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Entropy generation and cell growth with comments for a thermodynamic anticancer approach

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HIGHLIGHTS

- Cancer is an open complex dynamic and self-organizing system.
- A thermodynamic theoretical approach was introduced to study cancer.
- The numerical evaluation of this approach is obtained.
- The results agree with the experimental data.

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ABSTRACT

The chemical–physical analysis of the DNA have pointed out the connections between forces, thermodynamics and kinetics. The entropy generation approach has been suggested as a thermodynamic approach to evaluate the accessible states for cancer systems, in relation to their thermodynamic characteristic quantities. Cancer can be described as an open complex dynamic and self-organizing system. The stationary states of tumour systems are analyzed by a thermodynamic approach by using the entropy generation. The aim of this paper is to improve the thermodynamic approach to cell systems, based on the entropy generation. The results obtained consist of the theoretical analysis of the lifetimes of the processes which occur in cells and the numerical evaluation of the theoretical model proposed. Some considerations on the interactions between external fields and cell systems are developed. A possible new anticancer therapy based on the entropy generation is proposed.

1. Introduction

Cancer can be considered as a complex dynamic and self-organizing system in relation both to any cell and to the whole tumour [1–11].

The entropy generation approach [12–15] was used to obtain the stationary conditions of tumour cells [2–11]. Indeed, they can grow only for values of thermodynamic quantities in a stationary range: outside of this range, they cannot develop.

By using this thermodynamic approach a maximum value of volumetric growth has been proven, but only theoretically. In order to validate this approach it is necessary to obtain some numerical results in agreement with the current experimental data. Indeed, these thermodynamic results were suggested as a theoretical support to fundamental hypotheses [16–24] on

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the role of the fractal geometry of tumours [9,11]. Last, as a consequence, some new approaches to anticancer therapy have been suggested [10,11,25].

The entropy generation approach and its use in energy engineering was largely discussed and its bases were related [12–15,26–34] to many fundamental physical analyses of Nature [35–80,1,81–86].

In relation to cells, they interact with their environment using biochemical processes. So in order to understand their behaviour it is important to study how cells interact with their environment.

Consequently, it is important to be able to improve the thermodynamic approach with some computational information. But, the required data useful for numerical results are very difficult to be found. This is why, up to now this approach has not yet got numerical results. The aim of this paper is to obtain a thermodynamic method useful for quantitative applications. Last, the external fields' interactions will be analyzed. Consequently, new anticancer approach will be suggested. To do so, in Section 2 the theoretical basis of the thermodynamic approach will be summarized, in Section 3 some considerations useful for the numerical evaluations will be developed and in Section 4 some consequences of the results will be suggested. The last aim of this paper is to break new ground for applied thermodynamics.

2. The entropy generation bases

Cells are living systems. They grow and, at a characteristic time, each of them divides into two different cells. At this separation time, they vary in size as the size of the daughter cells do too. But the size can vary only in a particular range [84–86]. Cell life is a cyclic process. It begins when a cell emerges from a cell separation. It ends with the separation of the daughter cell itself.

The cell system is composed of [84,87]:

1. the cell wall, which represents the outside border of the cell: through its wall, a cell can exchange energy and mass flows with its environment;
2. the membrane, which controls the mass flows into and out of the cytoplasm;
3. the cytoplasm, which is an aqueous solution of many chemical species;
4. the organelles, which are specialized subunits which perform specific functions useful to the cell life: the organelles are suspended in the cytoplasm.

Within cells, some chemical species undergo chemical reactions with the consequent production of energy and macromolecules. Consequently, the cell volume increases. Moreover, a part of the energy is lost as heat outflow. Only the final products of the cell processes can be known, while it is impossible to know any individual step [84].

Consequently, cell results in an open and complex system. But, it spontaneously exchanges heat which is related to the cell behaviour itself. It represents the interaction between the cell and its environment, a sort of "spontaneous communication" of the cell with the external observer. This interaction is fundamental to develop a thermodynamic study of the cell system. Indeed, cells are too complex to understand the each process contribution to the global effects. So, studying a cell as a black box simplifies its analysis because this approach allows us to analyse only the inflows and outflows balances of energy, masses and chemical species. Last, it is easier to approach the cell environment than the living cell.

These considerations allow us to introduce the entropy generation approach to the study of the cells; indeed, this approach focuses that [19]:

1. an open irreversible real linear or non-linear system is considered;
2. each process has a finite lifetime τ which can be defined as the time range in which a process occurs;
3. what happens in each instant in the range $[0, \tau]$ cannot be known, but what has happened after the time τ (the result of the process) is well known (at least it is sufficient to wait and observe): the local equilibrium is not necessarily required;
4. the entropy balance equation is a balance of entropy and exergy flows.

Moreover, the entropy generation approach allows us to analyze the non equilibrium stationary states by studying the irreversibility of the systems. Last, as it will be highlighted in the next section, the entropy generation approach, by using the Gouy–Stodola theorem, considers only the work lost for irreversibility and the temperature of the system environment, which is always considered constant during any process. This approach is theoretically interesting because [19]:

1. it allows to obtain a range in which an open system persists in its stationary states;
2. it seems a good description of natural phenomena because it considers the global effects of the chaotic behaviour of the systems and the fluctuations around the stationary states;
3. it involves the definition of exergy, in accordance with the current approach which consider this available energy more than other physical quantities in the thermodynamic analysis of the complex systems.

Entropy, related to systems changes, was highlighted as the only effective criterion for spontaneity of change in any system. Indeed, the entropy variation due to irreversibility [84] is the result of the global effect of the entropy variation

1. due to the interaction with the environment,
2. within the system itself.

The entropy variation due to irreversibility is named entropy generation [19]. The entropy generation was introduced in order to avoid inequalities in the analytic relations. Entropy is a state function, so nothing is really produced or generated [40,51]. So, entropy is not more than a parameter characterizing the thermodynamic state. Its variation due to irreversibility, S_g, measures how far the system is from the state that will be attained in a reversible way [19]. It is always $S_g \geq 0$.