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HEAT ECONOMY OF THE WATER PLANET EARTH: PART II/REVISION AND SOME NEW RESULTS

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I. *Introduction*

In my article; "Heat Economy of the Water Planet Earth . . . ." which appeared in Vol. 25, No. 2 of this *Journal*, there were several inappropriate formulations to be improved. The purpose of this short article is to present a better way of formulating the entropy balance of the Earth, and to obtain some new results by reviewing the recent papers of myself and others.

II. *Entropy Balance Equation of the Open Steady Earth*

In the page 162 of that article [Murota (1984)], one finds the equation;

$$(1) \qquad \Delta S = \frac{Q}{T_1} - \frac{Q}{T_2}$$
$$= \frac{77}{290} - \frac{77}{250}$$
$$= -0.042 \text{ (kcal/deg·cm}^2\text{·y)}$$

where

ΔS=the entropy change of the Earth per cm²·year
Q=the remaining heat on the Earth
=77 kcal/cm²·y
T_1=the average, absolute temperature of the Earth surface
=290°K (degrees·Kelvin)
T_2=the average, absolute temperature at the top of the atmosphere of the Earth system
=250 °K (degrees·Kelvin).

This equation (1), essentially due to the preceeding work of [Tsuchida (1976)], shows the negative entropy balance. [Tsuchida (1976)] asserted that this entropy decrease had cancelled out the entropy increase which various animate and inanimate activities on the Earth were incessantly generated so that the entropy level of the Earth had been kept constant in annual average, at least before the rise of the contemporary oil civilization. Then, he interpreted the equation (1) as the key for the existence of renewable energy sources (e.g.,

water power, wind power and wood) on the Earth.

The constancy of entropy level implies that the entropy change is zero in annual average. In order to express this steady nature of the earth, I introduced the following equations;

$$(2) \qquad \Delta S' = \frac{Q}{T_1} - \frac{Q'}{T_2} = 0,$$

$$(3) \qquad A = Q - Q' > 0,$$

where A was interpreted as the energy source of the various activity and work carried on the Earth [Murota (1984), p. 163]. But the equation (2) lacks the proper account of entropy generation on the Earth. This also means that the implication of the consecutively appearing equations (4), (5) and (6) in that article becomes somewhat obscure. Hence, I present the following revision.

As in the recent articles [Kawamiya (1984)], [Murota (1985a,b)] and [Tsuchida (1985)], the open steadiness of the Earth can be betterly formulated in the following manner;

$$(2') \qquad \Delta S'' = \frac{Q}{T_1} + S_g - \frac{Q}{T_2} = 0,$$

where S_g stands for the total amount of entropy annually generated on the unit area of the Earth. This new equation can be read as of implying that the sum of entropy inflow to the Earth (Q/T_1) and entropy generation on it (S_g) balances with the entropy outflow from it (Q/T_2).

Combining this equation (2') with (1), I get

$$(3') \qquad S_g = 0.042 \text{ (kcal/deg·cm}^2\text{·y)}.$$

The next task is, then, to find out all conceivable components of this much of entropy generation. Tentatively, I list up the followings.

i) $S(eau)$=entropy due to the thermalization of water power W
ii) $S(vent)$=entropy due to the thermalization of wind power U
iii) $S(bio)$=entropy generation through all biological life processes
iv) $S(d\text{-}e)$=diffusion entropy associated with the phase changes of water
v) $S(d\text{-}v)$=diffusion entropy associated with the air's convection
vi) $S(d\text{-}m)$=diffusion entropy associated with the material dissipation
vii) $S(che)$=entropy generation due to non-biological, chemical processes
viii) $S(mis)$=entropy generation due to all other miscellaneous origins

The sum of all these components must be equal to S_g given as (3'). That is to say, we have

$$(4') \qquad S_g = S(eau) + S(vent) + S(bio) + S(d\text{-}e) + S(d\text{-}v) + S(d\text{-}m) + S(che) + S(mis).$$

In the next section, I present the quantitative analysis of each magnitude of entropy generation in a preliminary manner.

