Aspects of Production Ecologization of Machine-Building Enterprises as Part of the System Approach

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Abstract. The paper considers the role of the machine-building industry in Russia and the impact of its activities on the ecological situation in the country. As part of the problem we identified areas of environmental pollution from different production industries, including foundry, power, metal working and welding. In addition, the paper presents a strategy for production ecologization, based on a system approach viewed as a set of measures aimed at reducing the danger of technological processes for the environment and people.

1. Introduction
The machine-building industry is one of the strategic sectors of the Russian Federation; technical equipment of all branches of the economy and the country’s defense largely depend on the level of its development. Machine building includes twelve major sub-sectors, the main ones being heavy engineering, power engineering, chemical engineering, transport engineering, petroleum engineering, as well as machine-tool building and instrument machine-tool building.

The main role of the industry in question is to ensure that other sectors are provided with the necessary machines, aggregates, various complexes and other equipment.

Today, machine building defines the level of development of the domestic industry. In 2014, the share of engineering products released was 22% of the total volume of the manufacturing industry in Russia. In addition, it has a social importance as well, since more than a third of all industry employees are involved in enterprises of the machine-building complex.

However, development of machine building, improvement in the competitiveness of products and provision of faster growth of production require a high consumption of raw materials, energy, natural resources, having an adverse impact on the ecology of the Earth. More than twenty thousand Russian machine-building companies with a progressive development of processing play a significant role in environmental pollution. Moreover, in some areas of the industry with the most hazardous production emissions exceed all specified requirements and standards.

Despite a variety of eco-innovations, advanced equipment for waste disposal and wastewater treatment, management systems focused on ecological safety and environmental protection in accordance with international standards of ISO series 140001 "Environmental Management", the ecological situation in the world remains complicated. The machine building industry largely affects this fact.
In view of the above, the purpose of the article is to analyze potential environmental pollution types from various productions of machine building and apply a system approach as part of the ecologization of machine-building enterprises.

2. Results and discussion
Manufacturing of engineering products produces hazardous solid waste polluting soil and negatively affecting the flora.

Figure 1 shows the main polluting elements contained in emissions from the production of machine-building enterprises. One of the most hazardous substances entering the atmosphere is hexavalent chromium. This carcinogen causes various forms of cancer if it enters the human body. Among the most dangerous and harmful substances that accumulate in the ground are lead, mercury and cadmium, adversely affecting the human body and flora. Water pollution with heavy metal ions also has an adverse effect on the human condition and fauna.

![Main polluting substances from the activities of machine-building companies](image)

**Figure 1** – Main polluting substances from the activities of machine-building companies

By analyzing the information on the subject [1,2,3,4] it is possible to determine that the situation with the influence of various environmental pollutants is defined by the fact that modern factories of the machine-building industry use processes requiring production of harmful substances exceeding the permissible level of established standards. Depending on the type of production, various pollutants are identified, which are presented in Table 1.

Hazardous and noxious substances produced by different types of production pollute the environment and have a negative impact on human health. Hazardous waste solids occurring in each kind of production have carcinogenic, toxic, mutagenic and allergic properties which ultimately contribute to the development of various human diseases, among which the most dangerous are cancer and mutations. Besides, exceeding the established standard of pollutants in the air, soil and water leads to the extinction of animal and plant species, as well as disturbs the ecosystem as a whole.

According to statistics, emissions of harmful substances into the atmosphere from the Russian machine-building complex make up 32% of the entire industrial pollution from stationary sources [1], and only 30-50% of machine-building enterprises are equipped with wastewater treatment facilities.

Since anthropogenic factors are the main in a complicated environmental situation, it is necessary to reduce the risk of technological processes for the environment and humans with the help of a set of measures which, in general, is called production ecologization.
Ecologization activities are mainly aimed at limiting or reducing the environmental capacity of technological processes through the use of a highly efficient strategy of low-waste or cleaner production.

| №  | Type of production     | Technological process                                               | Hazardous and noxious substances                                           | Object of pollution          |
|----|------------------------|---------------------------------------------------------------------|---------------------------------------------------------------------------|-----------------------------|
| 1  | Foundry engineering    | Technological processes of cast iron and steel details production    | Carbon monoxide, dust, sulfur and nitrogen oxides, ammonia, phenol, formaldehyde and cyanide. Solid waste - spent sand | Soil, water bodies          |
| 2  | Intrafactory power production | Technological fuel combustion processes                  | Hazardous gases and solids from the combustion products                 | Atmosphere                  |
| 3  | Metalworking           | Technological processes associated with chip removal               | Metal shavings, chips, dust                                              | Air, soil, atmosphere       |
| 4  | Electroplating production | Technological processes: nickel plating, cyaniding, chrome plating | Mercury, lead, cadmium, bismuth, nickel, zinc and others                  | Wastewater and rivers       |
| 5  | Paint and varnish production | Technological processes associated with coloring and varnishing     | Lead, epichlorohydrin, tricresyl phosphate, dichloroethane and others     | Soil, air                   |
| 6  | Welding production     | Welding processes                                                   | Noxious welding fumes, manganese, copper, silicon, vapors of iron, zinc and nitrogen oxides, hexavalent chromium | Atmosphere                  |

To date, the scientific community [1,2,4,5,6] identified two ways of production ecologization. The first way - introduction of low-waste or non-waste technologies, the second way- application of a conditionally clean technology including the main production with special treatment facilities for waste disposal.

