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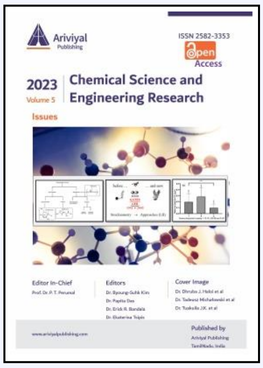

Thermodynamic Guidelines for Engineering and Design, and Sustainable Development

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Abstract: Based on engineering thermodynamics, we research that entropy as a new world view may be a key guideline for engineering and design, and we propose a concrete form: it is a continual optimization process, and corresponds to entropy of each stage constant decrease. From this we discuss "negative temperature" fallacy, which will derive impossible efficiency. Further, the knowledge economics and social sustainable development are searched, which are determined by engineering, design and entropy decrease.

Keywords: engineering; design; entropy; efficiency; negative temperature; knowledge economics; sustainable development

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1. Introduction

The earliest study of thermodynamics originated from thermal engines, so it is logical to explore the role of entropy in engineering and design. An important part of engineering technology is the thermodynamics of chemical processes. One of the important tasks of engineering technology is the conversion of various energy sources, including thermal energy, electric energy, chemical energy, and nuclear energy into mechanical energy.[1-4]

In *Advanced Engineering Thermodynamics*,[2] Benson discussed some basic thermodynamic concepts, including thermodynamic system equilibrium, thermodynamic properties, and thermodynamic application and introduced irreversible thermodynamics, Onsager reciprocal relation and so on. Doolittle introduced engineering thermodynamic principles and their applications.[3]

Moran, et al., provided a thorough development of the second law of thermodynamics (featuring the entropy-production concept), and discussed availability analysis, and a sound description of the application areas. Topics covered include control volume energy analysis, vapour power systems, gas power systems, thermodynamic relations for simple compressible substances, non-reacting ideal gas mixtures and psychometrics, reacting mixtures and combustion, and chemical and phase equilibrium.[4] In this paper, we research that entropy may be a key guideline for engineering and design, and propose "negative temperature" fallacy, and discuss the knowledge economics and social sustainable development.

2. New Research on Entropy

Since the second law of thermodynamics is based on isolated-equilibrium systems, it is in fact very limited. For non-equilibrium thermodynamics, Prigogine proposed the minimum entropy production.[5]

A well-known development of thermodynamics is the theory of dissipative structure proposed by Prigogine. We proposed that if internal interactions, fluctuations and their magnified exist among various subsystems of an isolated system, entropy decrease in the isolated system is possible.[6,7] They includes physics,[8-12] chemistry,[13-15] astronomy,[16,17] geoscience[18] and social sciences.[19-21] For various isolated complex systems,[6-21] we proposed a universal formula for any isolated system:[7]

$$dS = dS^a + dS^i. \quad (1)$$

It is symmetry with the formula:

$$dS = d_i S + d_e S, \quad (2)$$

in the theory of dissipative structure. Further, we derived a complete symmetrical structure on change of entropy:

$$Entropy \rightarrow \{decrease \xrightarrow{increase.} \begin{cases} dS = d_i S + d_e S. \\ dS = dS^a + dS^i. \end{cases} \quad (3)$$

Here entropy decrease may be the dissipative structure for an open system, or be the internal interactions for an isolated system.[10,19]

3. Entropy Guidelines in Engineering and Design

Thermodynamics as a guideline in engineering and design, energy conservation must be followed, while entropy changes can be researched. In fact, various self-organization, self-optimization, natural selection, self-lubrication, emergence, etc., are all internal interactions in system. Self-optimization means that the technical machining system possesses the ability to adapt and adjust itself without intervention by the operator in order to improve the performance with respect to part quality and accuracy, process stability, productivity, and resource efficiency. Self-optimization must be entropy decrease. Further, entropy as a new world view[22] may be a key guideline for design and engineering.

Koomen presented the design process based on the information flow. The detailing step paradigm is used as the modeling primitive, and the formalization is based on simple expressions and rules from information theory. A formal medium is provided for studying the relationship between the complexity of a design and the creativity involved in the design process. By making reasoning more precise when speaking about designing, creativity, model information, complexity, etc., understanding of the design process will increase. The aim is to improve the methods and techniques for the design of complex systems by formalizing the basic mechanisms involved and incorporating the acquired knowledge into these methods.[23]

The development of a design science requires that progress made through research and technology be accountable. The difficulty in measuring progress lies in the different points of view of researchers, teachers, managers, and practitioners. A common, universal measure is needed. LaFleur proposed that the entropy function measures in engineering design, which has the power to integrate the mass, energy, and information measures of multifunctional problems. This provides a way to measure, in an unbiased way, the efficacy of design solutions, design methods, technical systems, and the advancement of design science.[24] Khan, et al., outlined the pertinence of the concept of entropy in design theory and methodology, and resort the concept of design complexity.[25] Juan Torchia discussed entropy as an engineering approach in December 4, 2012 *The Engineering Daily*.

