GREEN TRIBOLOGY AND QUALITY OF LIFE

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Abstract: *Every system is immersed in its surrounding. The changes in this interaction (contact) leading to degradation processes will affect the safety of the system. If the processes of changes are in a steady state, it can be considered that the system is safe. Sustainability includes the quality merits. Being the science and technology of the tribological aspects in the ecological balance and environmental impacts, Green tribology can be used with the purpose of saving of energy and materials, as well as of enhancement of the environment and the quality of life. Following the principles of green tribology, by identifying safety-related requirements early in the development of the system, special design and technologies can be used throughout the system life to conduct its safe development and evolution.*

Key Words: *tribology, quality of life, sustainability and safety of systems.*

1. INTRODUCTION

1.1 Quality of life

According to EU 2020 Strategy – the vision for the 21st century, Europe must provide solutions to the grave societal disputes, among them the further reduction of energy-material-losses and radically improving the environmental protection by taking the challenge for sustainability as part of the overall management objective. Green quality is the grand opportunity to meet the extreme requirements of the present century [1]. An essential part of green quality is the Quality of Life (QL).

Quality of life is a term we hear frequently. At first sight, in the everyday discourse we mean by that notion how good life is referring to people's happiness and well-being. Scientists offered various alternative approaches to defining and measuring quality of life and the indicators that reflect it, e.g. social indicators such as health, subjective well-being measures, economic indices, etc. [2].

Although each of the various methods has a number of strengths and weaknesses, they are often methodologically and conceptually complementary. Quality of life is a complex, multifaceted construct that requires multiple interdisciplinary approaches from different angles. In fact, good life arises from a variety of conditions working together in a complex way. Further, the quality of life will be linked with the parameters sustainability and safety of social and ecosystems.

Recently, there have appeared in literature various approaches, incl. multicriterial ones, for assessment of the sustainability of complex systems [3-5]. Quantitative evaluation studies of those parameters are still in germ. In this paper, the problem will be approached hermeneutically, relying on the interpretation of some written sources.

Following the reasoning in [4] and the structure in Fig. 1, quality of life (QL) can be regarded as a construct of:

1. Resource affected QL;
2. Economics affected QL;
3. **Environment affected QL**;
4. Technology affected QL;
5. Social QL.

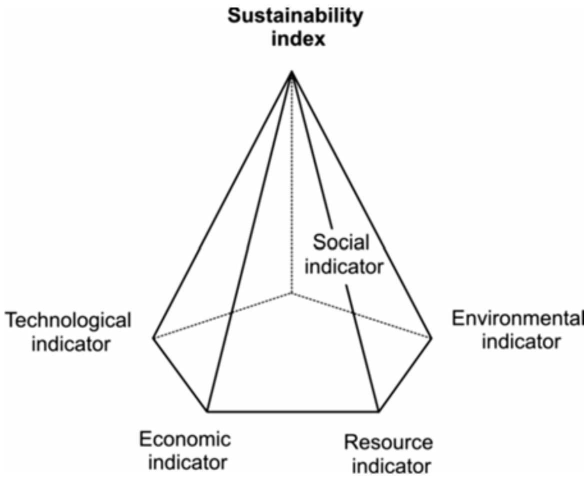

Figure 1. Sustainability index structure

In the expose, the focus will be on the **environmental quality of life**, regarding the properties safety and sustainability of systems resulting of their contact with the media where they are immersed.

1.2 Interaction between system and environment

The systems are embedded in their environment. The mutual interaction between the complex system and its surrounding is immanent for any life-support system [6]. For the complex system there are number of interactions like, e.g., the effects of the system on the environment – it is known that every system is taking material and energy resources from the surrounding and disposing waste to the environment. The human-induced changes in nature proceeding nowadays are at unprecedented rate and scale. For instance, carbon dioxide and other consequences from this interaction lead to global climate changes and add new elements to the complexity of the system.

In the assessment of long term behavior of the complex system, the notion of sustainability is introduced, as the measure for the quality of the system [7]. If the considered system is the society, sustainability is defined as a new quality which is measuring the ability of our society to secure the ability of future generation to have the quality of life at least the same as our generation.

