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Design of a trigeneration system for a hospital complex in Gran Canaria

C. M.González-Navarro, A.M.Blanco-Marigorta, andJ. A.Peña-Quintana.

Department of Process Engineering
University of Las Palmas de Gran Canaria
Edificio de Ingenierías-Tafira Baja,35017 Las Palmas de Gran Canaria(Spain)
Tel: +34 928 451934 Fax: +34 928 458975
e-mail:meritxell.gn@gmail.com, ablanco@dip.ulpgc.es, jpena@dip.ulpgc.es

Abstract. This article presents the design of a trigeneration system for a hospital complex in the city of Las Palmas de Gran Canaria (Canary Islands, Spain). The absorption refrigeration machine uses water as cooling fluid and lithium bromide as absorber. The energetic analysis shows high values of thermal performance and of electrical equivalent performance. The percentage of primary energy saving is about 23 %. The economic justification is realized taking into account the cost of the initial investment, the operating costs and the income forecast, turning out to be a profitable investment.

Key words

Trigeneration, cogeneration, heating, cooling, natural gas, H_2O/BrLi.

1. Introduction

During the last decade, the cogeneration or production of electric and /or mechanical power and of heat energy for industrial processes has been one of the best alternatives to diminish the consumption of primary energy.

In general, thermodynamic analysis of cogeneration systems shows that the self production of electricity with local utilization of the thermodynamic cycle heat yields good energetic and environmental advantages [1]. The economic profitability of cogeneration systems depends on various and complex factors that are in continuous evolution, such as the market, tariffs, legislation framework and available technology.

Trigeneration combines the production of electricity, heat and cooling and it is usually referred to as CHCP (combined heating, cooling and power generation). Trigeneration plants can reach system efficiencies that exceed 90%. In addition to the economic benefits and advantages, trigeneration plants reduce our dependence on foreign energy supplies and help our environment by dramatically reducing greenhouse gas emissions such as carbon dioxide - when compared to typical power plants.

This paper presents the results of a preliminary studyjustifying the replacement of the present energy, heat and cold producer system of the hospital complex of Las Palmas de Gran Canaria into a single trigeneration system [2]. Natural gas would be the primary energy source of the proposed system. The system will serve the heating, cooling and electrical needs of the 3 buildings of the hospital complex.

2. Planning and design aspects

A. Design requirements

The hospital complex of Las Palmas de Gran Canariaconsists ofthefollowing buildings:

- Maternity and children's university hospital.
- Insular university hospital.
- Industrial building.

First and second buildings are used for typical activities of taking care of the patients (about 1200 beds) whereas industrial building has most of its offices and the required equipment for the production of energy, heat and cold.

The energetic demand of the Hospital complex is characterized by its high value, from bothelectrical and thermal point of view. Electrical annual demand ascends approximately to 22.79 GWh. The thermal systemitself will have to satisfy following needs of the complex:

- Refrigeration.
- Heating.
- Domestic hotwater.

- Hot water for sterilization.
- Hotwater for air treatmentunits.

In the Complex 74 552 GJof heat and 61 651GJ of cold are demanded annually.

B. Formulation of the planning problem

The planning problem is formulated with the hypothesis of new installations, not the refurbishing of existing systems.

A cogeneration projects is typically represented by two basic types of power cycles, topping or bottoming, depending of the type of energy (electrical o thermal) obtained first.The topping cycle utilizes the primary energy source to generate electrical or mechanical power. Then the rejected heat, in the form of useful thermal energy, is supplied to the process. A bottoming cycle has the primary energy source applied to a useful heating process. The reject heat from the process is then used to generate electrical power.Due to its simplicity, the topping cycle has reached a high level of development and it has been used in a large number of facilities. It will be the chosen installation for this project.

Next consideration is if the cogeneration is going to be adjusted to the thermal or to the electrical demand. To adjust the thermal demand provides major energy efficiency and it is favored by present regulation because it saves fuel and decreasesgreenhouse gas emissions. Therefore, cogeneration in this work will be designed to cover the demand of heat energy needs of the complex. If electric power supply is needed, it will be bought.