The design process has increasing the information of the product/system. Such the design information entropy is introduced as a state that reflects both complexity and refinement, and it is argued that it can be useful as some measure of design effort and design quality. Krus illustrated the conceptual design of an unmanned aircraft, going through concept generation, concept selection, and parameter optimization.[26]

Entropy takes a backseat to energy in materials design. Geng, et al., demonstrated how to precisely engineer entropy to achieve desired colloidal crystals via particle shapes that can be made in the laboratory, and the inverse design of symmetric hard particles that assemble six different target colloidal crystals due solely to entropy maximization. This approach efficiently samples 108 particle shapes from 92- and 188-dimensional design spaces to discover thermodynamically optimal shapes. We design particle shapes that self-assemble into known crystals with optimized symmetry and thermodynamic stability, as well as new crystal structures with no known atomic or other equivalent.[27] Entropy plays a key role in the self-assembly of colloidal particles. Specifically, in the case of hard particles, which do not interact or overlap with each other during the process of self-assembly, the free energy is minimized due to an increase in the entropy of the system. Understanding the contribution of entropy and engineering it is increasingly becoming central to modern colloidal self-assembly research, because the entropy serves as a guide to design a wide variety of self-assembled structures for many technological and biomedical applications. Rocha, et al., highlighted the importance of entropy in different theoretical and experimental self-assembly studies. They discussed the role of shape entropy and depletion interactions in colloidal self-assembly, and highlighted the effect of entropy in the formation of open and closed crystalline structures, and described recent advances in engineering entropy to achieve targeted self-assembled structures.[28]

Jiang, et al., demonstrated that the thermoelectric properties of p-type chalcogenides can be effectively improved by band convergence and hierarchical structure based on a high-entropy-stabilized matrix. This provides an entropy strategy to form all-scale hierarchical structures employing this matrix, and promotes real applications of low-cost thermoelectric materials.[29]

We researched possible entropy decrease in various chemical reactions. The opposite exothermic and endothermic reactions, the acid and alkaline reactions, etc., cannot all be entropy decrease. We studied possible entropy decrease in various phase transformations, and searched membrane and enzyme in chemistry and biology, in which membranes is namely Maxwell demon. Moreover, a special growth of diamonds from low pressure is discussed, and various known calculated results on entropy decrease are listed.[15]

In the fields of living or inanimate, life is a movement that evolves freely. Diversity and class structure are essential features of natural mobile organization.[30] We should research entropy change in artificial intelligence and digital technologies. From the original management mode to the new management mode, entropy will decrease. Human may improve the social efficiency, and produce greater economic value.

Darwinian evolution and mutual help seem to conflict. In essence, the vast majority of systems in the universe and nature are constantly changing and evolving with "life". Based on Biophysics, we researched coevolution from thermodynamics and entropy by unified method. Let the entropy change dS_A of a subsystem A is a set of its elements dS_i, and corresponding

$$dS_A = f(dS_i, t). \quad (4)$$

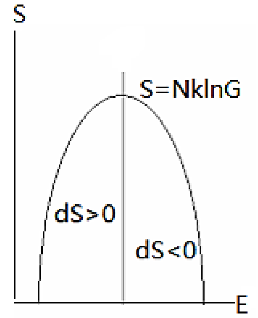


Fig. 1. The entropy as a function of the energy.

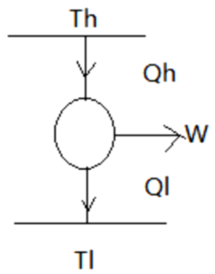


Fig. 2. Possible cycling modes

This may have various internal interactions with cooperation and complementary each other, so entropy may be decrease.[31]

We propose that entropy guidelines in engineering and design should be the continual optimization process, and corresponds to entropy dS_n of each stage constant decrease. This is similar to different stages dS_n of an evolutional process, and may be a comparison of own before and after.[31] For example, from steam engine to internal combustion engine, electric motor, automata and so on, their efficiencies increase from Rankine cycle 33%, to Diesel cycle 60%, and Otto cycle 73%, etc.[32] The hydrogen-oxygen fuel cells can reach 83%. The molecularmotor corresponds to efficiency almost 100%. The process of the increasing efficiencies is also theprocess of decreasing entropy.

This process of engineering and design corresponds to the principle of least action of entropy change:

$$\delta(dS_n) = \delta\int_{t_1}^{t_2} f(dS_i, t)dt = 0. \quad (5)$$

Let $f(dS_i, t)$ is a functional, its gradient $F = gradf(dS_i, t)$ is potential, and has limit value and the minimax principle.[33]
It is known that the entropy in magnetic material is[32]:

$$dS = du/T - (\mu_0 vM/C)dM. \quad (6)$$

If $du/T < (\mu_0 vM/C)dM$, there will be $dS < 0$.

