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Entransy concept and controversies: A critical perspective within elusive thermal landscape

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ABSTRACT

The concept of 'entransy', a product of heat and temperature, originally called 'heat transport potential capacity', was introduced in 2003, as analogy to product of electrical charge and voltage, as well as other similar quantities. The concept has been extended to entransy property, as integral product of 'stored heat' and temperature, $MC_vT^2/2$, thus representing quantity and quality of stored heat, or thermal energy in isochoric processes without work interactions. The entransy has been used for analysis and optimization of many heat transfer processes as described in many publications since its introduction, and is under further development. Later, the entransy concept has been criticized and denounced by a group of researchers, thus creating controversies that need to be put in a broader, historical and contemporary perspective, which is the main goal of this paper. Despite the need for further clarifications and development of the new concept, it would be premature and unjust to discredit entransy, based on limited and subjective claims, as if the 'already established' concepts and methodologies are perfect, and do not need alternatives and innovations, as if further progress is not needed.

1. Introduction

The *entransy concept* [1,2], while still in development [3] (with 173 references) and with certain deficiencies, has been challenged and criticized by several publications [4–9], as "inconsistent and not needed ... having lack of content in physics ... redundant to entropy," among others, thus creating controversies, as argued in published rebuttals by the Entransy Authors [10–14]. The 'entransy concept and controversy' need to be put in broader, including historical and contemporary perspective, with regards to still-elusive nature and many open issues within thermal phenomena. It appears that some criticism without due rigor of objective and all-inclusive analysis, of all positives and negatives of a newly developing concept, is not justified.

This author is familiar with and in occasional contacts with Professor Guo's group which introduced the 'entransy' concept, as well as with Professor Bejan, whose followers have criticized the new concept, thus generating an 'Entransy Controversy' [14]. Furthermore, this author is devoted to further comprehension of the fundamental *Laws of Thermodynamics* and nature, from *caloric* theory to *Carnot*'s reflections, to Clausius theory of heat and entropy, to the contemporary 'extension' of entropy and challenges of the *Second Law* of thermodynamics [15–19]. In that regard, after long contemplation, a critical perspective of entransy concept and the following controversies within elusive 'thermal landscape', is first time presented and discussed here by this author.

Regardless of entransy redundancy, being derived from other physical quantities, as are the enthalpy, free energy and exergy, for example, it does not diminish entransy uniqueness and usefulness in thermal analysis and optimization. Actually, it is contended here that the entransy, due to its unique nature, may contribute to better comprehension of often obscured thermal phenomena. Despite the need for further development and clarifications of the new concept, it would be premature and unjust to discredit entransy, based on limited and subjective claims, as if the "already established" concepts and methodologies are perfect, and do not need alternatives and innovations, as if further progress is not needed.

2. Heat and elusive thermal energy

Nature of heat was a mystery for a long time and still is elusive. Lavoisier proposed that "*heat is a subtle, weightless substance called caloric.*" Being a substance, the conservation of caloric was a central assumption, long before the energy conservation was established. Regardless of ingenious developments, the 'caloric theory' has been discredited since the 'caloric' was not obviously conserved during dissipative 'heat generation' processes, like drilling, and similar,

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nor in heat engines, as mistakenly assumed by Sadi Carnot [16]. To the contrary, after Einstein discovered 'generation' of energy from mass, $E = Mc^2$, the *First Law* of energy conservation was not discredited, but have been augmented with Einstein's theory. In fact, nothing is wrong with the caloric theory, it is invaluable in modern calorimetric property measurements, it only should be objectively re-assessed and augmented with modern thermal developments.

Heat is a unique and universal concept representing energy transfer of thermal random-motion and its interactions, all other energy transfers classified as different types of work. The stored heat or 'thermal energy' represents stored energy of relevant thermal motion and interactions due to thermal heat transfer or dissipation-conversion of all other energy types to thermal heat. The term '*thermal heat*' is used here to represent holistic meaning of both, the stored thermal energy, and heat as transfer of the stored thermal energy.

There is an important peculiarity about spontaneous heat transfer processes without any work interactions (like within heat exchangers): no heat conversion to work like in heat engine, and no other heat generation from work dissipation, but only the Carnot's 'thermal work-potential dissipation' to heat itself – resulting in conservation of heat, i.e., conservation of thermal energy [15–17,19]. Like original *caloric*, the thermal energy is conserved on its own, but spontaneously degraded to lower temperature, since it cannot be spontaneously reversed back to higher temperature. We like to name such processes, without work interactions, as '*caloric processes*' or '*caloric heat transfer*', also called 'pure heating or cooling' by Guo's group, referred here as Entransy authors. We also could define '*reversible heat transfer*,' when the heat source and sink are at a finite temperature difference, achieved by an ideal Carnot cycle so that thermal work potential is extracted (instead of being dissipated into heat, like in the above caloric processes), while reducing temperature level so that heat transfer takes place at infinitesimally small temperature difference at each temperature level ($dT \to 0$) [15,17,19], see Fig. 1.

