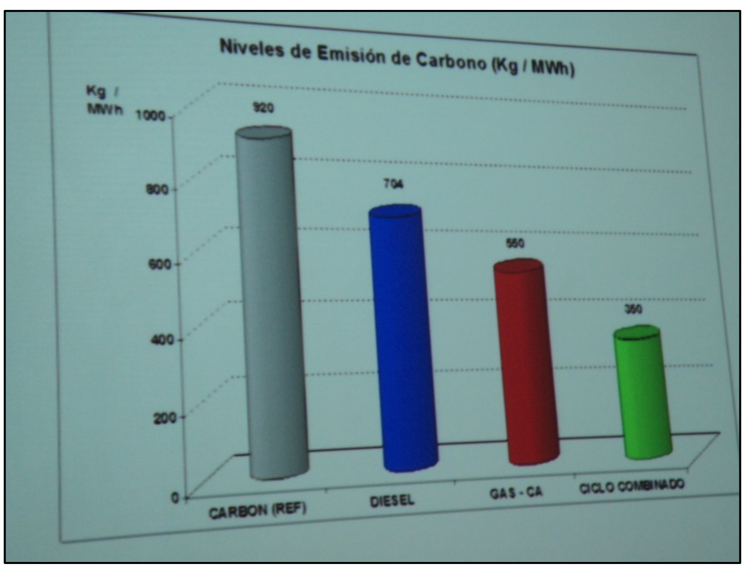
• Forced Induced Type

The Ventanilla Power Plant has Efficiencies, Effective Power and Variable Costs for each type of fuel and configuration, in which the combined cycle can obtain better efficiency, greater effective power and lower variable cost at maximum load; As can be seen in the following table:

Unidad	Potencia Efectiva MW	Eficiencia %	Costo Variable US$/MWh
TG con Diesel	152.7	36.3	153.9
TG con gas natural	159.2	37.2	25.8
CC 2x1 con gas natural	492.74	53.7	18.0

Source : EDEGEL

Obtain a high Efficiency in the configuration of combined cycle the Thermal Plant reduces the levels of carbon emission to the environment according to the following graph:



CHAPTER 3

APPLIED METHODOLOGY

3.METHODOLOGY USED

In order to comply with the objective of the report, the following methodology will be applied:

- Application of the concepts and theoretical equations of the thermodynamic cycles BRAYTON and RANKINE.
- Air / Fuel Ratio between 40 and 60.
- Selected the Calorific Power of Natural Gas: 39.9 MJ / Kg.
- Data provided. Presentation of the Company EDEGEL related to the Ventanilla Thermoelectric Power Plant, prior to the visit to the Plant.
- Data provided by the Control Room of the Ventanilla thermal plant during the visit, such as: pressure, temperature, fuel flows and steam, these data were very important to realize the thermal balance of the plant since for the date of the Visit November 18 of the Present Year at 11.30 am the plant was in full load, which are the best conditions for calculating Plant Efficiency.

CHAPTER 4

ENERGY EVALUATION

In order to find the data needed to perform the thermal balance, the following parameters were taken:

K ai	1
R a/c	40
Fuel Flow (Kg./s)	8,27
Air Flow (Kg./s)	330,80
Cp air(KJ/Kg.K)	1,0035
Cp steam (KJ/Kg.K)	1,8723

Applying the equations of the thermodynamic cycles of BRAYTON and RANKINE.:

$$\frac{T2}{T1} = \left(\frac{P2}{P1}\right)^{\frac{(K-1)}{K}}$$

Obtaining the following table of ideal and real values of the combined cycle

POINT	BRAYTON GAS TURBINE CYCLE 1							
	IDEAL				REAL			
	Pressure(Bar)	**Temp. (ºC)**	**Flow (Kg./s)**	**Enthalpy (KJ/Kg.)**	**Pressure (Bar)**	**Temp. (ºC)**	**Flow (Kg./s)**	**Enthalpy (KJ/Kg.)**
1	1,00	22	330,80	296,03	1,00	22		296,03
1C	26,00	17	8,27		26,00	17	8,27	
2	16,00	378		653,69	16,00	450		725,53
3	16,00	1.190	330,80	1.468,12		1.190		1.468,12
4	1,20	425	330,80	700,41	1,20	558		833,91
2C			0,67				0,67	
5			330,80			640		916,20
6			330,80			90		364,27

