EXERGY INDICATORS OF ENVIRONMENTAL QUALITY

A. V. Chamchine[1], G. M. Makhviladze[1] and O. G. Vorobyev[2]

[1]University of Central Lancashire, Preston, Lancashire, PR1 2HE, UK
Telephone: +44 1772 893239, fax: +44 1772 892916, email: achamchine@uclan.ac.uk and gmakhviladze@uclan.ac.uk

[2]St. Petersburg Marine Technical University, 3 Lotsmanskaya Str., St. Petersburg, 190008, Russia
Telephone: +7 812 1142949, fax +7 812 1138109, email: vog@smtu.ru

Abstract

Exergy, also known as availability, is proposed as an important parameter of environmental quality. This paper presents theoretical analysis of exergy indicators and their practical applications. Exergy indicators, based on rigorous thermodynamic calculations, can be used to estimate the environmental conditions. Information, obtained from analysis of exergy indicators, is proposed to use for managing the natural resources and reducing the environmental degradation. Life cycle analysis on the basis of exergy flows calculations is considered for comparisons of alternative technical solutions and decision making for an industrial object design in order to improve environmental quality. Application of exergy to geotechnic system stability and sustainable development is considered.

Introduction

Sustainability is a new and rapidly growing multidisciplinary area. Solving environmental problems is a great challenge to human ingenuity. Despite recent significant achievements in promoting sustainability there is no fundamental theory of sustainability. Main issues of sustainability concern physics, engineering, ecology, economics, law, social science and politics. Progress in sustainability has been offered to measure through the use of indicators. An indicator is a calculated value or estimated statistic relative to a baseline, threshold or standard established by scientific recommendations. Therefore, indicators of sustainability should combine environmental, economic and social trends, and identify links between and among systems. Indicators of environmental quality play one of key roles in system of sustainability indicators because they establish foundation for comparison and standartisation of environmental information. The main aim of this paper is to contribute to the system of environmental quality indicators by the use of exergy analysis of geotechnic systems.

A geotechnic system (GTS) is considered as an open system, in which an industrial object exchanges mass and energy with a surrounding environment. Such systems can be described by equations which are not susceptible to analytical solution and consequently a more productive approach is based on systems analysis and simulated mathematical modelling.

Exergy Analysis

The negative consequences of human activity continue to generate ecological problems, reflected in a growing wave of demands for the adoption of prompt remedial measures. Unfortunately, such calls frequently do not more than reiterate the necessity for environmental protection and lead at best to isolated and partial successes, most typically in blocking the construction of some environmentally damaging plant. It is substantially more difficult to tackle problems associated with already established industrial objects, especially if they are obviously profitable. In most such cases economic priorities prevail even if environmental damage results. The roots of the problem can be traced to a lack of ecological awareness in the planning of industrial projects. There is inadequate appreciation or even total ignorance of the fact that an industrial plant itself constitutes a unique pro- and reactive factor, transforming the substance of nature, generating mass-energy fields and producing local ecological stresses capable of developing into regional and in extreme cases even global tensions. To assess these effects integrative system-level indicators are needed. Different environmental indicators are available, but they mainly integrate sectoral aspects only (i.e. monitoring). Systemic indicators are rare. Exergy indicators are proposed for holistic assessment of environmental quality.

Exergy, also known as availability, is a measure of the maximum useful work that can be obtained when a system is brought to a state of equilibrium with the environment in reversible processes [1]. Due to the irreversibility of real processes, the work obtained is always less than the maximum work. Hence, by analysing work loss within a system, imperfections can be pinpointed and quantified, and possible environmental improvements suggested.

Szargut introduced application of exergy for economic analysis in [2]. Jorgensen and Major in [3] proposed to use exergy as a key function for ecological modelling. Wall and Gong outlined the basis ideas required to incorporate exergy into complex environmental assessment in [4]. Recent papers [5-9] in different application of exergy analysis have showed that the concept of exergy successfully links the fields of energy, environment and sustainability. Thus, exergy is gradually being adopted as a useful tool in the development and design of a sustainable society. Let us consider application of exergy flows as indicators of environmental quality.