III. *Analysis of Entropy Generation by Classified Origins*

In my previous article [Murota (1984)], the magnitude of water power W was computed through the equations (8) and (9) to be

$$W=1.17 \text{ kcal/cm}^2\cdot\text{y}.$$

Similarly, the magnitude of wind power U was given as

$$U=0.57 \text{ kcal/cm}^2\cdot\text{y}.$$

These water and wind powers eventually turn into waste heat with the surface temperature of the Earth, i.e., T_1, through frictions between them and air, and between them and land surface. Now, let $S(kin)$ represent the amount of kinetic-energy-oriented entropy generation so that $S(kin)=S(eau)+S(vent)$. From the above data, I then get

$$S(kin)=\frac{W+U}{T_1}=\frac{1.74}{290}=6.00\times10^{-3} \text{ kcal/deg}\cdot\text{cm}^2\cdot\text{y}.$$

Since $S_g/S(kin)=0.006/0.042=0.14$, the kinetic-energy-oriented entropy generation explains 14 per cents of the total entropy generation on the earth.

As to the entropy generation through biological activities, it partly occurs in the form of transpiration of water in the process of photosynthesis of plants. The analysis in [Tsuchida and Murota (1985)] shows that some 250 grams of water is to be transpirated for each gram of photosynthetic product. On the other hand, textbooks of biology tell one that the amount of annual photosynthetic product per unit area of the Earth is 3×10^{-2} g/cm^2·y. Hence, the transpirated water through plants is calculated as

$$3\times10^{-2}\times250 \text{ g/cm}^2\cdot\text{y}=7.5 \text{ g/cm}^2\cdot\text{y}.$$

The average amount of water which goes into the global water cycle is widely known as 100 g/cm^2·y. From these data, the ratio of photosynthesis-oriented water over total cyclic water is computed out as $7.5/100=0.075$. Using the already known value of W/T_1, I obtain the value of photosynthetic entropy $S(pho)$ as

$$\begin{aligned} S(pho)&=0.075\times(W/T_1)=0.075\times\times(1.17/290)\\ &=3.03\times10^{-4} \text{ kcal/deg}\cdot\text{cm}^2\cdot\text{y, and the ratio}\\ S(pho)/S_g&=3.02\times10^{-4}/0.042=0.007. \end{aligned}$$

This means that only 0.7 per cents of the total entropy generation on the earth is attributed to the photosynthetic entropy generation. Of course, one has to be aware that not only photosynthesis but also decomposition of plants- and animals-oriented organic wastes generate entropy. However, [Tsuchida and Murota (1985)] shows that the decomposition-oriented entropy for each mol of carbon dioxide (CO_2) is 381 cal/deg·mol while photosynthesis-oriented entropy amounts to 16,513 cal/deg·mol. Therefore, the former is almost neglibible, and it may be safe to say that the entropy generation $S(bio)$ through all biological life processes is less than one per cent of the total entropy generation S_g on the Earth.

A quantitative estimation of $S(d\text{-}e)$, $S(d\text{-}v)$, $S(d\text{-}m)$, $S(che)$ and $S(mis)$ requires much more complicated analyses, and is beyond the scope of this short article of a preliminary nature. Perhaps, the emphasis of [Georgescu-Roegen (1977)] on the dissipation of matter should be examined in the process of estimating $S(d\text{-}m)$, i.e., the entropy generation associated with the dissipation of materials other than water and air.

IV. *Remaining Problems*

In this article, my attention is focused only on the entropy phenomena on the earth surface in its interaction with the heat from the Sun. But entropy phenomena also arise from other origins. For example, the gravity force with zero entropy between the Moon and the Earth creates the tidal power in oceans, which eventually becomes waste heat on the Earth surface through friction. And, the geothermal energy is considered to be originated from the decay heat of the radioactive nucleids in the Earth lithosphere. Entropy generation due to these types of useful energy may be minimal compared with the one already mentioned in this article. Since the human beings have sometimes benefited, and are still benefiting from tidal mills (particularly in Britain) and hot spring bathing (especially in Japan), however, one cannot ignore entropy generation through them.

Finally, effects of mankind's massive burnings of coal, oil and natural gas, and of artificial unclear fission and fusion on the total entropy balance of the Water Planet Earth must be carefully examined in future researches.

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