According to Eq.(6), entropy of simple magnetic material is[32]:

$$dS = C_H\, dT/T + \mu_0 v(\partial M/\partial T)_H dH. \quad (7)$$

For a reversible isothermal process the enhanced magnetic field causes exothermic heat $dT = 0$, $(\partial M/\partial T)_H$ of paramagnetic material is always negative value, $dS > 0$ for $dH > 0$. Magnetohydrodynamical generator is a great concern.[34]

4. Negative Temperature and Impossible Efficiency

Few applications of physical technology seem to derive the negative temperature. A great physicist Landau's book Statistical Physics[35] and a well-known book Statistical Physics[36] are the same on the states on the negative temperature.

For negative temperatures

$$\frac{1}{T} = \frac{dS}{dE} = \frac{k}{2h}\log\frac{Nh-E}{Nh+E}. \quad (8)$$

From this derives[35,36]:

$$\lim_{E\to -Nh} T = 0. \quad (9)$$

$$dS = \left(\frac{k}{2h}\log\frac{Nh-E}{Nh+E}\right)E. \quad (10)$$

The entropy is shown as a function of the energy (Fig. 1), in which the maximum entropy is S=NklnG.[35] It has a left-right symmetry for $dS > 0$ and $dS < 0$. The temperature increases with increasing energy beginning at $E_0 = -Nh$ monotonically until $E = 0$ is reached. Entropy is maximal for $E = 0$, and is the state disordered completely. In the region $E > 0$ the temperature is negative (!).[35]

Schwabl emphasize that the energy dependence of S(E) represented in Fig. 1 and the negative temperatures result from it are a direct consequence of the boundedness of energy levels. But, if the energy levels were not bounded from above, then a finite energy input could not lead to an infinite temperature or even beyond it.[36]

Landsherg discussed the negative temperatures.[37] Landsherg, et al., comprehensively analyzed 24 possible cycling modes in the positive and negative temperatures field, in which only 12 are possible.[38,39] If the negative temperature is not introduced, we can unify into Fig. 2 and its opposite process:
According to an efficiency of heat engines

$$\eta = 1 - \frac{T_2}{T_1}. \quad (11)$$

Here if either temperature is negative, the efficiency will be greater than unity. "The results arrived at for negative temperatures which are strange to our intuition have no practical significance in the field of energy production." But, "systems at negative Kelvin temperatures obey the second law and its many corollaries". Of course, "it would be useless to consume work in order to produce a reservoir at a negative temperature which can be used to operate a very efficient heat engine".[35] Therefore, this seems to imply that negative temperature is introduced only in order to obey the second law of thermodynamics.

In the interval $-Nh \le E < 0$, the temperature is positive, as usual,[36] and $dS > 0$. But, "with increasing energy, the absolute temperature become negative, i.e., $T < 0$! With increasing energy, the temperature T goes from 0 to ∞, then through $-\infty$, and finally to

-0. Negative temperatures thus belong to higher energies, and are therefore, 'hotter' than positive temperature."

In fact, Fig. 1 shows that 'the negative temperature' on energy from 0 to $E = Nh$ is just a region of $dS < 0$ with increasing energy.[8] The statement of negative temperature is based on some premises, for example, entropy of the system increase monotonically. From this some strange arguments[35,36] are obtained:

(a). "The temperature $T = -\infty$ is physically identical with $= \infty$; the two values give the same distribution and the same values of the thermodynamic quantities for the system".[35] According to the general definition, temperature cannot be infinite, since the quantity of heat or molecular motion all cannot be infinite. Negative temperature, even negative infinite temperature is stranger. In the same book *Statistical Physics*,[35] Landau proved a very important result that the temperature must be positive: $T > 0$. Moreover, $T = \infty = -\infty$ is excluded by mathematics.

(b). "A further increase in the energy of the system corresponds to an increase in the temperature from $T = \infty$", and "the entropy decreases monotonically".

(c). "At $T = 0-$ the energy reaches its greatest value and the entropy returns to zero, the system then being in its highest quantum state." This obeys Nernst's theorem, but in which the quantity of heat is zero at $T = 0$, while at $T = 0-$ it possesses highest quantum state! We do not know whether $T = 0 = T = 0-$ holds or not.

(d). "The region of negative temperature lies not below absolute zero but above infinity", i.e., "negative temperatures are higher than positive ones".

The negative temperature is contradiction with usual meaning of temperature and with some basic concepts of physics and mathematics.[8] It is a fallacy in thermodynamics.

There is still debate about whether new thermodynamic laws exist at negative temperatures.