Related to power enginethere are more than one alternative:vapor turbine, gas turbine,internal-combustion engineor others like Stirlingengine,organic Rankine cycle, fuel battery, microturbine, etc. In our case not all of them will be viable. Non-conventional technologies, for example, are rejected becausethey do not fit into power requirements. On the other hand, fuel-batteries,in spite of their present interest, are not sufficiently proved in commercial exploitation and they are still under development.A combined cycle will not form part of this study due to its complexity:this kind of cycle produce major quantity of electricity with the same amount of fuel but it needs more rigorous treatments of water, more precise systems of regulation and major levels of safety. All these requirements will be justified and compensated in industries dedicated entirely to the production of electricity but not ina Hospital.Next rejected technology is the steam turbine. It isrecommended when thermal demand is high (900°C) but not here, because the maximum demanded temperatures will be about 100 ºC. Besides, investment costs of combined cycles are high due to infrastructure needs for its installation.

Therefore, the election between gas turbine or internal combustion-engine will determine the following step of the study.Different alternatives of every technology were considered, taking into accountfuel consumption, electric power production and heat delivery. Natural gas was usedas fuel.Natural gas has the lowest negative impact on the environment and its´ economic efficiency is high. Gas turbines are rejected because the recoverable heat from their exhaust gas results excessive for the hospitalneeds.

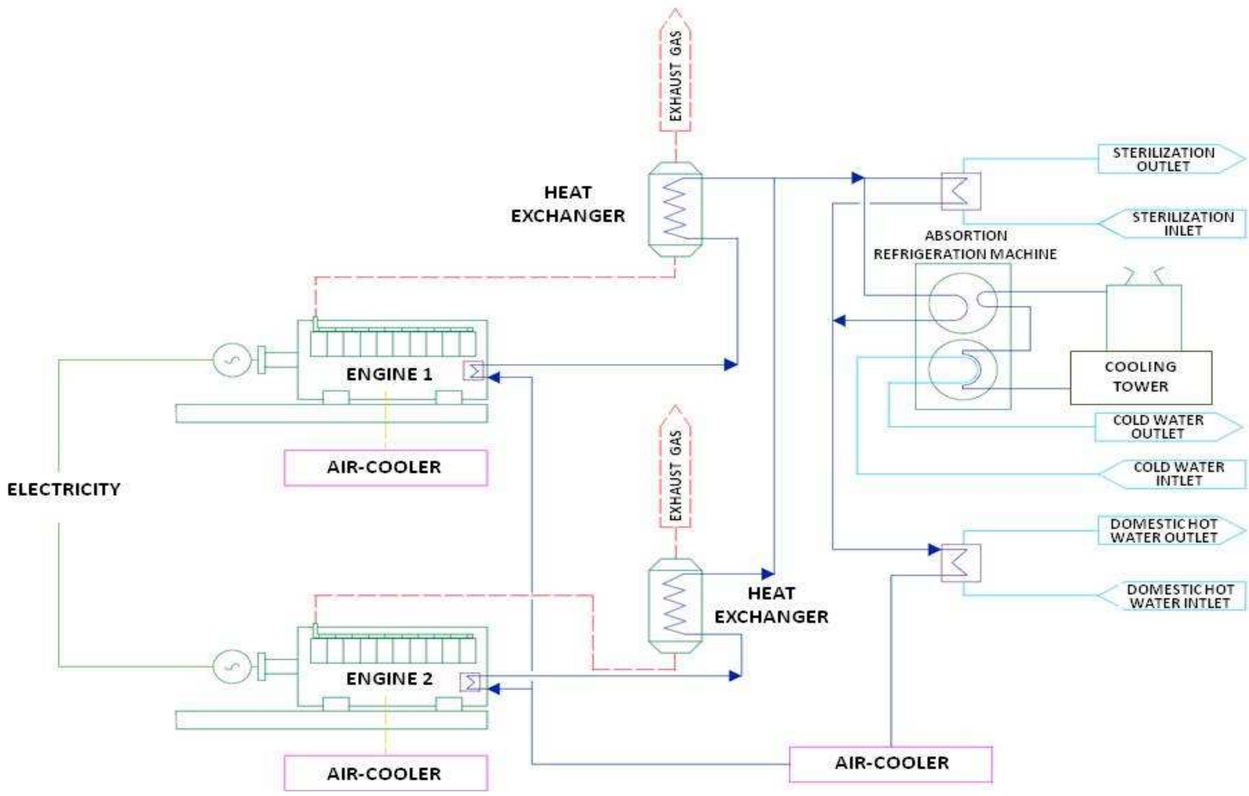

Fig. **1**.Schematic of the thermal installation for the trigeneration system

There are still many possibilities within internal combustion engines according to its size and characteristics. The election of the proper engine will finally take into account following requirements(a detailed explanation can be found in reference [2]):

