Conference paper

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Systemic approach to the development of green chemistry

DOI 10.1515/pac-2015-0701

Abstract: The development of chemistry is closely related to the sustainable development of human civilization. The problems of exposure to chemicals on the human body are complex. Humans are potentially more susceptible to the damaging effects of chemical pollution if they are in a weakened physical or mental state (already in a state of physical or mental stress). One of the approaches, that simultaneously addresses both of the above mentioned issues, is the green chemistry concept. Governmental regulation should be seen as a framework mechanism. We see great potential in using the principles of green chemistry in the framework of the Responsible Care program. Green chemistry is a tool for the sustainable development of chemistry and the chemical industry.

Keywords: chemical pollution; governmental regulation; green chemistry; Green Chemistry V; quality of life; Responsible Care program.

The development of chemistry is closely related to the sustainable development of human civilization. On the one hand, chemistry helps to find practical solutions to many issues concerning food, energy, building materials and clothing. On the other hand, chemistry and chemicals are a significant cause of environmental pollution. In the outcome document "The Future We Want," adopted at UN Conference "RIO+20" one can read: *We recognize that sound management of chemicals is crucial for the protection of human health and the environment*.

In 2009 in the journal *Nature*, an article about estimates of values of the main anthropogenic pressures was published [1]. "Planetary boundaries" have been identified in nine key parameters: climate change, ocean acidification, ozone depletion, nitrogen and phosphorus cycles, global freshwater use, change in terrestrial ecosystems, the level of biodiversity loss, the concentration of emissions of aerosols and chemical pollution. For seven of the nine parameters, boundary values were defined. Going beyond the boundary values can lead to irreversible changes in the biosphere. But the boundaries have not been determined for aerosols and chemical contamination due to their complexity. A lack of boundaries for chemicals leads to the lack of knowledge about the global risk and to a lack of ability to manage risk. But today, chemical pollution is a serious concern in the world [2]. Planetary boundaries are one of the foundations of the sustainable

Article note: A collection of invited papers based on presentations at the 5th international IUPAC Conference on Green Chemistry (ICGC-5), Durban (South Africa), 17–21 August 2014.

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development goals and the criteria for their achievements. The absence of planetary boundaries for the causes of chemical pollution leads to the lack of criteria in this field.

However, the problems of exposure to chemicals on the human body are more complex. It is not correct to consider chemical influence separately from other factors. It is important to understand that human health depends not only on exposure to chemicals. Humans are potentially more susceptible to the damaging effects of chemical pollution if they are in a weakened physical or mental state.

Could the exposure to toxic substances have social consequences? Trying to find the answer, the scientists from the A. N. Sysin Research Institute of Human Ecology and Environmental Health of the Ministry of Healthcare of the Russian Federation have performed an assessment of the subjective perception of societal burden by chemical plant workers and the representatives of the control group, and then, using the same parameters, the comparisons have been made between people in a state of psychological comfort and emotional maladjustment [3]. Studies have shown that people exposed to the combined action of hazardous chemicals, are subject to nonadaptive stress more often than those in the control groups.

It is important to understand that human health depends not only on exposure to chemicals (including mutagens and carcinogens). Also human health depends on the body's response to these impacts. The body's response to impact is defined as "stress."

Hans Selye defines the term "stress" as "the non-specific response of the body to any demand for stressor" [4, 5]. Selye's scheme can be described as follows. The level of resistance of the body to any exposure (e.g., chemicals exposure) is represented as an interval. This interval is called "homeodynamic corridor" (Fig. 1). Within a homeodynamic corridor all changes (neural, immunologic, endocrinal) are adaptive (adaptative stress, psychological comfort and health). The "width" of the homeodynamic corridor defines the health condition. It is much wider for healthy people and significantly narrowed for people with various diseases

