On Energy Efficiency Using The Humid Air Turbine (HAT) Cycle

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Abstract. An approach from the point of view of Thermodynamic Principles about energy efficiency concept is presented. Such efficiency intends to maximise the benefits of an energy generation technique, simultaneously minimising all negative results derived from its use.

As an illustrative example a thermodynamic analysis of the sensitivity of a humid air turbine cycle performance is presented according to several parameters. This study is based on a relatively simple model developed by the authors. This kind of analysis could be useful in the decision-making process of energy policies.

Introduction

Analysing energy generation from a sustainability point of view leads to two main lines of action. Efficient energy generation is the first one, the second being related to the progressive replacement of the current energy generation techniques with renewable energies [1].

This work is intended to deepen the analysis of the energy efficiency concept and the steps that need to be carried out to attain it. Currently 20% of the world population consume 60% of global energy resources. Legitimate desire of nations for economic development should not bring about energy waste. Such approach would be neither sustainable over a long period nor socially responsible.

To this purpose, efficient use of energy over the whole cycle, from generation through end use should be encouraged. Also technological innovation should be promoted in order to develop and implement increasingly efficient processes.

In the world biggest and more dynamic economies, those of the European Union, the United States and Japan [2], end consumption of energy has been observed to grow significantly in the period of 1985-1998, although this growth has been far from continuous in its trend. When analysing the energetic sources these economies have resorted to in the period, it can be found that coal has been partially replaced by oil and gas. Another interesting fact is the presence of a strong demand for electricity of about 20% of total energy demand towards the end of the period.

In Spain the share of energy demand by oil and derived products has kept steady around the 68% level, a relatively high figure when compared to the 54% share that oil holds in the European Union. *However, coal demand dropped from 10% to 3% and gas demand trebled from 4% to 12%* in the same period.

A synthetic indicator employed in the measure of energy efficiency is energy intensity, defined as the ratio of total energy consumption over the gross national product measured in monetary units. In the European Union energy intensity as been gradually declining while in Spain the same indicator has been growing over time underlining a deterioration of the energy efficiency in Spain. This can be explained by the rise in energy demand that Spain has experienced in the residential and service transportation industries, which has offset the beneficial effect of the diffusion of efficient technologies such as cogeneration and renewable resource electricity generation.

Energy intensity is therefore considered as an indicator of the long term sustainability of the processes of production and consumption of energy in a given economy.

Besides these kind of indicators known as synthetic other sort of indicators of a stronger technical nature are needed to determine whether the energy production processes are efficient. In a first stage the improvement of the performance of the energy generation techniques will be targeted. This will contribute to savings of primary energy and consequently to overall energy sustainability.

Assessing Energy Efficiency with the Variables of Thermodynamics.

The goal of improving the overall energy efficiency of a national economy can be achieved through simultaneous actions of various natures: technological, social, economic and political among others.

In Spain electrical energy demand amounts for about 18% of total demand while natural gas demand supposes around 12%. Current use of natural gas includes electrical energy production and also in combined cycles (cogeneration) where both heat and electrical energy are simultaneously produced. Technological innovations aimed at improving the performance of gas turbine installations operating in either simple or combined cycle will have direct impact in the improvement of overall energy efficiency.

The evaluation of energy efficiencies of complex systems such as gas turbine and others requires a professional knowledge of the problem. Thermodynamics provides the concepts of temperature T, pressure P, heat Q, work W, energy U and entropy S together with four laws of Thermodynamics.

The first law defines energy as a conserved quantity that manifests itself in various ways. This law generally fails to identify losses of work and potential improvements or the effective use of resources. The second law defines the concept of entropy and shows that for some energy terms only a fraction of the energy is convertible to work (i.e., the exergy).

Exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. Unlike energy, exergy is not subject to a conservation law except for reversible processes. Exergy is rather consumed or destroyed in any real process.

Thermodynamic analysis makes use of the first and second laws for designing and improving energy systems. The exergy method is useful for improving the efficiency of energy resource for it quantifies the locations, types and magnitudes of wastes and losses. Therefore exergy helps to design more efficient energy systems by reducing inefficiencies.

Moreover, aspects related to environmental impact associated to the use of a given method of energy generation have started to be assessed through the use of the exergy variable. Because of this many scientists and engineers are suggesting exergy as an specific indicator of efficiency within the energy industry as it allows to evaluate energy sustainability.