The safety property is immanent to any system. It regarded as a reflection of the quantitative value for degradation of the system, as well as of the rate of changes of any process leading to degradation of the system. **Environmental degradation** is one of the most critical global issues facing our society. Sustainability is an aggregation function of physical, social, technological, environmental and resources parameters (Fig. 1). Relation between the safety properties of the complex system and any other property of the complex system is a fundamental quality indicator of the system. The rate of changes of entropy production in the system [8], being measure of the irreversibility of the processes in it, can be taken as characteristic quality of the system, which describes the **safety** of the system.

Different approaches to achieve safety in real systems are described in [9]. Safety, however, is not something that is easy assessed. By identifying safety-related requirements and design constraints in earlier time of the development process, special design and techniques, e.g. as in the stated below principles of **green tribology**, can be used throughout the system life cycle to guide safe development and evolution.

2. GREEN TRIBOLOGY

2.1 Tribology

Being not quite widely known as notion, **tribology** deserves few words to be popularized. Generally speaking it is the science of contact interaction, concerning the processes of friction, wear, lubrication, hermeticity and other processes in the interface of contacting surfaces.

Tribology (from the Greek word 'τριβω' meaning 'to rub') is defined as 'The science and technology of interacting surfaces in relative motion and of the practices related thereto. Tribology encompasses the science and technology of friction, wear and lubrication. It deals with the phenomena occurring between interacting surfaces in relative motion related to physics, mechanics, metallurgy and chemistry [10]'. The term 'tribology' was introduced in 1966 by Prof. H. Peter Jost in his report for the UK Department of Education and Science. It was stated in Jost Report that huge sums of money have been lost in the UK as the consequences of friction, wear and corrosion. Nowadays, losses resulting from ignorance of tribology amount to about 6% of the gross national product (GNP) in the United States alone. This figure is around USD 900 milliard annually. As far as China is concerned, they could save above USD 40 milliard per year by the application of tribology, or above 1.5% of the GNP [11].

Many new areas of tribological studies have been developed at the interface of various scientific disciplines, and various aspects of interacting surfaces have been the focus of tribology. These areas include, for example, nanotribology, biotribology, the tribology of microelectromechanical systems (MEMS)/nanoelectromechanical systems, etc.

Recently, the new concept of '**green tribology**' has been defined as 'the science and technology of the tribological aspects of ecological balance and of environmental and biological impacts' by H.P. Jost [12]. The former notion was ecotribology underlined mainly the interaction of contact systems with the environment [13,14]. Green tribology means saving materials, energy, and improving the environment and the quality of life. The area of green tribology will directly affect the economy by reducing waste and extending equipment life, improve the economical, technological and environmental balance, reduce the carbon footprint of mechanical systems helping thus the mitigation of climate changes, and improve in general the sustainability and safety in the human society [15].

The specific field of green or environment-friendly tribology emphasizes following aspects [16]:

- tribological technologies that mimic living nature (biomimetic surfaces) and thus are expected to be environment-friendly,
- control of friction and wear, which is of importance for energy and resource's conservation,
- environmental aspects of lubrication, surface modification techniques and tribological aspects of green applications, such as wind turbines, tidal turbines or solar panels.

Green tribology can be viewed in the broader context of two other 'green' areas: green engineering and green chemistry. The US Environmental Protection Agency defines **green engineering** as 'the design, commercialization and use of processes and products that are technically and economically feasible while **minimizing** generation of pollution at the source and risk to human health and the environment' [17-19].

Green chemistry, also known as sustainable chemistry, is defined as the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances and negative environmental impacts [17]. Green chemistry technologies provide reduced waste, safer products, reduced use of energy and resources.

Since tribology is an interdisciplinary area, the principles of green engineering and green chemistry are applicable to green tribology.

2.2 Lubrication: A pertinent example of green tribology

2.2.1 Imitating lubrication in nature

Biomimetics deals with the knowledge transfer from biology to technology. It might assist getting control over some current tribological problems. An advanced method in biomimetics is the biomimicry applied to identify nature's best practices regarding key issues in tribology, e.g. searching improved lubrication solutions [19-22].