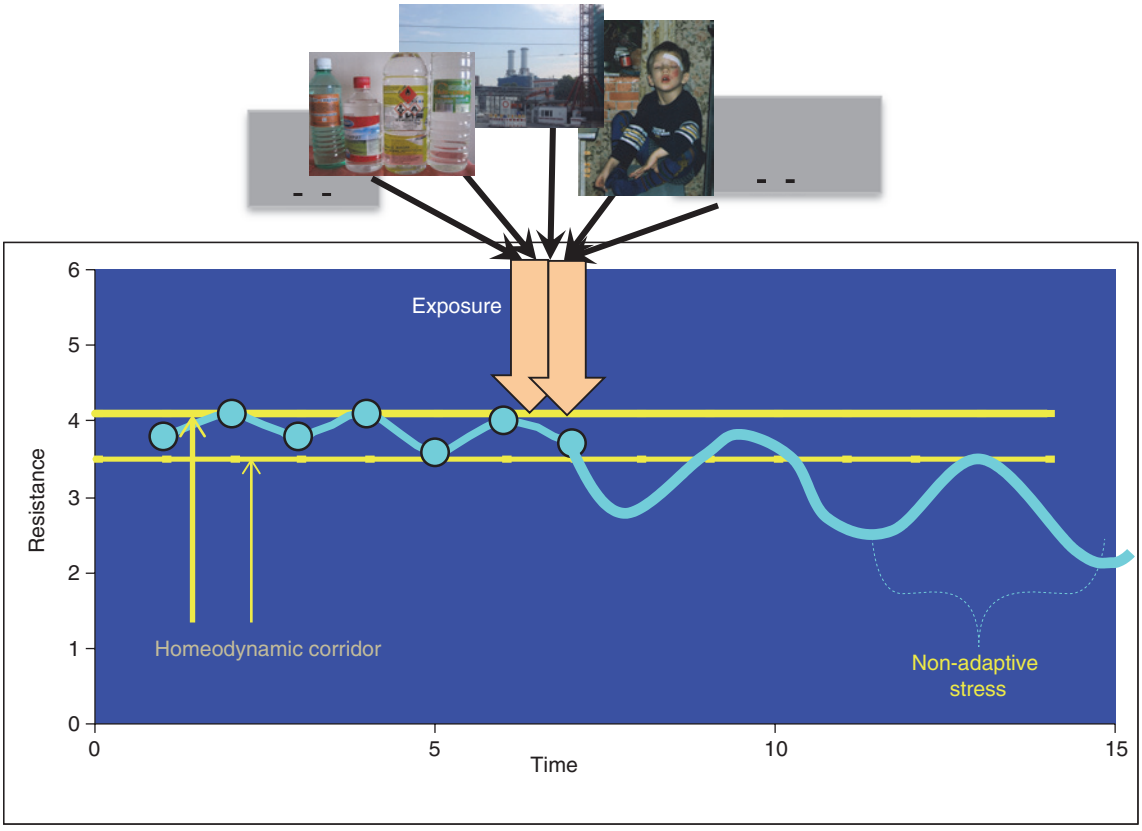

Fig. 1: Oscillatory dynamics of the body's response to repeated or long-term exposure during a narrowed homeodynamic corridor state is the reason for a possible emergence of maladjustment (non-adaptive stress).

and people under non-adaptive stress. It means that the same exposure will have uneven responses for different people. Oscillatory dynamics of the body's response to repeated or long-term exposure during a state of narrowed homeodynamic corridor is the reason for a possible emergence of maladjustment (non-adaptive stress).

Human emotions are good indicators of health. So, psychological testing for detection of different kinds of emotional stress is a good indicator of body and mental health as well as, unexpectedly, a good indicator of stability of all of the genetic structures (Fig. 2). In this picture can be seen the common results of several complex psychologic and cytogenetic investigations of nine groups of adults (men and women, who are workers at different Russian chemical enterprises). The coefficiency of Spearman's correlation between the results of Cholms–Ray scale testing for social adaptation and frequency of chromosome aberration in blood lymphocytes of tested people was 0.8069. These results demonstrated that increased emotional stress expression is one of the sources of genetic damage.