Tykodi is considered present.[40,41] Conversely, Tremblay, et al., does not exist.[42-45]

Two well-known examples of the negative temperature are[35,36]:

1) Nuclear spins in a magnetic field.[46] In a nuclear magnetic resonance experiment using the nuclear spins of 7 *Li* in LiF. The spins were first oriented at the temperature T by the field H. Then the direction of H was so quickly reversed that the nuclear spins could not follow it that is faster than a period of the nuclear spin precession. The spins are then in a state with the negative temperature –T. The mutual interaction of the spins is characterized by their spin-spin relaxation time of $10^{-5} - 10^{-6}$ sec. This interaction is important, and the spin system can be regarded as completely isolated for time in the range of seconds.

2) Laser. By means of irradiation with light, the atoms of the laser medium are excited. The excited electron drops into a metastable state. When more electrons are in this excited state than in the ground state, i.e. when a population inversion has been established, the state is described by a negative temperature.[36] But, when an excited electron falls into a metastable state, it should be more order process, and corresponds to entropy decrease.

The two examples should be from lower energy to higher energy, which as the special case seem to have violated the second law of thermodynamics, only for a very short time. It is not, and is not necessary to introduce the negative temperature.

The internal energy with rotation is[36]:

$$E_{rot} = NkT^2 \frac{\partial}{\partial T} \log Z_{rot} = \begin{cases} 3Nk\Theta_r e^{-\Theta_r/T}\left(1 - 3e^{-\Theta_r/T} + \cdots\right), T \ll \Theta_r \\ NkT\left(1 - \frac{\Theta_r}{6T} - \frac{1}{180}\left(\frac{\Theta_r}{T}\right)^2 + \cdots\right) T \gg \Theta_r \end{cases}. \tag{12}$$

These are entropy decrease applied to engineering thermodynamics. Finite-time thermodynamics studies the laws of energy and entropy flow in nonequilibrium systems in finite time. Its main tool is the optimal control theory. The entropy change of high temperature heat source is:

$$dS_x = C \ln[1 - (Q_1/CT_H)]. \tag{13}$$

Here as long as $Q_1/CT_H > 0 \;\; dS < 0$.

The fluctuation of entropy is $\overline{(\Delta S)^2} = kC_p$. At the critical point $C_p \to \infty$, the relative fluctuation of entropy is very large. The diagram of the heat capacity C_v and T for the ideal Bose gas, it will reach a maximum of 1.925 JNK (J is spin degeneracy) at critical temperature T_c, and then become smaller (3/2) NK. Of course, it and the extreme low temperature are not isolated systems.

Landau average field theory and the experimental results have quantitative differences, but the total basic characteristics are the same. Towards the critical temperature, the correlation length tends to infinity. The fluctuation is the inherent property of macroscopic objects, such as light scattering and critical emulsion are the reflection of the fluctuation. The fluctuation theory and its application are still worthy of research and development.

The evolution of nature tends to produce greater and more flows.[30] This corresponds to a higher space-time level. Evolution develops toward more power generation, or toward less dissipation or more efficiency. This corresponds to an entropy decrease.

Now the molecular-sized machines can be self-assembly. One of the important techniques is that Whitesides, et al., designed self-assembled monolayer (SAM).[47]

The new optimization design during the evolution should be the process of entropy decrease. Schuster describes the physical phenomena of life: Evolution drives systems in nature, and enables unparalleled optimization and adaptation.[48] This is for living things, further it may be developed to ecology, the Earth, society and so on.

5. Knowledge Economics and Sustainability

The social sustainable development is determined by the continuous improvement of design and engineering technology, which is linked to the full use of resources and cycle economy. Information is the flow of knowledge. Knowledge should lead to entropy decrease.[30] Bejan discussed Maxwell's demons everywhere and evolving design as the arrow of time.[49]

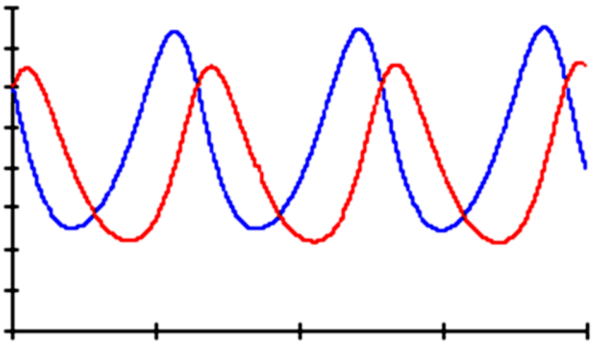


Fig. 3. Lotka-Volterra Model.