Example: The Humid Air Turbine Cycle

A thermodynamic analysis of the cycle represented in Fig. 1 has been carried out. This is one of the possible configurations that the conceptual design of humid air turbine (HAT) can adopt.

The good performance offered by the gas turbine cycle have converted it into one of the most used options in the production of electricity and also in the simultaneous production of energy and heat. In the humid air turbine cycle water injection is added into the combustion chamber in order to further reduce emissions of NO_X, and CO_2 .

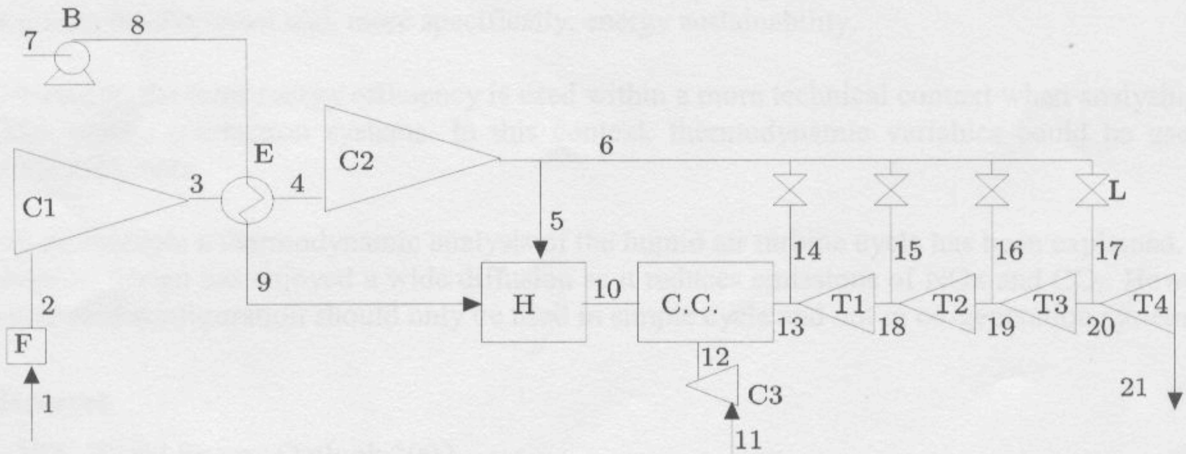

Figure 1. Scheme of the humid air turbine cycle. F, air filter; C1, low pressure compressor; C2, high pressure compressor; C3, fuel compressor; B, pump; E, regenerative exchanger; H, humidifier; CC, combustion chamber; L, valves; T1....T4, stages of the turbine.

The study is based on the use of a simulation program developed by the authors within the frame of MATLAB mathematical language which is called PATITUG (*Programa de Análisis Termodinámico de Instalaciones de Turbina de Gas).* This program has already been used in other studies [3] and yields results in line with the performance and design data provided by manufacturers. Thus, it is considered adequate for the type of studies presented in this paper.

The following basic operating parameters of a turbine have been analysed:

1. Specific work (related to the operational costs). Specific work curves for various humidification percentages are derived from the ratio of pressure at the exit of the compressor over pressure at its entrance. Humidification percentages are defined as the ratio of injected water flow over air flow to be compressed and lie in the range 2%-28%. If we make the comparison with a reference case where no water is injected, we observe that specific work increases as injection percentage grows. For different Temperature Inlet Turbine this effect is observed for all temperatures.
2. Efficiency (related to economic investment) is defined as the ratio of net power of calorific power of the combustible.

The research carried out shows that use of HAT is recommended only if the production of steam is not needed for a certain use. In other words, it is useful in single cycle but not in combined cycle. Szargut [4] has proven than with a configuration different from the one we proposed hot water for industrial use could be produced.

The improvement in performance in a simple cycle compared to the reference case begins to appear as significant with a 14% of injection, getting improvements as high as 7% for a 24% of injection. The ratio of pressures to achieve this improvement has to be high.

Summary

An analysis of the energy efficiency concept has been presented within the framework of sustainable development and, more specifically, energy sustainability.

Moreover, the term energy efficiency is used within a more technical context when analysing the various energy production systems. In this context, thermodynamic variables could be used as specific indicators.

As an example a thermodynamic analysis of the humid air turbine cycle has been explained. This conceptual design has enjoyed a wide diffusion as it reduces emissions of NOx and CO_2. However, the proposed configuration should only be used in simple cycle and not in co-generation systems.

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