The analysis of average data (228 people) of these investigations have shown that people in a state of emotional disadaptation usually had an increased level of genetic damage (chromosome aberration, for instance).

Using blood lymphocyte in more recent cytogenetic tests – a micronuclei test with cytokinetic block, we demonstrated that people in a state of emotional disadaptation had an increased speed of cellular division, increased level of cells with micronuclei (usually, DNA-fragments) and lower levels of apoptosis (the very complex cellular reaction, directed to killing cells with non-reparable genetic damage) (Fig. 3).

So, results of the two cytogenetic tests matched what allow us to understand the common mechanism of development of stress-induced cancer.

There are several causes of change (constriction) of the homeodynamic corridor: emotional and social factors, genetic predisposition and high levels of environmental pollution by hazardous chemicals. Repeated exposure may be the reason for non-adaptive stress and, consequently, the narrowing of the homeodynamic corridor, which, in turn, becomes the cause of diseases.

Chemical pollution, among different types of adverse effects, may cause the development of disadaptation. It turns out that, given the equality of other social factors, occupational exposure to highly toxic compounds through induction of non-adaptative stress leads to the perception of social burden as feeling greater. The higher the degree of stress the more likely the pressure of social factors is perceived, as being severe or intolerable. It forms a vicious circle of negative human health effects.

A series of studies, performed by scientists across the globe (including Russia), have proven that human disadaptation causes an increased genomic instability and susceptibility to any genotoxic influences, including stress expression, which is one of many new genotoxic factors. As a result, there is a predisposition to diseases of cardiovascular and neuroimmune-endocrine systems and chronic gastrointestinal diseases. Due

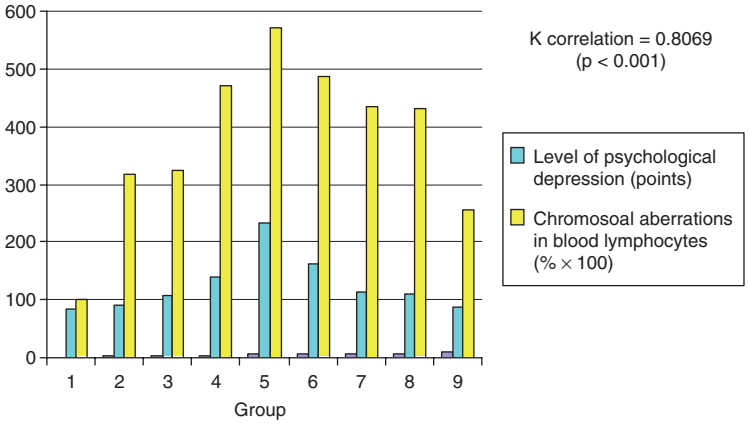

Fig. 2: Spearman's correlation between results of Cholms–Ray scale testing for social adaptation determination and frequency of chromosome aberration in blood lymphocytes of tested people.