Natural lubrication is highly effective, providing low friction coefficients even at low speeds, and relies entirely on water as base lubricants, rendered effective by the presence of a variety of dissolved biomolecules. Imitating such constructs of molecules in the laboratory is very helpful. We have to endeavor to understand the influence of the composition and architecture of such molecules on their tribological performance. An example can be the process of imitating natural lubricants, e.g. glyco-proteins in synovial fluid [22]. In order to mimic this mechanism in the laboratory, molecules were synthesized that spontaneously produce polymer brushes on surfaces. Brushes are formed on surfaces in an aqueous environment when end-grafted, water-soluble polymers are spaced within approximately one radius of gyration (R_g) of each other (Fig. 2), and stretch out in order to maximize their interaction with the water, simultaneously reducing their interaction with each other.

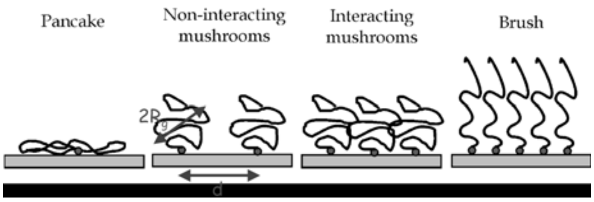

Figure 2. The formation of polymer brushes on surfaces [22]

2.2.2 Environmentally acceptable lubricant products

Vegetable oils and animal fats have been used as lubricants for a very long period of time through the history of mankind. However, after the industrial revolution and the introduction of lubricants produced from mineral oil, bio based lubricant products have been again considered as an environmentally acceptable alternative for lubricant production and have gained currency effectively only in the last decades. Tribological studies show that a properly formulated biolubricant is comparable with mineral base lubricant, and that it could be an adequate substitution in appropriate cases [23]. In general, the advantages of using vegetable oils as a base for environmentally acceptable lubricants are: non-toxicity, biodegradability, resource renewability, good lubricity and high viscosity index, and the disadvantages are: oxidative instability, poor low temperature properties and poor hydrolytic stability.

The considerations of environment aspects of lubricants are mainly focused on health and pollution [24]. In order to emphasize the environmentally acceptable products, the institutions in several countries have developed special signs or labels with the aim to draw the attention of lubricant's consumers to the user's friendly lubricants (Fig. 3).

EU Ecolabel | Green Seal (USA)

Figure 3. Environmental ecolabels

2.3 Tribology in the Renewable Energy Sources (RES)

Today, Europe's energy supply is characterized by structural weaknesses and geopolitical, social and environmental shortcomings, particularly as regards security of supply and climate change. Whilst energy remains a major component of economic growth, such deficiencies can have a direct impact on EU stability and the quality of life of Europe's citizens. These elements provide the main drivers for energy research, within the context of sustainable development. In helping to meet these goals, research & development will contribute directly to the success of EU policy, e.g. achieving a reduction in greenhouse gas emissions as per Kyoto protocol; increasing the share of renewable energy systems (RES); increasing the share of liquid biofuels, etc.

Sustainable energy applications should also become priority of the tribological design, as well as of the engineering design in general.

Tribology of renewable sources of energy is a relatively new field of tribology. Unlike in the case of the biomimetic approach and environment-friendly lubrication, it is not the manufacturing or operation, but the very application of the tribological system that involves green issues, namely, environmentally friendly energy production. If we throw attention on the wind power's share of total installed power capacity over the last decade in Europe, it has increased more than fourfold from 2.2% in 2000 to 10.5% in 2011, as per data of the European Wind Energy Association [25].

The transformation of wind energy will be in the spotlight, as a pivotal element in the transition to a green growth economy, and some of the tribological problems and issues related thereto.

Wind turbines have a number of specific problems related to their tribology (Fig. 4), and constitute a well-established area of tribological research. The problems include water contamination, electric arcing on generator bearings, issues related to the wear of the main shaft and gearbox bearings and gears, the erosion of blades (solid particles, cavitation, rain, hail stones), etc. Most frequently observed and considered tribological problems in wind turbines are in the transmission system, in the gearbox. They are mainly a consequence of inadequate lubrication and/or lack of routine maintenance having in view the extremeness of the working conditions. An issue out of this trouble is to meet the demand of lubricants with improved characteristics [26].