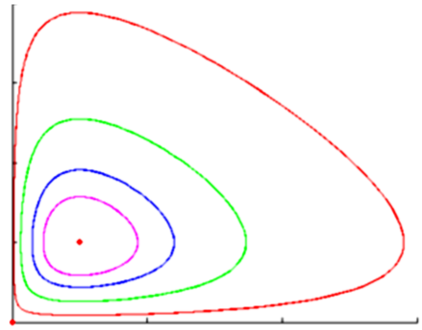


Fig. 4. Limit Cycle

For the cycle economics and social sustainability, the material bases are the science and the engineering technology, and a theoretical basis is the knowledge economy.[50]

Based on the main characteristics of knowledge economy as a new paradigm of economic growth, we proposed the four theorems of the knowledge economic theory[50]:

1) The innovation theorem by talented persons. The knowledge economy is innovative economy, in which talented persons are the most important. Labor and capital will fall to second roles.
2) From zero to things theorem. This is a process of information translated into substance and wealth. Its mathematical representation is $\int 0dT = C$.
3) The increment theorem by cooperation. A main character is networking, which must emphasize cooperation in a system.
4) The continuous cycle theorem. The output of knowledge economy possesses very high scientific and technological content, so it is light and corresponding waste is also little. This includes two aspects:
    a. Since the capital is smaller, so that the required natural resource and corresponding waste are also very little, therefore, it is a model of sustainable development.
    b. Many riches may be created due to talented persons, and capital can attract more talented persons, such it will enter a fine cycle.

For the epoch of knowledge economy, knowledge is first in various bases, talented person is first in various resources, innovation is first in various developments, and cooperation is first in various managements. Its precondition is a right design-making, which requires confirming a developed mode and a choice function. The talented person is only an order parameter for the new epoch. The production function in the classical economy $Y = F(K, L, X_i)$ will be simplified to an approximate single variable function $Y = F(T)$. It is the most important mathematical character on knowledge economic theory. The talented person is a mostly stanchion, and knowledge and information are the most important and the essential production factors.

Knowledge is namely power. Form www to ChatGPT shown the knowledge economy and its power, whose entropy is very small. The worth of knowledge is a scale of developed level on the microscopic knowledge economics.

Entropy as a measure of disorder is very important in society. Cooley discussed human nature and the social order.[51] Society should keep a lower entropy state, and has slow rate of entropy increase, so it can be sustainable development. New tendency---simple living[52] may decrease desires, and decrease entropy. Eisenberg searched the ecology of Eden as a human idea.[53] Meadows, et al., investigated beyond the limits that are global collapse or a sustainable future.[54]

Usually, entropy is applied mainly in ecological economics.[55] Ayres edited book: Resources, Environment and Economics: Applications of the Balance Principle.[56] Chapman and Roberts studied metal resources and energy.[57] Hall, et al., researched the ecology of the economic process: energy and resource quality.[58] Faber, et al., discussed some concepts and methods of ecological economics.[59] Daly discussed the controlled throughput by physical method at the point of lower entropy in the economics of the steady state.[60] Wisman discussed toward a humanistic reconstruction of economics.[61] Georgescu-Roegen studied that the entropy law in the economic process imposes an absolute resource scarcity which cannot be overcome with technological change, exploration, or substitution.[62,63] Evolutionary economics is origin of Darwinism, and economics is determined by society and civilization.[64]

In 1990s neoclassical economics begins to consider the problem of sustainability—how to provide for the well-being of future generations given ecological constraints. Hawken discussed the ecology of commerce as a declaration of sustainability.[65] Renewable energy source corresponds to entropy cycles and sustainable development.[65] Daly researched beyond growth from the economics of sustainable development.[66] Zevenhoven researched engineering thermodynamics and sustainability.[67] He discussed the role of engineering thermodynamics in a world where mankind wishes to have access to low-cost energy. In practice, this implies a central role in the fine balance between economic growth, a risk of modern slavery, exploitation of the Earth's resources and global environmental problems such as climate change and scarcity of water, often leading to armed conflict. Engineering thermodynamics is an important tool by selecting proper and low-cost energy sources and resources and using these as effectively as possible with zero or a minimum of negative side-effects. The methods and tools as guidelines describe and optimize energy use and energy-intensive processes and activities, and used available energy and material resources and the environmental footprint.

Based on the basic social laws on energy and entropy, we discussed some sustainable development patterns.

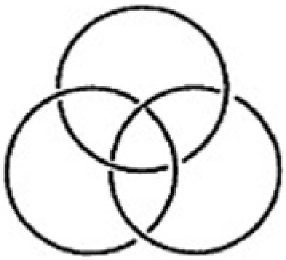
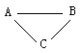


Fig. 5. Borromean Rings.

1) The nonlinear limit and cycle pattern of three elements (Fig. 4). Assume that the general nonlinear evolutional equations of social system are[68]:
   Everything involves the catalytic process and catalyst. Otherwise, it is the inhibitor. Specifically, they are Lotka-Volterra (LV) equation (Fig. 3), Belousov-Zhabotinsky (BZ) reaction, Brusselator, Oregonator, etc.
2) The synergetic pattern on society-economy-environment developed together. This corresponds to Borromean rings (Fig. 5) with three loops in topology,[19] here united they stand, divided they fall. It is also a general model with three elements. Further, this corresponds to three dimensional philosophy, in particular, the 

   structure.[49]
3) The promotion-restraint pattern on Five-Elements. Combining Chinese traditional culture, we proposed the promotion-restraint sustainable developed pattern on the Five-Elements (Fig. 6), which include social (S) progress (democracy, justice, stabilization), economic development (F), science-technology (K), education-civilization (J) and environment-resource (H).