POINT	BRAYTON GAS TURBINE CYCLE 2							
	IDEAL				REAL			
	Pressure (Bar)	**Temp. (ºC)**	**Flow (Kg./s)**	**Enthalpy (KJ/Kg.)**	**Pressure (Bar)**	**Temp. (ºC)**	**Flow (Kg./s)**	**Enthalpy (KJ/Kg.)**
1	1,00	22	330,80	296,03	1,00	22		296,03
1C	26,00	17	8,27		26,00	17	8,27	
2	16,00	378		653,69	16,00	450		725,53
3	16,00	1.190	330,80	1.468,12		1.190		1.468,12
4	1,20	425	330,80	700,41	1,20	559		834,91
2C			0,67				0,69	
5			330,80			641		917,20
6			330,80			99		373,30

POINT	RANKINE STEAM TURBINE CYCLE							
	IDEAL				REAL			
	Pressure (Bar)	Temp. (ºC)	Flow (Kg./s)	Enthalpy (KJ/Kg.)	Pressure (Bar)	Temp. (ºC)	Flow (Kg./s)	Enthalpy (KJ/Kg.)
1	26,00	156	138,00	803,22	26,00	156	138,00	803,22
2	26,00	155	12,00	801,34	26,00	155	12,00	801,34
3	61,00	155	18,00	801,34	61,00	155	18,00	801,34
4	152,00	156	104,00	803,22	152,00	156	104,00	803,22
2A	26,00	155	6,00	801,34	26,00	155	6,00	801,34
3A	61,00	155	9,00	801,34	61,00	155	9,00	801,34
4A	152,00	156	51,00	803,22	152,00	156	51,00	803,22
2B	26,00	155	6,00	801,34	26,00	155	6,00	801,34
3B	61,00	155	9,00	801,34	61,00	155	9,00	801,34
4B	152,00	156	51,00	803,22	152,00	156	51,00	803,22
2C	5,00	236	6,00	953,00	5,00	236	6,00	953,00
3C	31,70	546	60,40	1.533,41	31,70	546	60,40	1.533,41
4C	116,00	546	51,80	1.533,41	116,00	546	51,80	1.533,41
5C	29,00	352	51,40	1.170,19	29,00	352	51,40	1.170,19
2D	4,50	236	6,10	952,63	4,50	236	6,10	952,63
3D	31,80	538	60,20	1.518,44	31,80	538	60,20	1.518,44
4D	115,00	543	51,00	1.527,80	115,00	543	51,00	1.527,80
5D	29,00	352	51,40	1.170,19	29,00	352	51,40	1.170,19
6	105,00	541	102,80	1.524,05	105,00	541	102,80	1.524,05
7	29,00	352	102,80	1.170,19	29,00	352	102,80	1.170,19
8	27,00	536	120,60	1.514,69	27,00	536	120,60	1.514,69
9	5,00	230	120,60	941,77	5,00	230	120,60	941,77
10	5,00	236	12,10	953,00	5,00	236	12,10	953,00
11	5,00	230	132,70	941,77	5,00	230	132,70	941,77
12		60	136,00	623,48		60	136,00	623,48
13								
14								

Finding the efficiency of the Combined Cycle:

$$\frac{\boldsymbol{Wturbine\ 1 + Wturbine2 + Wsteam\ turbine}}{\boldsymbol{Calorific\ power\ of\ natural\ gas}}$$

$$\mathbf{n} = \frac{\mathbf{566.97}}{\mathbf{714.21}}$$

$$\mathbf{n} = \mathbf{79\%}$$

In order to find the Efficiency Value of the plant, other factors such as Efficiency at the Axis and the selected Efficiency 0.80 and 0.80 should be considered.

$$\mathbf{n\ plant} = \mathbf{0.79} * \mathbf{0.80} * \mathbf{0.80}$$

$$\mathbf{n\ plant} = \mathbf{51\%}$$

CONCLUSIONS

1. When carrying out the Energy Evaluation, an efficiency of 51% is obtained, very close to the actual efficiency of the Plant, 53.7%, concluding that the factors considered were adequate for the calculation of the efficiency mentioned above.

BIBLIOGRAPHY

• http://www.edegel.com/m_cyclo_combinado_ventanilla.htm