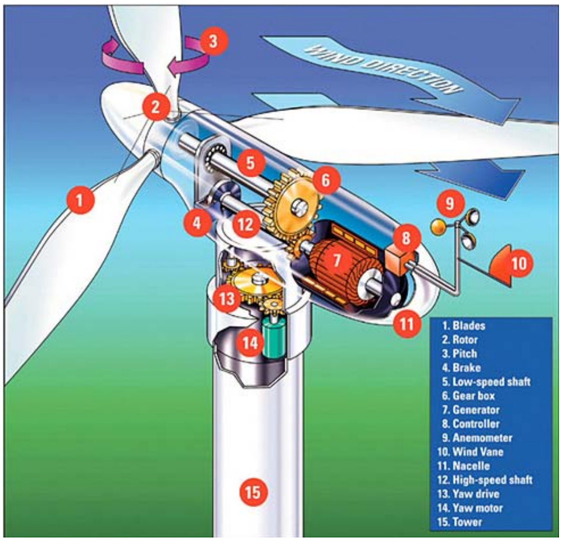

Figure 4. Wind generator

Diverse issues related to tribology of the different renewable energy sources are discussed in literature [26-30].

2.4 Sustainable and secure energy for better quality of life

It is not only EU strategy, but also a global trend to produce competitive, sustainable and secure energy. One of the ways thereto is the transforming of the energy from renewable sources to electrical energy. Some statistical data related to the 'green energy' (Fig. 5). Ever since 2009, in USA 10% of the electricity generation was related to the renewable energy sources (RES).

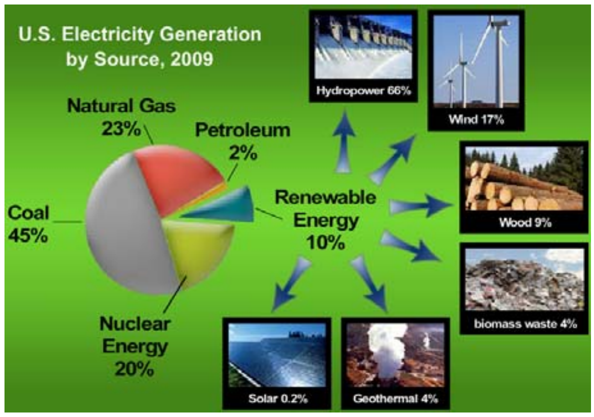

Figure 5. The green energy in USA

China adopted Renewable Energy Law in 2005 and is eyeing 500 GW of renewable energy power by 2020. This is a move that could place China head and shoulders above its contemporaries in power production, and shall account for one-third of the country's power production through renewable sources by that time. About one-fifth of the RES are to the wind-power fields.

As regards **Europe**, the shares of EU electricity generation from RES total power of 32,043 MW (Fig. 6) will be commented. In 2011 9616 MW of wind energy capacity was installed in the EU, making a total of 93,957 MW; enough to supply 6.3% of the EU's electricity [31].

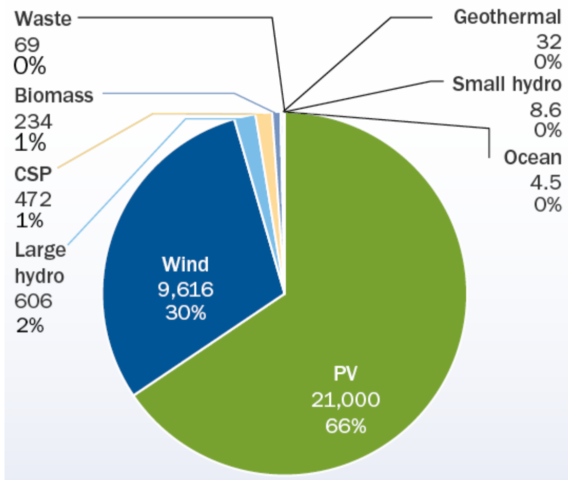

Figure 6. Share of the new renewable installations for 2011 in Europe [32]

The European Union RES targets related to wind fields energy are as follows [32-34]:

- The RES directive of the European Commission (2009/28/EC) exposes the present situation for wind energy:
  - 580 to 680 TW and
  - 15 to 18% of electricity consumption.
- The target of the European Wind Energy Association EWEA for 2030 is:
  - 1150 TW of wind energy, which will be
  - 26.2 to 34.3% of EU electricity demand.

2.5 Summarizing of the green tribology tasks with relevance to the environmental quality of life

2.5.1 Friction (minimization of heat and energy dissipation)

Friction is the primary source of energy dissipation. Most energy dissipated by friction is converted into heat and leads to the heat pollution of atmosphere and the environment. It has been estimated that approximately one-third of the world's energy resources in present use appear as friction in one form or another. The control of friction and friction minimization, which leads to both energy conservation and prevention of damage to the environment, is a primary task of green tribology.