- Equivalent electrical performance superior to the values established by the regulation.
- High use of the residual heat.
- Satisfaction of cold and heat demand.

Finally, a configuration with two engines from the trademark MWM, each of 3,3 MWM, will be used. They will be scheduled as:
Engine 1 (3 MW) → 24 hour/day
Engine 2 (3 MW) → 15 hour/day

3. Description of the trigeneration system

Recoverable heat from internal combustion engines is distributed among three circuits:

- Exhaust gases.
- Refrigeration water from the shirts of the engine and from the high temperatureair circuit.
- Refrigeration water from oil and low temperature air admission.

In present trigenerationsystem only exhaust gas heat and heat from the high temperatureair circuitwill be recovered.Available low temperature air admissionheat goes to the atmosphere, by an air-cooling system.

Figure 1 shows a schematic of the thermal installation. First, water at 63 ºC goes through the high temperature heat exchangers of the engines, where the water temperature will ascend to 88 ºC. Next, the heat of the exhaust gases from the boilers will elevate the water temperature to 112 ºC. Final exhaust gas temperature will never decrease under 120 ºC to avoid condensation problems.

The utilization of the heat absorbed by the water is realized first in a heat exchanger, where the water from the sterilization system of the hospital is warmed up. Later on, hot watergoes through the absorption machine where the water from the air conditioning system of the hospital is cooled from 12ºC to 6ºC. The selected absorption refrigeration machine uses water as cooling fluid and lithium bromide as absorbent fluid. A unique refrigeration circuitfor both condenser and absorber require the use of refrigeration towers.

Water leaves the absorption refrigeration machine at 85 ºC and it is next used for increasing domestic hot water temperature from 30 ºC up to 70 ºC.

In case of both air conditioning and domestic hot water demands, water would have a final temperature of 63 ºC. This is the predictedinlet temperature to the high temperature heat exchangers of the engines. At this point, the process runs again. To avoid higher water temperature values, the system is provided with 3 air-cooling heat exchangers.

The regulation of the thermal system is carried out by means of a few controllers. If no consumption is detected,combustion exhaust gases exit through the chimney.

4. Energeticanalysis

Global energy balance is represented by aSankey diagram in Figure 2. This diagram shows that 44 % of the chemical fuel energy is destined to the production of electricity. The production of hot water by the residual heat uses 34 % of the fuel energy. Approximately 8 % of the fuel energy isused for the production of low temperature warm water, but this energy is not going to be recovered in any stage of the process. The rest of the fuel energy is lost in the system devices: alternator, engines, boiler, pipes and chimney.

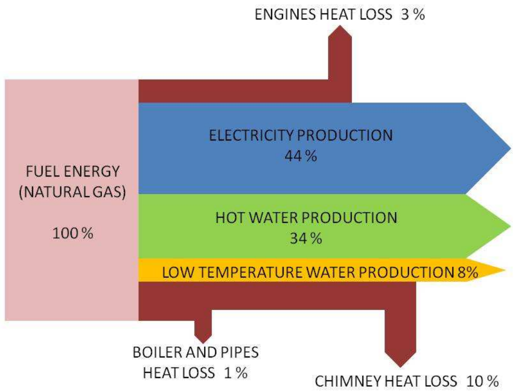

Fig. **2**.Sankey diagram for energy balance

Global thermal efficiency is 78 % and equivalent electric efficiency reaches 71 %, which represent very good results.

