Preface

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Biographical notes: Hisham A. Abdel-Aal obtained his Doctoral Degree from the University of North Carolina in Charlotte in Mechanical Engineering. He taught at the University of Wisconsin and is currently an Invited Research Professor at Arts et Métier ParisTech. He is interested in problems of tribology at all scales and in the thermodynamic behaviour and stability of tribological systems.

The science of tribology seeks solutions for the detrimental effects of rubbing on the performance and longevity of moving assemblies. It stands at the core of improving reliability and enhancing recoverability of engineering systems. In doing so, tribological investigations often deal with complex systems that, while nominally homogeneous, are practically compositionally heterogeneous. Compositional heterogeneity is either inherent (structural), or evolutionary (functional). Inherent heterogeneity is due to variation in composition, material selection, component chemistry, etc. Evolutionary heterogeneity, on the other hand, arises because of the variation in the local response of different parts of the sliding assembly to external operation conditions and the evolution of the response during operation. Subsystem components react distinctly to any external influence affecting the system as a whole. Their response is a function the share of the external influence with which the particular subcomponent interacts. Distinct responses lead system subcomponents evolving into entities that differ from their initial state. System heterogeneity, thus, introduces a level of functional complexity to the sliding assembly that defines system attitude patterns and characterises the interaction of system sub-components with their surroundings (local or global). Attitude patterns, meanwhile, reflect the manner by which fluctuations in the content of internal energy of the system components evolve.

Sliding systems are either of natural design (bio-sliding systems such as knees, hip joints etc.) or are man engineered. Natural systems, regardless of the degree of functional complexity inherited within, display harmonious characteristics that derive from an ability to self-regulate in accordance to the provisions of natural laws (mainly the laws of thermodynamics). Whence, as a general rule such class of systems operates at an optimal state marked by economy-of-effort. Man-engineered systems, in contrast, do not exhibit comparative levels of harmonious function. Consequently, while natural systems exhibit a functional profile that is streamlined with the provisions of natural law, man engineered systems often cross path with the trajectories of natural law.

This brings about a complex array of damage modes that individual components may undergo during operation. Accordingly, system failure takes place due to the inherent complexity that encompasses tribosystem-surroundings interaction along the different possible functional planes. Ignoring such complexity a common practice among designers of this class of systems. Here design considerations stem principally stem from system response in a single functional domain (as opposed to considering response under coupled modes of operation, i.e., under thermo mechanical, thermo-elastic or high flux coupling conditions). The absence of a design approach that accommodates functional complexity is a direct consequence of our current understanding of the synergetic nature of tribo-systems.

Our current view of tribo-systems stemmed from observing behavioural patterns within a narrow envelope of applications. Within such an envelope, there is no interaction between functional planes. As such, any effect of coupling between thermodynamic forces is deemed practically insignificant. When, however, a tribo-system operates within an expanded envelope, where trajectories of operation cross path in the functional planes, discrepancies between observed behavior and predicted system behaviour, that is based on conventional views, do arise. Such a state challenges the very premise upon which current tribology theory stands.

Tribology literature is full of examples where experimental results stand at odds with conventional theory. For example, under certain experimental conditions, harder materials wear more than softer ones. Some experimental reports indicate the failure of the Oxidation theory of wear for non-steel based materials. Moreover, many studies of the running-in phenomena challenge our understanding of the connection between friction and wear. Similarly, several reports pause interesting questions regarding the state of our current comprehension to the nature of contact between rough surfaces, what constitutes the true area of contact, its magnitude; and the pattern describing contact spot migration in dynamic contact.

Thermal response of a sliding surface is an issue that adds to the list of open questions. Indeed, questions regarding the very nature of a temperature flash, its location on the surface, or beneath the surface, and pattern of migration with respect to the asperities are yet to be fully answered. Fundamentally questionable, moreover, is the very definition of a temperature within a system-represented by the asperity layer in rubbing bodies – that typically operates in a state of disequilibrium. Under disequilibrium conditions, such as those of migrating contact, what are the fundamental bases that justify defining a 'temperature' in the thermodynamic sense with any certainty? More important is the validity of the heat transfer models, currently applied to rubbing pairs, when originally they address thermal transport within equilibrium conditions?