2.5.2 Wear (minimization of wear)

Wear limits the lifetime of components and creates the problem of their recycling. Wear can lead also to high consumption of the natural resources. In addition, wear creates debris and particles that contaminate the environment and can be even hazardous for humans in certain situations.

2.5.3 Lubrication

Lubrication is a focus of tribology since it leads to the reduction of friction and wear. However, lubrication can also lead to environmental pollution. It is desirable to *reduce* lubrication or achieve the *self-lubricating* regime, when no external supply of lubrication is required. Tribological systems in living nature often operate in the self-lubricating regime. For example, joints form essentially a closed self-sustainable system. *Natural lubrication* (e.g. vegetable based oil) should be used in cases when possible, since it is environmentally friendly.

Biodegradable lubrication should also be used when possible to avoid environmental contamination.

2.5.4 Material and surface production and treatment

Sustainable chemistry and green engineering principles should be used for the manufacturing of new components for tribological applications, coatings and lubricants.

Biomimetic surfaces and materials should be used whenever possible since they tend to be more ecologically friendly.

Conventional engineered surfaces have random roughness, and the randomness is the factor that makes it extremely difficult to overcome friction and wear. On the other hand, many biological functional surfaces have complex structures with hierarchical roughness, which defines their properties. *Surface texturing* design provides a way to control many surface properties relevant to making tribo-systems more ecologically friendly.

2.5.5 Tribology in the renewable energy sources

A primary task is advancing tribological R&D in the area of RES in order to assist economic development, protection of the environment and respectively the quality of life.

3. CHALLENGES

As a new field, green tribology has a number of challenges. One apparent challenge is the development of the abovementioned fields in such a manner that they could benefit from each other. Only in the case where such a **synergy** is achieved is it possible to see green tribology as a coherent and self-sustained field of science and technology, rather than a collection of several topics of research in tribology and surface engineering. There is apparently potential synergy in the use of the biomimetic approach, microstructuring, biodegradable lubrication, self-lubrication and other novel approaches, as well as in developing methods of their applications to sustainable engineering and energy production. Much more research should be done for the integration of these fields. Some ideas could be borrowed from the related field of green chemistry and green engineering, for example, developing quantitative parameters to assess the environmental impact of tribological technologies.

Green tribology should be integrated into world science and make its impact on the solutions for worldwide problems, such as the change of climate and the shortage of food and drinking water. In 2009 H.P. Jost mentioned the economical potential of the new discipline: 'The application of tribological principles alone will, of course, not solve the world-wide problems. Only major scientific achievements are likely to be the key to their solution, of which I rate energy as one of the most important ones. For such tasks to be achieved, the application of tribology, and especially of green tribology can provide a breathing space which would enable scientists and technologists to find solutions to these, mankind's crucial problems and allow time for them to be implemented by governments, organizations and indeed everyone operating in this important field. Consequently, this important – albeit limited – breathing space may be extremely valuable to all working for the survival of life as we know it. However, the ultimate key is science and its application. Green tribology can and will play its part to assist science to achieve the required solutions and for policy makers to implement them'.

4. CONCLUSION

Green tribology is a novel area of science and technology. It has been defined as the science and technology of the tribological aspects of ecological balance and of environmental and biological impacts. Its main objectives are the saving of energy and materials and the enhancement of the environment and the quality of life.

In accomplishing these goals, there are following rules to be applied:

- Minimize heat, energy dissipation and wear;
- A basic appeal is to make lubricants less harmful to the environment: Use natural

lubrication and biodegradable lubrication, if possible;

- Use sustainable chemistry and green engineering principles;
- Use biometric principles of engineering whenever possible;
- Appropriate environmental protection by coatings should be applied to control surfaces and materials;
- Design in an early stage for prevention of the degradation of surfaces;
- Apply sustainable energy methodology and sources, especially RES whenever possible.

These principles can greatly reduce the environmental impact of tribological process's products. The aim of this paper is to invite you to explore the world of tribology and specifically green tribology and develop a new appreciation for the approaches in the assessment of safety and sustainability of our ecosystem, and hence of our quality of life.

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