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Thermoeconomics and Exergy Method in Environmental Engineering

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The optimization of energy systems design is of great importance for a rationale use of natural fossil, renewable and economic resources to obtain a beneficial consequence in the direction of minimizing the effect and reducing the impact on the environment.

In the industrial and economical international scenario rapidly and continuously growing and the need of energy primary sources, thermoeconomics and exergy method appear to be one of the perspectives for more efficient and rationale use of energy resources and the evaluation of impact on environment and sustainability. During the past decades, we have witnessed revolutionary changes in the way thermodynamics is researched and research line of methods underpinned by exergy method, entropy generation minimisation, exergo-economic and exergo-environmental analysis have become the most established framework of this development[1]. The emphasis is nowadays focused on modelling of systems and thermodynamic optimisation, not only in the mainstreams of engineering (e.g., mechanical, civil, chemical, environmental, industrial, etc.) but also in physics, chemistry, biology, economics and management.

The exergetic method is a powerful tool for assessing the thermodynamic efficiencies and losses of systems and processes. Since the beginning and through its evolution [1] this method has recently undergone a significant evolution and has been adopted in many engineering applications. In particular, the exergy method is based on the Second Law balance of processes adopting the physical exergy and chemical exergy properties defined as entropy-related concepts able to take into account the impact of exergy losses due to reversible interactions between systems and reservoirs and exergy destruction due to internal and external irreversibilities [2,3]. Moreover, being exergy an additive property, the method evaluates exergy balance as well as the mutual influence of equipment and components of plant configurations, process sequences and equipment performance, operations and maintenance [4]. In other terms, exergy property represents an indicator to evaluate the thermodynamic quality of energy content of all systems and process streams from a more complete and rigorous standpoint.

The applications of exergy method concern the thermal power plants performance optimization such as internal combustion engines, critical and supercritical cycles of steam power plants, gas turbines and combined cycle plants in different configurations. Nevertheless, more specific environmental evaluations may be executed by means of exergy balance of natural systems like, for example, rivers for which chemical exergy accounts for disequilibrium caused by water chemical potential with respect to natural reservoirs constituted by the seas. Waste water treatment plant are a further case of exergo-environmental analysis based on exergy method [5,6]. Specific applications have been reported in civil [7]and industrial engineering including Liquified Natural Gas (LNG) [8,9].

Thermoeconomics is the discipline, underpinned by the exergy method,that allows the thermoeconomic evaluation, cost optimization and cost-effective saving of energy systems and processes by using costing equations and the elaboration of estimation and optimization algorithms.

At the beginning of the 60'es, almost simultaneously and resulting from independent researches, the joint application of exergy analysis and engineering economics was proposed, under the name of Exergo-Economics (in Europe) and Thermo-Economics (in the US). Thermoeconomic analysis is based on exergy method analysis, exergo-economic and exergo-environmental fundamentals and principles of plant and process design and cost optimization including the local and global modeling of the systems as well as the effects due to the environment behavior.

The basic idea of this method is to apply the usual procedures of Engineering Accounting, linking the prices of equipment and components to their operating parameters and to their exergetic efficiency, and "pricing" not the unit mass, but the specific exergy content of a stream normally evaluated in quantitative terms of material and energy [1,10]. The basic assumption is that the cost of a product is determined by the cost of its exergetic content and not only by the material and energy necessary to obtain the same product.

From a different standpoint, thermoeconomics is a part of the engineering discipline that results from the combination and integration of thermodynamic principles and economical concepts, with the scope of applying a method of systems analysis that would be objective and thermodynamically correct and complete to multi-production system products costs evaluation.

A definition of Thermoeconomics quoted in literature is the following:"In science, Thermoeconomics is the application of the principles of thermodynamics to economics as well as the application of principles of economics to the efficient design and engineering of processes." [1]

Within the context of process design applications, the analysis carried out in terms of Thermoeconomics can be used for the following purposes:

- Execute feasibility and basic studies and preliminary design of systems;
- Compare alternative plant arrangements to evaluate the cost of multiple products and by-products;
- Optimize the design of a system considering the quantity of consumption resources and the total investment cost (as well as environmental costs where required);
- Execute revamping and debottlenecking intervention by additional and/or replacement of plant process units and equipment;

A positive impact can derive from the possibility to investigate and calculate the cost of a plant based on the cost of equipment and the

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cost of the process streams depending on the quality of energy and the related monetary evaluation with an improved approach. Feasibility studies can be executed based on licensor and owner assumptions, requirements and economical expectation; basic design projects can be executed taking into account the degree of freedom for an economical optimization of equipment and material costs.

A wider approach recently conceived and developed is the Extended Exergy Accounting (EEA) [11,12] that represents today one of the most advanced methodologies adopted with the aim of a more complete evaluation of all cost components concurring to the production in terms of raw materials (final and intermediate products and waste and by-products), energy, and the so called "externalities" (or monetary factors) constituted by capital and labor costs for installation and operation. Also the environmental cost was included to evaluate the depletion remediation costs that today represent and important aspect in evaluating industial initiatives and investments. The EEA is a method of analysis that expresses the externalities in equivalent exergy units by calculating an equivalent exergy amount for each externality included in the system balance by means of the respective equivalent exergetic flux.

Within the framework of the approach to natural and biological systems evolution and complexity theory, the method of Entropy Generation Minimization (EGM) [13-14] has been developed to investigate about the geometric configuration and shape optimization of natural structures constituted by fluid-carrying branched-pipe systems of distribution networks.

The thermodynamic properties related to the available energy and exergy of a system have become the objective of studies and researches [13-26].

The present developments of the exergy method [21-26] are envisaging the investigations and applications to all systems, from large and complex configurationsto systems characterized by small number of molecules and sub-particles. Moreover, systems in equilibrium and non-equilibrium, with respect to the reference systems or environments, constitute the phenomenological scenario for future theoretical researches and applications to engineering design.

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