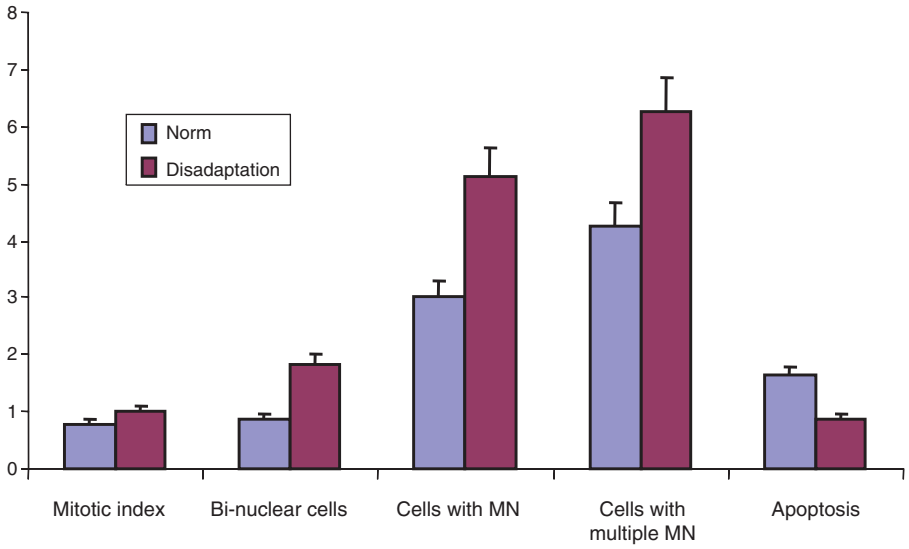

Fig. 3: Results of micronuclei test with cytokinetic block (60 people): people in a state of emotional disadaptation had an increased speed of cellular division (by the index of frequency of bi-nuclear cells), increased level of cells with micronuclei (MN) and cells with multiple MN and a lower level of apoptosis (the very complex cellular reaction, directed to killing cells with non-reparable genetic damage).

to immune deficiency and abnormal functioning of the endocrine system, a whole range of diseases (including premature aging and cancer) have the possibility of emerging. So, for example, amongst children living in Kazakhstan, either in state of psychological comfort or distress, very significant differences in the number of chronic diseases were detected: gastrointestinal, cardio-vascular, chronic respiratory diseases, anemia, hypotrophy below the low limit, neural and psychological disorders (Fig. 4).

Is there any way out of this vicious circle? As the problem is systemic and has several feedback loops with synergistic effects in place, there is a need for a systemic solution that takes into account all possible factors.

One of the approaches, that simultaneously addresses both of the above mentioned issues, is the green chemistry concept. On the one hand, green chemistry (green production, green products) has an unequivocally positive image for most people. On the other hand, the main goal of green chemistry, according to Paul Anastas, is the "discovery, development and application of chemical products and processes that reduce or

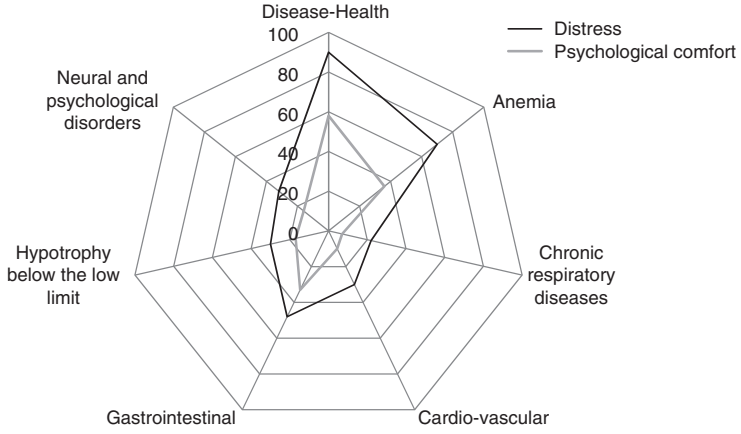

Fig. 4: Differences in morbidity of children, living in states of psychological comfort (gray) or distress (black) (detected by the 8-color M. Luscher test) in Kazakhstan.

eliminate the use and generation of hazardous substances" [6]. Meeting this goal, very obviously leads to a reduction of environmental pollution.

A positive perception of chemical enterprise and/or the idea of pursuing a career in this field would reduce the level of social burden on the personnel and people living nearby. Reduction or elimination of hazardous substances in the technological processes of chemical enterprise will lead to a reduction of environmental pollution. Thus, two or three causes of maladjustment mentioned above can be effectively reduced.