Here a solid line represents a promotion relation, and a dotted line represents a restraint relation. Both relations are all internal interactions in a system.

The sustainable developed patterns should be unification of human-nature, are a harmonious development of society-economy-environment. These social sustainable developed patterns are based on the states with lower entropy, even entropy decrease. The old and modern methods compare and combine, we will enlarge thinking domain, and will obtain possibly inspiration for development of modern sciences.

According to the cycle economics of the sustainable development, the resources should form three elements cycle of produce-consumption-reclaimed waste. Chinese traditional agriculture had formed the most complete cycle economy, in which an important basis is to use farm manure, whose character use local materials, and may increase organic matter of soil, and improve soil structure and recycle of organic fertilizer.

> "Fallen flowers are not merciless and useless,
> They transform manures, and enrich flowers".

It is a poetic recycle. Moreover, the crop rotation and interplanting may preserve fertility of soil, and realize the agricultural sustainable development. Further, Chinese traditional farm forms a complete recycling system on farm-mulberry-herd-fish. Chinese

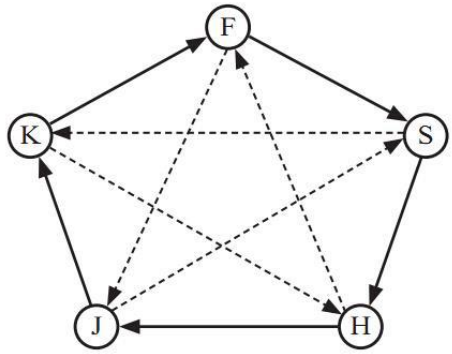


Fig. 6. Promotion-restraint Developed Pattern on the Five Elements

traditional house used grass as roof and land as wall are easy for regression to nature. Our clothing is cotton, our house is a structure of land-tree-grass, they may be used as manure, and recur to land. Such a complete recycle is formed by $land \rightarrow farm\ produces \rightarrow human \rightarrow wastes \rightarrow land$, and it is a basis of Chinese existence and development through thousands years. This may provide a paradigm as reference for the sustainable development of world.

The ancient Chinese agronomical treatise "*Important Methods to Condition the People's Living* (Qi Min Yaoshu, 齐民要术)" pointed out that a successful farmer must critically observe the seasons, weather, and the quality of the soil, in order to adapt his work to these factors. Such a method would save labour and increase yields (**用力少而成功多**). This is consistent with entropy guidelines in agricultural engineering and the principle of least action of entropy change.

Further, the cycle surrounds people as centre. It is a key for any ideal society. On the one hand there is a natural cycle (birth, age, illness and death) for life, and it corresponds to medical treatment, health care, and provides for the aged, etc. On the other hand this is a cycling development of matter and morality, and corresponds to education, science, technology, culture and so on. Both aspects are related closely, and form a big hypercycle. It is also development of the social synergetics.[69]

6. Conclusions

Social progress and human happiness are closely related to the continuous development of engineering technology and design. Entropy as a new world view[22] can guide engineering and design. This should be the entropy changes with constant decrease in different stages of development.

In a word, engineering, design and entropy decrease determine the cycle economics and the social sustainable development.

Conflicts of Interest

The authors declare no conflict of interest.