Exergy Indicators

Exergy analysis of a GTS characterises its thermodynamic conditions. It is possible to conclude that exergy is a measure of quality and quantity [5]. Exergy has more than information aspect than energy, but it is generally more difficult to calculate exergy flows in comparison with energy ones. The Poiting vectors for energy and exergy flows are as follows [10]

$$\delta = \varphi \cdot j_q + V \cdot j_p + G \cdot j_m + T \cdot j_s \ , \tag{1}$$

$$\delta_\varepsilon = \varphi \cdot j_q + V \cdot j_p + G_\varepsilon \cdot j_m + (T - T_0) \cdot j_s \ , \tag{2}$$

where φ - electrical potential; V - velocity of movement; G - chemical potential (Gibbs function); G_ε - chemical exergy potential; T - thermal potential; j_q - density of electrical current; j_p - density of impulse flow; j_m – density of substance flow; j_s - density of entropy flow.

Changes of G to G_ε and T to $(T-T_0)$ before entropy flow are defined differences between (1) and (2). There is no saving law for density of exergy flow due to irreversible processes in a technical system. Therefore, exergy is the most general expression of thermodynamic potential and it relates to the local environment. Exergy is better related to the ecological effects then energy, which makes exergy flows better as ecological indicators [5].

It is suggested that exergy as a special thermodynamic potential characterises environmental danger, since exergy determines work, which will be done in the local environment. Exergy indicators, based on rigorous thermodynamic calculations, can be used to improve the resource use and to reduce the environmental degradation.

Exergy indicators of GTS load into the environment during fixed time τ (stationary regime of GTS operation) are exergy flows per square or volume of the surrounding environment:

$$i_{F,\tau} = \frac{\sum E_W}{F} \qquad i_{V,\tau} = \frac{\sum E_W}{V}, \tag{3}$$

where E_W is chemical exergy of waste from industrial object; F and V are accordingly square and volume of the surrounding environment.

Environmental response on technogenic load is determined by indicators of environmental change. They describe a change of chemical composition of environment by the difference of entropy per volume of the surrounding environment:

$$j_{V,\tau} = \frac{\Delta S}{V}, \tag{4}$$

where ΔS is a difference of the environment entropy by comparison with background value [11].

Exergetic Environmental Assessment

Exergetics combined with economics, both macro- and micro-, represent powerful tools for the systematic study and optimisation of systems. Exergetics and microeconomics form the basis of thermoeconomics [2], which is also named exergoeconomics and exergomics. The concept of utility is a central concept in macroeconomics. Utility is also closely related to exergy, and an exergy tax is an example of how exergy could be introduced into macroeconomics [4].

Exergy measures the physical value of a natural resource (material, energy and information). Due to universal concept of exergy, exergetic life-cycle analysis is effective for calculating energy and resource efficiency and total emissions in GTS. Life cycle analysis on the basis of exergy flows calculations is also considered for comparisons of alternative technical solutions and decision making for an industrial object design in order to improve environmental quality.

In Figure the scheme of interaction processes in GTS is represented (arrows represent all type of mass, energy and information exchange between the GTS blocks). It is proposed to use exergertic assessment of all processes of energy and mass transfer in atmosphere, surface waters, ground waters and litosphere. This assessment can be done for the life-cycle of the GTS core – industrial object (Production in Fig.), because exergy is additive function and all exergy flows can be compared in the same energy units. Emission flows, which take place in the industrial object life0cycle, can be calculated and summarised. Therefore, on the stage of design of the GTS it is possible to make adequate scenarios of all emissions occurred in the GTS life-cycle stages (exploitation, renovation, utilisation). This information can be used for ecological certification of the GTS core.