In essence, tribo-systems fall under the broad classification of energy driven systems. These principally operate in a state of thermodynamic disequilibrium. Optimal performance of this class of systems depends on reaching an equilibrium state (that is not a dead state) between system components on the one hand and between the system, as a unit, and the contacting reservoirs. The mechanism that allows the system to reach this objective is the construction of an energy-flow network of optimal shape and structure. Through constructing this network the system attempts to redistribute its imperfections (i.e., the internal resistance to the flow of energy within the system) in order to minimise the different gradients existing within the components with respect to the surroundings. That is, to optimise performance the system will tend to adapt in order to allow the system to evolve into a state where the input energy supply, the effect of that supply on subsystem components, and the surroundings (immediate or remote), are in a stable balance. It follows that system reliability, as well as the integrity of sub-components, are in essence consequences of the specific path a tribo-system adopts in order to morph into a stable equilibrium state (i.e., the path the system adapts to self regulate (or self organise)). Accepting the notion of a tribo-system that self organises (or self-regulates) through morphing into optimal shape (or geometry) offers a window to an alternative view of wear.

The goal of system morphing is to optimise energy passage within the system, and to maximise the efficiency of any energy conversion process within the system-surroundings frame (i.e., work into potential energy, heat into chemical energy etc.). Morphing of shape and geometry, can be an internal or an external process, depending on the constraints bounding the system. Thus, it is conceivable that under certain conditions, internal morphing may be energetically prohibited. That is, due to loads and speeds of rubbing, reaching an optimal, stable, balance between the passage of work of friction into the system and the dissipation mechanisms necessary to accommodate this work, may not be possible. In such a case, the allowable energetic option may very well be mass loss through generation of wear particles. In this manner wear particles would facilitate energy exchange between tribosystem and surroundings. Within such a view, identification of the conditions leading a tribo-system to self regulate through mass loss is essential for devising a holistic design methodology. Such a methodology, then, will realise a tribo-system that enjoys an extended useful life. Fulfilling such a condition, however, requires thorough comprehension of the kinetics of energy flow in tribological events and the synergy that characterises conversion between different energy forms. Accordingly, we may view a tribo-system as an entity that alternates between two fundamental states: equilibrium-disequilibrium. Therefore to study the response of this system (or one of its components) one can study these paths (or possible states) leading to a stable or unstable response. Moreover, we can characterise circumstances where fluctuations around a threshold of stable responses take place, then relating these to damage modes. Thermodynamics is a natural candidate for such a purpose. This is because of generic ideas, such as system-stability, equilibrium, and entropy, which stand at the foundation of this science. These powerful tools facilitate studying the evolution of tribo-system response within an equilibrium-disequilibrium frame of reference. An additional attraction is the flexibility afforded by thermodynamics in defining a 'system'. This allows greater latitude in focusing the study on a subcomponent rather than the whole assembly and vice versa.

Thermodynamics stand at the core of several damage criteria developed for non-sliding systems. These rarely find their way to tribology literature. Indeed, when applied, they do not extend to include coupled modes of damage or the manner by which energy is channeled within the system to induce damage. Interesting perhaps is the observation that both continuum mechanics descriptions of material response in tribo-contacts and energy-based description of tribo-systems share a common thermodynamic origin: consistency with the Clausius–Duhem inequality (second law of thermodynamics). Historically, however, continuum mechanics-based studies maintained a constant thrust since the early days of tribology (even when studying thermal aspects of contact). Energy based studies, on the other hand, traditionally have only witnessed sporadic flurries of developmental activities. Indeed, with the exception of few studies that originated in Russia and the former East Germany, almost all of the energy-based studies belong to the realm of thermo-tribology. These are confined to quantifying the temperature rise encountered by a sliding pair rather than exploring energy transfer mechanisms in the tribopair and its relation to wear.

This issue of IJMPT focuses on the feasibility of formulating an energy-based description of tribo-systems. The topics were chosen so as to provide the interested reader with the background necessary to delve into the energetics of tribo systems. Papers included herein furnish a comprehensive review of previous attempts. In addition, they introduce several possible ideas to describe tribo-systems based on the thermodynamic concepts of entropy, complexity and principles derived from information energy particularly the relation between informational (Shanon's Entropy) and statistical free energy. Naturally, there are more efforts ongoing in the field comprehensive inclusion of which is not possible due to space limitations. However, we hope that including such a sampling will stimulate more efforts leading, ultimately to a reliable predictive holistic theory of damage in sliding systems.