Taking into account that one of the basic aims of cogeneration is fuel saving, the calculation of the percentage of primary energy saving*(PES)*is quite interesting. This value represents the primary energy saving of cogeneration compared togenerating heat and power separately in two different processes. Board 2004/8/CE of the European Parliament (relative to cogeneration promotion on the basis of useful heat demand), Annex III, (efficiency of the process of cogeneration) includes the calculation of *PES* as:

$$PES = \left[1-\left(\frac{CHP\,H\eta}{\text{Ref}\,H\eta}+\frac{CHP\,E\eta}{\text{Ref}\,E\eta}\right)^{-1}\right]\cdot 100 = \\ = \left[1-\left(\frac{34\%}{90\%}+\frac{44{,}4\%}{48{,}49\%}\right)^{-1}\right]\cdot 100 \approx 23\% \quad (1)$$

PES is the primary energy saving in %.*CHP Hη* is the heat efficiency of the cogeneration production defined as annualuseful heat output divided by the fuel input used to produce the sum ofuseful heat and electricity from cogeneration.Ref *Hη* is the efficiency reference value for separate heat production.*CHP Eη* is the electrical efficiency of the cogeneration production defined asannual electricity from cogeneration divided by the fuel input used toproduce the sum of useful heat output and electricity from cogeneration.Where a cogeneration unit generates mechanical energy, the annualelectricity from cogeneration may be increased by an additional elementrepresenting the amount of electricity which is equivalent to thatmechanical energy.Ref *Eη*is the efficiency reference value for separate electricity production.

Ref *Hη*andRef *Eη*values are tabulated in the Annexes I and II of the mentioned regulation on the basis of the fuel used, the year of construction of the plant, several environmental conditions, and the quantity of self-consumption electricity. Here, they take the values of 90 % and 48,49 % respectively. The values of *CHP Hη*and *CHP Eη*werealready exposed in Sankey'sdiagram: 34 % and 44 % respectively.

5. Economic analysis

A cogeneration system reports obvious benefits from both environmental and industrial points of view. Nevertheless, it is not a universally adopted systemyet. The reasons are merely economic:the investment costs not always justify the economic savings that can be achieved. In other words, not always the profitability of the investment turns out to be attractive.Therefore, the study of the economic viability of the projectwas carried out [2].

A. Parameters involved in the economic viability of the project:

1) *Cost of the initial investment.* It consists of thebudget for provision of the contracted services and of safety and health. It includes purchase and installation of the equipments, civil work, engineering, legalizations and quality control,giving a total amount of 6 478 925 €.
2) *Operation costs.*They include fuel costs, operation and maintenance staffsalaries and general maintenance needs (like engines lubricating oil, makeup water, additives, etc.). The first year they sum up the quantity of 2 933 094 €.
3) *Income forecast.*It will be obtained from the price of sale of the remaining electric power. It meansa positive cash flow.The sale of the electricity is highly influenced by present regulation conditions. The total amount of positive cash flow was estimated in approximately 4 820 322 €.

The amortization scheduleis prepared taking into account: useful life of the plant of 20 years;a bank lending of 60 % of the initial investment (commission 0.15 %, interest rate 2.77 %, reference Euribor 2010, 1 grace period and a consumer price indexof 1.5 %) Following basic financial analysis criteria are then obtained:

- Pay-back: 6 years
- Net present value (*NPV*): 16 260 205 €
- Internal return rate (*IRR*): 22%

With these results,the investment is considered as profitable. Nevertheless, it is necessary to take into account that the viability of the project will change with any of the following factors:

- Costs of present fuel.
- Purchase price of electricity.
- Costs of natural gas.
- Price of sale of the remaining electricity.

A sensibility analysiswas carried out taking into account the raise of the price of the natural gas or the decrease of the price of sale of the remaining electricity [2]. The result of this analysis shows that,in spite of predictable fluctuations on fuel costs, the profitabilityis remained (an increase of 15 % on fuel costs produce a decrease of 8 points on the *IRR*). The hypothetical case of a 15 %decrease in the price of sale of electricity, would not affect seriously the investment.

5.Conclusion

The trigeneration system developed in this paper is an effective option to be evaluated in the planning and design of a new energy system for the hospital complex of Las Palmas de Gran Canaria with electricity, heat and cooling demand.

The energetic analysis shows high values of both global thermal efficiency and equivalent electric efficiency. The percentage of primary energy saving is about 23 %. Also the economic analysis results in a profitable investment.

Acknowledgement

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