Starting from Clausius till nowadays, the obvious but in general not quantified thermal energy, is 'lumped' into the internal energy,

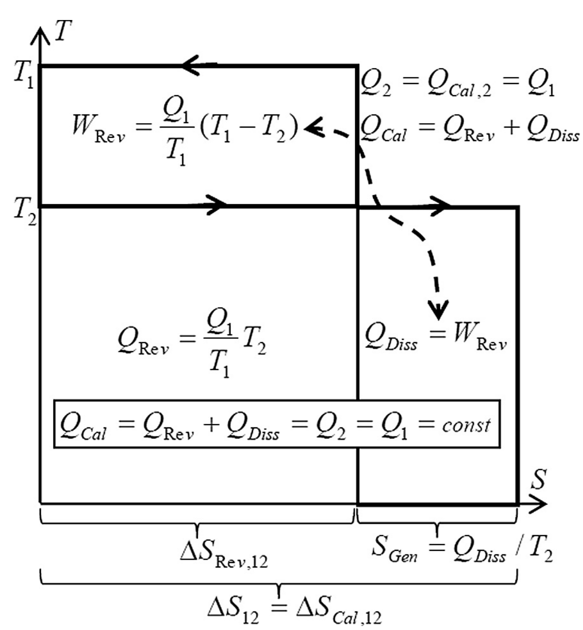

Fig. 1. During a *caloric heat transfer process* between two thermal reservoirs, the work potential, W_{Rev}, is completely dissipated into heat at a lower temperature, Q_{Diss}, which after being added to the reduced reversible heat at lower temperature, Q_{Rev}, will result in conserved heat or thermal energy, $Q_{Cal} = Q_{Rev} + Q_{Diss} = constant$, with increased, generated entropy in the amount of dissipated work potential per relevant absolute temperature [17].

the latter well-quantified and tabulated in Thermodynamic reference books. Some (or many) argue that thermal energy is not definable, but internal thermal energy is manifested as heat transfer due to temperature difference. It is argued here and elsewhere (related manuscript being finalized by this author) that heat (and anything else for that matter) could be transferred only if it exists as stored quantity in kind, in the first place. Therefore, thermal energy is stored heat (directly related to the system heat capacity), $U_{Th} \equiv Q_{Stored}$, and heat is the thermal energy transfer, $Q \equiv U_{Th,transfer}$. It is obvious and self-evident in caloric processes and quantified by the caloric quantities, i.e., system heat capacity and related properties [19].

In modern times, there is a tendency by some scientists to unduly discredit the 'thermal energy' as being indistinguishable from internal energy. However, the thermal heat capacity is well defined property and directly related to thermal energy. Denying existence of thermal energy is the same as denying existence of its transfer (heat transfer) [16,17,19]. Some others consider the Thermodynamic internal energy to be the thermal energy, although the former represents all energy types stored as the kinetic and potential energies of the constituent microstructure, namely, the thermal and mechanical elastic energies in simple compressible substances, in addition to the chemical and nuclear internal energies. In more complex system structures there may be more energy types. The stored system heat increases the system's entropy and 'thermal energy', the latter is distinguished from the other internal-energy types, e.g., mechanical (elastic) energy. For example, the heating or compressing an ideal gas with the same amount of energy will result in the same temperatures and internal energies (the latter also equal for an elastic spring, for example), but it will result in different states, with different volumes and entropies, and similar for other material substances, see Fig. 2. It is reasoned here (and elsewhere by this author), that the thermal energy, as a system property, is distinguishable, regardless of its coupling with the other internal energy forms. A related manuscript is being finalized, to quantify the thermal energy within the system internal energy, see Fig. 2 [19].

2.1. Where does the 'entransy' fit in?

The new *entransy* concept and related analyses are inherently suited for heat transfer processes, without work interactions, called here 'caloric processes', but also provide certain advantages as a complementary approach for other processes in general, as discussed here. The entransy, as a new Thermodynamic function, related to heat and internal 'thermal energy' (the latter to be further developed) and relevant temperature, has its role to complement and clarify the elusive thermal phenomena with a potential to contribute in further optimization of thermal devices and processes. To better comprehend the concept and potential of entransy, it should be put in perspective and correlated with other concepts and many challenges in thermal physics. Some of those challenges will be discussed elsewhere and here. Richard Faynman once stated, "It is important to realize that in physics today, we have no knowledge what energy is." This statement has a deeper meaning, since we tend to simplify, pre-judge, and proclaim definite meanings of the fundamental concepts, or to discredit new concepts. However, we have to keep our eyes and our minds open, and avoid premature judgements, especially of new and fundamental concepts.

3. Entransy concept and definitions

Entransy, a new thermo-physical quantity, based on "physical analogy between electrical conduction and heat conduction of heating an object (pure heat transfer - heating or cooling only),"