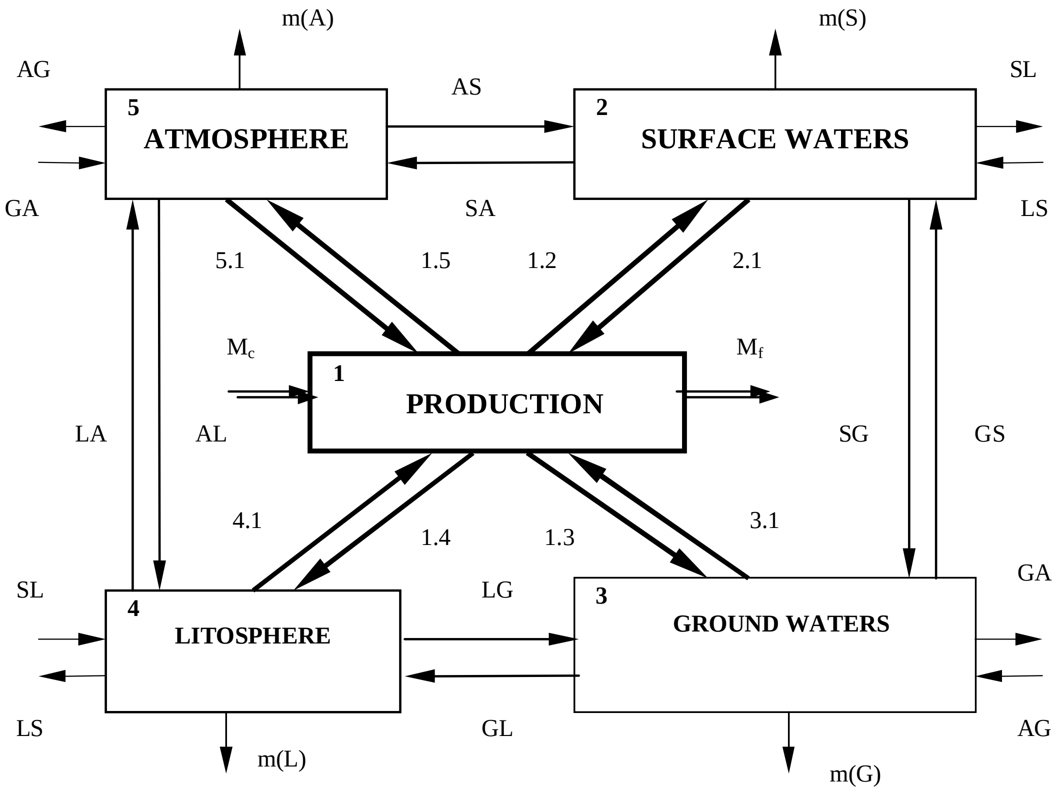

Fig. Scheme of Interaction Processes in Geotechnic System

Sustainable GTS should be defined as systems which make use of renewable resources in such a way that an input of non-renewable resources will be paid back during its life cycle. To encourage the use of renewable resources and to improve resource use, an exergy tax could be introduced [4]. It is possible to divide the resource inflow into two parts – renewable and non-renewable resources, which should be taxed. Nuclear energy can be considered as a non-renewable resource and taxes for nuclear waste would be extremely high due to the high-level of nuclear waste danger and the expensive utilisation process. Waste products, i. e. exergy waste, should be taxed by the amount of exergy released since this is related to the environmental impact.

Conclusions

Exergy is a well-defined concept, which offers the challenging opportunity to assess a GTS on the basis of strict thermodynamic calculations. Exergy systemic indicators of environmental quality focus on the nature of linkages between the GTS parts, its subsystems and elements comprising an integrated whole, identifying the functions of each component within that whole, investigating the dynamics of the GTS development and the conditions of its functioning and, finally, working towards prediction of the state of the GTS as a basis for its subsequent optimisation. Application of exergy to sustainability of a GTS includes the following issues: (i) estimation of environmental quality in the GTS and technogenic load on the environment; (ii) assessment of energy efficiency and resource use in the GTS; (iii) complex technical, economical and environmental optimisation of the GTS; (iv) estimation of the GTS stability by analysis of maximum permissible load on local environment; (v) sustainable design of the GTS by exergy life-cycle analysis. Further work is underway to apply exergy indicators in case study of different built environments.

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