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Entransy: A misleading concept for the analysis and optimization of thermal systems

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ABSTRACT

The purpose of this article is to assess the value of entransy for use in the thermal system engineering domain and in particular for design. The conclusion is that use of entransy is not recommended. This finding is in keeping with increasing uneasiness that has emerged recently in the technical literature about this concept. Throughout this article emphasis is on concise discussions of *salient* entransy aspects and the presentation is shaped to reach a broad technical audience. Accordingly, because secondary entransy aspects do not play a central role in reaching the above recommendation, they are considered only in passing or deferred.

1. Thermal system engineering: state-of-the art

Consider an *existing* integrated thermal system comprised of components such as heat exchangers, turbines, compressors, pumps and other components, including electronics, required for system operation. One way to assess how modifications to this integrated system might lead to improved performance is to develop a detailed analytical model and use it to explore options. For this we invoke a well-established methodology applicable to a conceptually very wide realm of thermal systems.

This methodology includes use of the conservation of mass and conservation of energy principles together with the second law of thermodynamics. Principles from fluid mechanics, including values of key parameters such as friction factors and loss coefficients, will commonly be used as well. Principles from heat transfer accounting for relevant conduction, convection, phase change, and radiation modes will also play a part. Important in such modeling are the material properties of the gases, liquids, and solids present, and associated constitutive relations. Conventional efficiency and effectiveness values that recognize constraints imposed by the first and second laws of thermodynamics are also commonly employed. Costing as well as manufacturing considerations will be relevant in many, if not most instances. In short, this approach is comprehensive, painstaking, and to a greater or lesser extent universally practiced.

Furthermore, if the objective is to maximize or minimize particular aspects of the performance of the integrated system mentioned above, an embodiment is sought that achieves this aim while meeting specified constraints (size and/or cost, for example). The components of such an embodiment necessarily work in concert and it is unlikely that any of them will operate *ideally* on *any* basis, including an entransy basis [1], an entropy basis [2], and an exergy basis [2].

Specifically, to maximize or minimize particular performance aspects it is unlikely that any components of the integrated system, or the integrated system itself, will operate so as to maximize or minimize *entransy dissipation*, as considered next.

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2. Why not entransy?

In Ref. [3] entransy (called *heat transport potential capacity* in Ref. [9] of the article cited) is introduced using an analogy between heat conduction and electrical conduction having these aspects: The entransy of a system corresponds to the electrical energy stored in a capacitor. Further, the entransy of a system describes its 'heat transfer ability' [3, p. 2547], as the electrical energy in a capacitor describes its charge transfer ability. Still further, it is argued that entransy is dissipated owing to thermal resistance just as electricity is dissipated owing to electrical resistance. On this modest foundation entransy advocates have constructed a burgeoning body of literature that has promised much but delivered little. Subsequent efforts by advocates to place entransy on a surer footing theoretically do not result in greater real-world applicability, which for entransy is intrinsically limited in scope.

A primary reason for the negligible real-world significance of entransy is that it is intended for use only in a conceptually very narrow realm. According to the last sentence on p.1014 (carrying over to p.1015) of Ref. [1], entransy is applicable for study of a heat transfer process not involving a heat-work conversion. This is called the "direct heating and cooling" realm.

However, it is important to observe here that the performance of a heat exchanger, for example, is influenced by work interactions occurring elsewhere in an integrated system in which it is a component. Accordingly, the analysis and design of the heat exchanger should not be done in isolation but only in concert with the other components of the system. This finding is not limited to heat exchangers, but is generally applicable, strongly suggesting that exceedingly few real-world applications will fall neatly into the direct heating and cooling realm.

The authors further state (p.1016) that in the direct heating and cooling realm entransy dissipation is the preferred measure of irreversibility; whereas, they say, for heat-work conversions entropy generation or exergy destruction is a better measure. However, this assertion reveals a cursory interpretation of thermodynamics since entropy generation and exergy destruction rest firmly on the second law of thermodynamics, which is universally applicable, while entransy dissipation not only arises by analogy but also has significant deficiencies as noted by several qualified reviewers [4–7].

