THE PRESENT THERMAL SCIENCE AND BEYOND

by

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The Fourier law and its various modifications have been widely used to study various thermal problems with great success, but many thermal phenomena cannot yet be explained, for example, the effect of pore size and distribution on the heat transfer of a porous medium, the extremely high thermal conductivity of metasurfaces, and the moisture transfer through a fabric. This short article shows the current state of thermal science for modern science and technology, and its challenge in the future.

Key words*: fractal solitary wave, 5G, fluid-structure system, nanotechnology*

Introduction

Thermal science has become an essential tool for modern science and technology, and everyone is familiar with Fourie's law of heat conduction. The 1-D heat conduction can be expressed as:

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right) \tag{1}$$

where T is the temperature and k – the thermal conductivity coefficient.

This equation is excellent for thermal phenomena occurring in continuous media, but when applied to a porous medium, *e.g.* concrete [1], it cannot describe the effect of pore size and distribution on thermal performance. Engineers have tried their best to modify eq. (1) by assuming that k is a function of geometric parameters [2, 3]. We can, of course, assume that k is a function of porosity:

$$k = k_0 \exp(-a\varphi) \tag{2}$$

where k_0 is the thermal conductivity for the continuous medium, φ – the porosity, and a – the experimental parameter.

Yes, eq.(2) can partially explain some thermal phenomena, but its physical understanding is lacking. Fabric moisture transfer is a common thermal performance, it depends not only on the geometry of the fabric but also on the wetting property of the yarn. Moreover, when the medium tends to be extremely small in micro/nano scale, many thermal phenomena cannot

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be explained by the present thermal science, *e.g.* the thermal property of nanofluids [4], the solvent evaporation of nanoscale moving jets in bubble electrospinning [5-7], and the amazing high thermal conductivity of 2-D surface (*e.g.* metasurface) [8], and Fourier's law seems to become weak and incompetent for these phenomena. This regular issue, therefore, focuses on the present thermal science and its future challenge, and the emphasis is put on the following items.

Travelling solitary wave

Solitons have been widely studied mathematically under an ideal condition, but when a solitary wave moves along an unsmooth boundary, how should we predict its motion? Wang *et al*. [9-11] pointed out that the fractal boundary greatly affects the dynamic properties of the tsunami, and now the fractal solitary theory is becoming a hot topic in non-linear science [12, 13]. The future frontier in this direction is the thermodynamic properties of fractal solitary waves, for example, a tsunami wave might suddenly change its direction when it meets a heat source just like Tai Chi Kungfu, the tsunami has too high energy, it's impossible for the traditional idea as an old Chinese saying, when the water rises, we use earth to hold it back, for coastal protection, but the future thermal science can be used to change easily the tsunami's moving direction.

Thermodynamics for 5G technology

Everyone is now familiar with 5G technology, which can be applied almost anywhere, such as automated control of train traffic [14] and intelligent communication [15], but the road ahead for 6G or even 7G technology is the thermal barrier that is difficult to be overcome so far.

Now, 5G base stations have produced too much wasted heat, and high temperature makes highly integrated devices inefficient or even unusable. Materials scientists have used metasurfaces to solve the problem [16]. Yes, it works excellently, the 2-D metasurfaces with extremely high thermal conductivity can quickly and effectively transfer the wasted heat produced by communication devices so that the temperature can be adjusted to an acceptable level, but why? The answer from thermal science may be more important than the metasurface itself. The future research frontier in this direction is nano-thermodynamics, *i.e.* thermodynamics for thermal performance at the nano- or even molecular scale.

Fluid-induced vibration and energy harvesting

Fluid-structure interaction plays an important role in many fields. A tanker with half volume of oil has seen a sudden collapse, an optimal design of C919 giant aircraft's airfoil cannot yet find its procedure to avoid fluid-induced vibration, which is considered as an inherent property and cannot be avoided, so the present focus was put on numerical simulation [17] and fluid-induced vibration [18], and energy harvesting [19]. Through the energy harvesting device, the fluid-induced vibration can be greatly attenuated, and the frequency-amplitude relationship of vibration affects the efficiency of energy harvesting, now we have some effective methods to find the nonlinear frequency-amplitude relationship [20-22]. The future research frontier in this direction is the thermal energy harvesting to absorb the fluid-induced heat instead of vibration, so that the fluid-induced vibration can be completely avoided, and the fluid-structure system becomes absolutely stable.

Thermal science for radiology and medicine

Thermal science is an important tool for diagnostic radiology [23] and steam sterilization [24], and thermal therapy is also a hot topic in thermal science [25]. The future research frontier in this direction is the thermal approach to radiation protection and virus protection, furthermore, thinking why animals have different body temperatures, why hibernation is a must for some animals, thermal science should open a new window to maintain or regulate immune homeostasis, and offers a new way to antibiotic resistance.

Nanoscale fluid mechanics and nanomaterials

The well-known Navier-Stokes equation has been widely studied in fluid mechanics, although it is still an open problem to be solved, now nanoscale fluids are becoming common in academic communities, for example nanoscale jetting for the fabrication of nanofibers. The thermal performance of a fast moving nanoscale jet can be used to control solvent evaporation and solidification, as well as nanofiber properties. Is it possible for scientists to construct a Navier-Stokes-like equation from a molecular block instead of a continuum assumption? The future research frontier in this direction is to study the thermal performance in nano/macromolecule scale, just as for the blood circulation system in capillaries and the spider spinning process [26].

Mathematics for Thermal Science

Mathematics should focus not only on pure mathematics, *i.e*. prime numbers, but also on its applications, *e.g*. the application of the prime number distribution to the sequence of plants might attract much more attention than prime number theory itself [27]. Applications of mathematics to thermal phenomena are very welcome to engineers, now fractal theory and fractional calculus are hot topics in present thermal science [28-30], the future research frontier in this direction is thermo-mathematics, that will be a new branch of mathematics to study various unsolved thermal problems arising in modern technology, when known mathematics is not enough, we should learn from Newton and Leibniz to create a new mathematics.

Concluding remarks

Thermal phenomena are the most common from our respiratory system to the big bang property of the universe. This short article elucidates the present thermal science to deal with cute frontiers in modern science and technology, but most importantly it predicts the future thermal science and its road to Rome.

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