Comments on the Table of Exergy Flows in the Paper 'A Brief Commented History of Exergy from the Beginnings to 2004'

E. Sciubba and G. Wall
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and Authors' Response

The paper listed above by two eminent authors, which was recently published in IJoT [1], is a rather large effort aimed at creating a navigation through the sea of thousands of papers on exergy. Without a doubt, the paper will be of interest to a wide readership, especially for young people beginning to learn about exergy analysis. That is why it is impossible to leave unanswered some questions about Table I entitled "Specific exergy content of different energy flows", where unfortunately a number of deviations from the book by Bejan, Tsatsaronis, and Moran [2, eq. 3.7 - 3.10a] with regards to the description of exergy flows (transfers) occur. I will try here to formulate the questions or express my disagreement on a number of points.

To begin with, I wish to recall here what it is that we know from school physics:

- Specific energy quantity is either per unit of mass (J/kg) or per unit of volume (J/m^3)
- Specific energy flow is per unit of surface and unit of time (J/m^2 s = W/m^2)
- Energy flow may be by convection (for example, hot water heating), by conduction (wall of home battery) and by radiation (magnetron oven).

Now let us look at the rows of the Table I:

- Specific kinetic and potential energy are seen in convective flow only. In the conductive flow of energy by mechanical work, they are absent.
- Heat is the energy transfer (flow) measured not in J/kg but in W/m^2. The specific thermal energy (CT) or exergy might be measured in J/kg, but they are not heat.
- Mechanical work (force times distance) is the transfer of kinetic or potential energy; it is not exergy itself and is measured not in J/kg but in W/m^2. The amount of work in a given time only is measured by J.
- $I\Delta Vt$, which is the product of electrical current, voltage, and time, is neither exergy nor flow nor a specific quantity. It is the amount of electrical work which has been done, not the ability to do work.
- The flow of chemical exergy is easily understandable as products with velocity, like fuel flow in the pipe of a filling station. It is measured in W/m^2. The chemical exergy of rocket fuel via the mechanical work of a jet is transferred to the potential and kinetic exergy of the rocket body.
- The specific energy of radiation in the table is hidden under the letter I. As it is the electromagnetic wave transfer of exergy, does it have a specific quantity? Actually, electromagnetic radiation is energy transfer in a field described by a Pointing vector. In monochromatic radiation, energy and exergy flows coincide; but in a spectrum with different frequencies, entropy appears, hence the exergy decreases.

After these comments I wish to recall here a better description of the exergy balance. Following Max Plank, there exist 6 kinds of specific energy**: kinetic, potential, thermal U, chemical G, electrical, and magnetic**. In the specific exergy e appears the entropy term (the last term):

$$\rho e = \tfrac{1}{2}\, \rho\, V^2 + g\, Z + \rho U + \rho G + \tfrac{1}{2}\, \varepsilon\, E^2 + \tfrac{1}{2}\, \mu H^2 - To\, \Delta S$$

where ρ is the mass density, ε and μ are the electrical and magnetic permeabilities, and E and H the electrical and magnetic fields. The associated exergy flow vector (without gravity, polarization, and magnetization) is

$$\boldsymbol{\delta} = \rho \mathbf{V}\, (1/2\, \rho V^2 + G) + P \bullet \mathbf{V} + (T - To)\, \mathbf{j}_s + \varphi\, (\mathbf{j} + \partial\, \mathbf{D}/\partial\, t) - \partial \mathbf{A}/\, \partial t \times \mathbf{H}$$

Here φ and $\mathbf{A}$ are the electric and magnetic potentials, $T\mathbf{j}_s = \rho \mathbf{V}U + \lambda \mathrm{grad}T$, $\bullet$ and $\times$ are scalar and vector product symbols, **j** is the electrical current density, **D** the electrical induction, and P the mechanical stress tensor.

The exergy balance is given by $\underline{\partial e/\partial t + \mathrm{div}\ \boldsymbol{\delta} = -T_o S_g}$ where S_g is the entropy gain. For more details see Yantovski [3].

References

[1] Sciubba E., Wall G. A brief Commented History of Exergy From the Beginning to 2004. Int.J. of Thermodynamics, Vol.10 (No1) pp.1-26, March 2007.

[2] Bejan A., Tsatsaronis G., Moran M. Thermal Design and Optimization. J.Wiley, N.Y. 1996.

[3] Yantovski E. Energy and Exergy Currents. NOVA Sci. Publ. N.Y. 1994. eq.2.34 – 2.40

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Authors' Reply to E. Yantovski's Comments

We thank Professor Yantovski for his very accurate and detailed comments. In the following, we use the same numbering of his comments, and the numbers of the references are those of our extended bibliographic list (published on the IJoT website):

1 through 6): The comments are basically correct, but they do not, in our view, invalidate the data we present in Table I. We want to underline that our paper is a review article, and that (as stated in the response to Professor Tsatsaronis' comments above) we had to make some choices as of the definitions to present. The quantities reported in Table I are all specific in the sense that they refer to the unit of the "flowing quantity". So, for instance, heat is in J/kg because a material stream is assumed to be the carrier. Other formulations are valid, and Professor Yantovski enumerates some. As for radiation, the exergy content we quote is for the entire spectrum.

As for the proposal of a "different" way to present the exergy balance, Professor Yantovski prefers of course his own, based on his "vector representation" recently published [2640]. The form we adopted for expressing the exergy "balance" is fully compatible with Plank's list of "specific energy types" as quoted by Yantovski. Though the matter is surely worth of a detailed discussion, such a discussion clearly exceeds the limits of a general review paper like ours.

We are of course available to further discussing these and other issues with the readers of IJoT, and are continuously updating our reference list: we shall be grateful to Authors who will communicate additions or signal omissions and misquotes, so that we can improve it and place an amended list on the Journal site.

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