References

1 Hall N.A.; Ibele W.E. Engineering Thermodynamics. NJ: Prentice-Hall, Inc. Englewood Cliffs. 1960.
2 Benson R.S. Advanced Engineering Thermodynamics (2nd Ed.) Thermodynamics and Fluid Mechanics Series. Elsevier. 1977. [Link]
3 Doolittle J.S. Thermodynamics for Engineers. Wiley; SI version edition, 1984.
4 Moran M.J; Shapiro H.N.; Boettner D.D.; Bailey M.B. Fundamentals of Engineering Thermodynamics (9th Ed.). New York: Wiley, 2018.
5 Prigogine I. Introduction to Thermodynamics of Irreversible Processes. New York: Wiley-Interscience, 1967.
6 Chang Y.F. Possible Decrease of Entropy due to Internal Interactions in Isolated Systems. *Apeiron*, 1997, **4**, 97-99. [Link]
7 Chang Y.F. Entropy, Fluctuation Magnified and Internal Interactions. *Entropy*, 2005, **7**, 190-198. [CrossRef]
8 Chang Y.F. "Negative Temperature" Fallacy, Sufficient-Necessary Condition on Entropy Decrease in Isolated Systems and Some Possible Tests in Physics, Chemistry and Biology. *Int. Rev. Phys*., 2012, **6**, 469-475.
9 Chang Y.F. Unified Quantum Statistics, Possible Violation of Pauli Exclusion Principle, Nonlinear Equations and Some Basic Problems of Entropy. *Int. Rev. Phys*., 2013, **7**, 299-306. [Link]
10 Chang Y.F. Entropy Decrease in Isolated System and its Quantitative Calculations in Thermodynamics of Microstructure. *Int. J. Modern Theo. Phys*., 2015, **4**, 1-15. [Link]
11 Chang Y.F. Self-Organization, Critical Phenomena, Entropy Decrease in Isolated Systems and its Tests. *Int. J. Modern Theo. Phys.* 2019, **8**, 17-32. [Link]
12 Chang Y.F. Entropy Decrease in Isolated Systems: Theory, Fact and Tests. *Int. J. Fundam. Phys. Sci*., 2020, **10**, 16-25. [CrossRef]
13 Chang Y.F. Chemical Reactions and Possible Entropy Decrease in Isolated System. *Int. J. Modern Chem.*, 2013, **4**, 126-136. [Link]
14 Chang Y.F. Catalyst Theory, Entropy Decrease in Isolated System and Transformation of Internal Energy. *Int. J. Modern Chem.*, 2014, **6**, 74-86. [Link]
15 Chang Y.F. Possible Entropy Decrease in Physical Chemistry. *Chem. Sci. Eng. Res.*, 2022, **4**, 48-53. [Link]
16 Chang Y.F. Grand Unified Theory Applied to Gravitational Collapse, Entropy Decrease in Astronomy, Singularity and Quantum Fluctuation. *Int. J. Modern App. Phys.*, 2013, **3**, 8-25. [Link]
17 Chang Y.F. Belief of Entropy Increase, Fallacy of Black Hole Thermodynamics, and its Development. *Int. J. Modern App. Phys.*, 2018, **8**, 1-10. [Link]
18 Chang Y.F. Hypercycle of Geoscience, Nonlinear Whole Geoscience and Possible Entropy Decrease. *World J. Geomat. Geosci.*, 2023, **3**, 1-12. [Link]
19 Chang Y.F. Social Thermodynamics, Social Hydrodynamics and Some Mathematical Applications in Social Sciences. *Int. J. Modern Soc. Sci.*, 2013, **2**, 94-108. [Link]
20 Chang Y.F. Entropy Economics, Entropy Sociology and Some Social Developed Patterns. *Int. J. Modern Soc. Sci*., 2015, **4**, 42-56. [Link]
21 Chang Y.F. Development of Entropy Change in Philosophy of Science. *Philos. Study*, 2020, **10**, 517-524. [Link]
22 Rifkin J.; Toward T. Entropy——A New World View. New York: Bantam Edition. 1981.
23 Koomen C.J. The Entropy of Design: A Study on the Meaning of Creativity. IEEE Transactions on Systems, Man, and Cybernetics (SMC-**15**). 1985, 16-30. [CrossRef]
24 LaFleur R.S. Entropy Measures in Engineering Design. Mechanical Design: Theory and Methodology. Springer, 1996, 275-298. [CrossRef]
25 Khan W.A.; Caro S.; Pasini D.; Angeles J. The Role of Entropy in Design Theory and Methodology. Proceedings of the Canadian Engineering Education Association (CEEA). 2008.
26 Krus P. Information Entropy in the Design Process. ICoRD '13 International Conference on Research into Design. Indian Institute of Technology Madras. Lecture Notes in Mechanical Engineering (LNME). 2013, 101-112.
27 Geng Y.; van Anders G.; Dodd P.M.; Dshemuchadse J.; Glotzer S.C. Engineering Entropy for the Inverse Design of Colloidal Crystals from Hard Shapes. *Sci. Adv*., 2019, **5**, 1-6. [CrossRef]
28 Rocha B.C.; Paul S.; Vashisth H. Role of Entropy in Colloidal Self-Assembly. *Entropy,* 2020, **22**, 1-15. [CrossRef]
29 Jiang B.; Yu Y.; Chen H.; Cui J.; Liu X.; Xie L.; He J. Entropy Engineering Promotes Thermoelectric Performance in p-type Chalcogenides. *Nat. Commun*., 2021, **12**, 32-34. [CrossRef]
30 Bejan A. The Physics of Life: The Evolution of Everything. Hardcover. 2016. [Link]