It should be noted that green chemistry is one of the tools for improving the quality of human life and welfare. The WHO defines quality of life (QOL) as "an individual's perception of their position in life in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns" [7]. The human health condition is largely dependent on the satisfaction of personal needs; according to the WHO, the contribution of quality of life values to human health is about 50 %.

In addition, green chemistry has an impact on the welfare of the community. In order to assess the relevance of green chemistry among chemical enterprises and/or related industries in the Russian Federation, the UNESCO Chair "Green Chemistry for Sustainable Development" has performed a sociological survey. The results show that 20 years since its introduction to the public, the principles of green chemistry have been welcomed by almost half of the chemical industry in Russia [8, 9].

Since it is stated that the concept of green chemistry could possibly be instrumental in increasing public well-being, the assessment of commercial effectiveness has been made by the UNESCO Chair scientists for possible directions of development and implementation of green chemistry. Figure 5 shows the comparison of the results of the perception of risks associated with green chemistry by chemical enterprises in Russia and OECD countries. These diagrams clearly show that Russian companies, as well as businesses located in OECD countries, are regarding green chemistry initiatives as having medium commercial and research and development risks.

Such a cautious attitude of industry indicates that for the successful implementation of green chemistry, joint efforts of business and government are required. The main governmental tasks contributing to the practical advancement of green chemistry could be: setting up priorities; developing assessment criteria for hazardous substances; regulation of hazardous chemicals handling; creation and implementation of information and education programs and creation of mechanisms to support proactive activities.

It should be noted that governmental efforts only are not enough for putting successful implementation of green chemistry principles into practice, especially when state regulation is characterized as inflexible and not focused on details and nuances. The instruments of governmental regulation are often not suited to gradual transition to green technologies.

Therefore, governmental regulation should be seen as a framework mechanism. The practical implementation of the objectives and principles should be defined by the initiative of enterprises. Moreover, the state should support and encourage these initiatives.

We see great potential in using the principles of green chemistry in the framework of the Responsible Care program. Green chemistry is a tool for the sustainable development of chemistry and chemical industry. This goal unites it with the Responsible Care program put forward by chemical industry as a sustainable

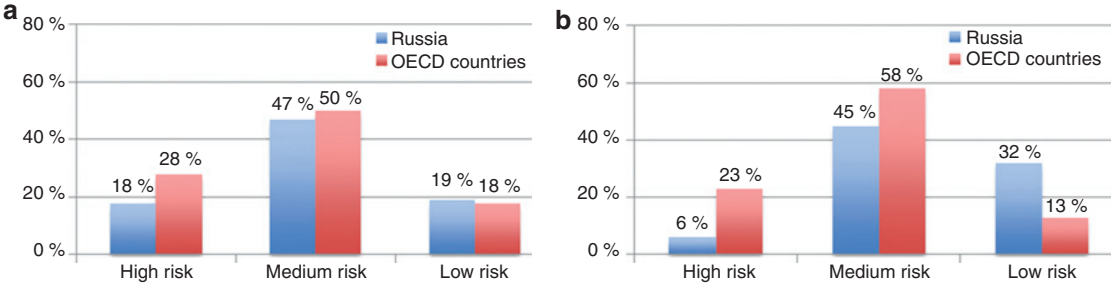

Fig. 5: Results of perception of risks associated with green chemistry by chemical enterprises in Russia and OECD countries: (a) R&D risk, (b) commercial risk.

development program for the whole sector. This statement is recognized and supported by international organizations, UNEP being one of them.

The positive acceptance of green chemistry as one of the possible directions of Responsible Care implementation lies in the fact that it helps to promote green chemistry principles among enterprises and utilizes existing mechanisms to promote voluntary initiatives. The green chemistry principles and basic provisions of Responsible Care program should be the elements of an integrated management system of an individual plant, factory, etc.

Acknowledgments: The work was supported by the Russian Science Foundation (project 15-17-30016 "Development of methodology for determination of chemical footprint in order to investigate the impact of chemicals on the environment and human beings taking into account planetary boundaries").

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