Finally, within the direct heating and cooling realm the term "optimization" has a very specific meaning: Heat transfer optimization aims at minimizing the temperature difference for a given heat transfer rate or maximizing the heat transfer rate for a given temperature difference (see [1, Eqs. (4.1) and (4.2)]). Taken in the terms in which [1] describes either goal, these considerations are very rarely, if ever, significant in thermal systems engineering.

These findings about entransy are addressed further through the two applications considered next.

2.1. First application: one-dimensional heat conduction

The discussion of heat transfer optimization in [1] continues in the third paragraph of p.1020 for the special case of one-dimensional heat conduction using what is called the entransy dissipation extremum principle and resulting in these assertions: (a) For an assigned boundary heat flow rate, minimizing the entransy dissipation leads to the minimum temperature difference—that is, the "optimized" heat transfer. (b) For an assigned temperature difference, maximizing the entransy dissipation leads to the maximum boundary heat flow rate—that is, the "optimized" heat transfer.

It is worth noting in passing that nothing is said in [1] about what to do when these boundary conditions are not applicable. Moreover, the authors do not provide any guidance about how such findings might be decisive in modeling real-world thermal systems. Finally, it is important to recognize here that entropy and exergy analysis *do* apply in the direct heating and cooling realm, despite what the authors of [1] say, and in fact are well-established means for analyzing thermal systems of all kinds.

2.2. Second application: two-dimensional volume-point heat conduction

The discussion of optimization then continues on p.1021 for another special case—namely a case involving two-dimensional volume-point heat conduction for the system shown in Ref. [1, Fig. 2], called the *cooling element* in the present discussion for ease of reference. While this case is characterized by the authors as a "practical" one inspired by devices for cooling electronics, no details are provided. Indeed, how this cooling element might contribute within an integrated system involving electronics is simply not addressed, leaving readers wondering if the application considered actually has practical value or is purely an academic exercise.

That uncertainty is greatly reinforced by the methodology described in the paragraph concluding with Eq. (4.15). Briefly, the optimization objective is to minimize the volume-averaged temperature and the optimization criterion is the minimum entransy dissipation. While the methodology can be stated succinctly, it entails an iterative 16-step procedure, the full discussion of which stretches nearly to the end of p. 1024.

Such an elaborate 16-point procedure suggests that the cost of the cooling element, if one could be determined, might be a more important consideration than saving entransy, but there is no mention of that. Additionally, there is no discussion about how such an entransy-designed cooling element compares with state-of-the-art cooling elements that may provide acceptable performance with, for example, a lower production and/or operating cost.

2.3. Additional remarks

Taking a broader view, attempts by entransy advocates to extend entransy to applications involving convection and radiation are no more compelling than for the applications discussed here involving conduction. Moreover, entransy advocates seemingly do not recognize that any component adhering to idealizations such as inherent in their entransy methodology may introduce performance penalties when integrated in a larger system where it is but a single component. Also, they seemingly do not recognize that an entransy-based design could never be the final step in a design process but at best an initial step in an iterative design process aimed at achieving specified integrated system outcomes through trade-offs among its components.

Finally, it is worth reiterating that when the objective is to optimize the performance of an integrated thermal system the final embodiment does not correspond to the case where individual components are optimized, in isolation, according to some criteria. For instance, heat exchangers are inherently irreversible and their irreversibility levels are also partially imposed by other components of the thermal system. Indeed, taken in isolation each of the participating heat exchangers will unlikely function on a minimum entransy dissipation basis or a minimum entropy generation basis. Moreover, while a correct application of the minimum entropy generation method requires calculation of the overall entropy generation rate for *all* components of an integrated system—in other words, requires a global system approach, the entransy literature is seemingly silent on this important aspect of integrated thermal system analysis.