31 Chang Y.F. Thermodynamic Basis of Coevolution and Self-Optimization, and Ecosystem. *Phys. Sci. Biophys. J*., 2023, **7**, 1-9. [Link]
32 Holman J.P. Thermodynamics. Third Edition. McGraw-Hill. 1980. [Link]
33 Berger M.S. Nonlinearity and Functional Analysis. New York. 1977. [Link]
34 Sutton G.W.; Sherman A. Engineering Magnetohydrodynamics. NY: McGraw-Hill Book Company. 1960. [Link]
35 Landau L.D.; Lifshitz E.M. Statistical Physics. Pergamon Press. 1980.
36 Schwarbl F. Statistical Mechanics (2nd Edition). Springer-Verlag. 2006. [CrossRef]
37 Landsherg P.T. Negative Temperatures. *Phys. Rev*., 1959, **115**, 518. [CrossRef]
38 Landsherg P.T. Heat Engines and Heat Pumps at Positive and Negative Absolution Temperatures. *J. Phys. A*, 1977, **10**, 1773. [Link]
39 Landsherg P.T.; Tykodi R.J.; Tremblay A.M. Systematics of Carnot Cycles at Positive and Negative Kelvin Temperatures. *J. Phys. A*., 1980, **13**, 1063. [Link]
40 Tykodi R.J. Negative Kelvin Temperatures: Some Anomalies and a Speculation. *Am. J. Phys*., 1975, **43**, 271-273. [CrossRef]
41 Tykodi R.J. Negative Kelvin temperatures. *Am. J. Phys*., 1976, **44**, 997-998. [CrossRef]
42 Tremblay A.M. Comment on: Negative Kelvin Temperatures: Some Anomalies and a Speculation. *Am. J. Phys*., 1975, **44**, 994-995. [Link]
43 Danielian A. Remarks on Tykodi's note on negative Kelvin temperatures. *Am. J. Phys*., 1976, **44**, 995-995. [CrossRef]
44 White R.H. Anomalies at Negative Kelvin Temperatures. *Am. J. Phys*., 1976, **44**, 996-996. [CrossRef]
45 Dunning-Davies J. Negative Absolute Temperatures and Carnot Cycles. *J. Phys. A*, 1976, **9**, 605. [Link]
46 Purcell E.M.; Pound R.V. A Nuclear Spin System at Negative Temperature. *Phys. Rev*., 1951, **81**, 279. [CrossRef]
47 Whitesides G.M. Self-assembling Materials. Scientific American, 1995, 146-149. [Link]
48 Schuster P. How universal is Darwin's Principle? *Phys. Life Rev*., 2012, **9**, 460-461. [Link]
49 Bejan A. Maxwell's Demons Everywhere: Evolving Design as the Arrow of Time. *Sci. Rep.*, 2014, **4**, 4017. [CrossRef]
50 Chang Y.F. Structure-function-result Mode in Sociology, Hypercycle and Knowledge Economic Theory. *Int. J. Modern Soc. Sci*., 2013, **2**, 155-168.
51 Cooley C.H. Human Nature and the Social Order. New York: Schocken Books. 1964.
52 Elgin D. *Voluntary simplicity: Toward a way of life that is outwardly simple, inwardly rich*. New York: Morrow. 1981. [Link]
53 Eisenberg E. The Ecology of Eden. New York: Alfred A.Knopf Press. 1998.
54 Meadows D.H.; Meadows D.L.; Randers J. Beyond the Limits: Global Collapse or a Sustainable Future. London: Earthscan. 1992. [Link]
55 Common M.; Stagl S. Ecological Economics: An Introduction. Cambridge University Press. 2005. [Link]
56 Ayres R.U. ed. Resources, Environment and Economics: Applications of the Balance Principle. New York: John Wiley and Sons. 1978. [Link]
57 Chapman P.; Roberts F. Metal Resources and Energy. London: Butterworth. 1983. [Link]
58 Hall C.A.S.; Cleveland C.J.; Kaufmann B. The Ecology of the Economic Process: Energy and Resource Quality. New York: Wiley-Interscience. 1986.
59 Faber M.; Manstetten R.; Proops J. Ecological Economics: Concepts and Methods. Cheltenham: Edward Elgar. 1996. [Link]
60 Daly H.E. The Economics of the Steady State. *The American Economic Review*, 1974, **64**, 15-21. [Link]
61 Wisman J.D. Toward a Humanist Reconstruction of Economic Science. *J. Economic Issues*, 1979, **13**, 19-48. [CrossRef]
62 Georgescu-Roegen N. The Entropy Law and the Economic Process. Harvard University Press. 1971. [CrossRef]

63 Georgescu-Roegen N. The Entropy Law and the Economic Process in Retrospect. *Eastern Econ. J*., 1986, **12**, 3-25. [Link]
64 Tool M.R. Ed. Evolutionary Economics. Journal of Economic Issues. 1988. [Link]
65 Hawken P. The Ecology of Commerce: A Declaration of Sustainability. New York: Harper Collins Publisher. 1993. [Link]
66 Daly H.E. Beyond Growth: The Economics of Sustainable Development. Beacon Press. 1996.
67 Zevenhoven R. Engineering Thermodynamics and Sustainability. *Energy*, 2021, **236**, 121436. [CrossRef]
68 Chang Y.F. Social Physics, Basic Laws in Social Complex Systems and Nonlinear Whole Sociology. *Int. J. Modern Soc. Sci*., 2013, **2**, 20-33. [Link]
69 Chang Y.F. Social Synergetics, Equations on the Rule of Law and Two-Party Mechanism. *Int. J. Modern Soc. Sci*., 2013, **2**, 10-19. [Link]