The above problems can only be solved if the production is viewed as a system which includes the following elements: personnel, machinery and equipment, technique and technology, product, management and control, each of which is aimed at minimizing the negative impact of industrial emissions on the environment of the country as a whole. The main areas of production ecologization of enterprises of the machine-building industry are presented in Figure 2 as an Ishikawa diagram.

One of the most important areas in the field of an eco-oriented machine building enterprise is personnel as one of the key elements of the production system. In this area it is necessary to attract new personnel for the modernization and ecologization of production, highly qualified and competent in the field of activity. To implement this directly, at first it is necessary to perform selection and evaluation of candidates by determining the selection criteria, and then organize adapting activities to the eco-innovation strategy of the enterprise. Key selection criteria or qualitative characteristics of applicants are divided into three groups: individual, professional and psychological.

Individual characteristics, most effectively contributing to the development of the eco-oriented enterprise concept, include: creativity – the ability to creatively tackle professional problems, think and act non-traditionally; flexibility – a qualitative characteristics of an applicant, which is the
readiness of an employee to accept innovations and to learn quickly; adaptability - the ability of a person to adapt quickly to changes in the external environment and to life conditions.

Professional qualities of candidates are their qualification, that is, the degree and type of their professional readiness for a certain employment; competence - a body of knowledge, skills, grasps and the ability to apply them in their work; erudition - in-depth knowledge and awareness in one or more areas of professional activity.

Of all the psychological characteristics of an eco-oriented person the most important in this sphere are:
- ecological loyalty - commitment to the principles of ecological production, preservation of environmental quality;
- ecological responsibility - the ability to practically apply environmental trends, views and ideas by investing tangible assets into procedures ensuring the protection of the environment [2].
- ecological discipline - the ability to comply with the principles and norms of behavior that are focused on achieving cleaner production preventing the ingress of polluting emissions into the environment.

For hired personnel and existing staff of enterprises it is expedient to develop training programs aimed at improving their skills, competence and knowledge in the area of production ecologization. In addition, it is required to carry out various activities in the field of environmental safety training and conduct training and retraining on the modernization and ecologization of machine-building production.

The most essential programs are programs of motivation in the considered area that promote the involvement of all personnel in the work on environmental safety and protection, the creation of conditions for effective and efficient operations of all staff.

When implementing measures in the field of the aforementioned production ecologization at the "personnel" level, apart from the listed positive factors there can arise risks associated with the development and implementation of inefficient personnel motivation systems which lead to losses in the financial part of the company's capital. In addition, substantial material expenditures are required for training and retraining, as well as selection of employees from the external reserve and their adaptation.

The next level of an eco-oriented machine building enterprise is "Management", as an element of the production system in the area of the eco-oriented strategy. It involves introducing systems for monitoring and control of the ecological state of the area, as well as hazard identification, assessment and management of professional risks. In addition to this, the best procedure in this case is to manage and exchange experience between enterprises in the field of ecology and ecological innovations and, as a result, implementation of best international and domestic practices in the field of engineering, technology and management of environmental safety. Development and implementation of the systems require current material and labor resources which are accompanied by costs to assess the efficiency and effectiveness of systems implementation, as well as the cost for their further maintenance.

The area "techniques and technology" is by far one of the top priority and is actually implemented, as humanity has accumulated extensive experience in the field of innovative technologies and practices for production ecologization [1,3,4,5,6,7,8,9,10,11]. The main ones include: introduction of eco-innovative technologies, including innovative technologies for monitoring and control of the environment, biotechnology, wastewater treatment and re-use in production; introduction of modern low-waste technologies; improvement of waste water filtration systems for enterprises and application of treatment technologies that reduce environmental pollution; processing of hazardous substances and waste disposal; use of energy-saving technologies that use natural resources sustainably.

These technologies and methods require material costs for environmental activities and improvement of intellectual potential of employees in the sphere of eco-innovations development.

To ensure eco-oriented concepts in the field of machine-building enterprises it is important to consider such an area as "machinery and equipment", which consists in upgrading the main assets of
the enterprise, introducing innovative equipment for waste recycling, using energy-saving facilities. These activities are also financially expensive, since they require investment in the purchase and installation of new equipment.

The area "product" includes ecologization of the entire product life cycle, from market research, research and development activities to its production, promotion and utilization. The main areas of investments for the realization of this area are as follows:

- development of human capital, its labor and intellectual potential;
- research and development activities in the field of technically feasible innovative solutions focused on the ecological principles of the enterprise concept;
- promotion of eco-products: study of supply and demand, analysis of the internal and external environment of the enterprise, advertising and marketing policy.

The end product is an object that satisfies the requirements of the Russian legislation and the demands of consumers, and in addition it does not violate the ecosystem and does not pollute the environment.

3. Conclusions
Thus, to solve the problems related to the influence of the production of machine-building enterprises on the ecological situation of the country, more attention should be paid to production ecologization.

Besides, it is not enough to use only non-waste or low-waste technologies, it is also necessary to consider the company as a system, a set of interrelated elements: personnel, equipment, management, technique, product. It is essential to introduce the eco-oriented production strategy which main goal is
to ensure the safety and protection of the environment from exposure to harmful and hazardous emissions and waste.

The main aspects of this strategy, as described above in detail, are: improvement of the personnel competence and knowledge on the environmental safety; creation of conditions and methods of motivation and involvement of all employees in the efforts to ensure the protection of the environment; introduction of eco-innovations and modern technologies for processing of hazardous substances and waste through the use of innovative equipment; implementation of systems for monitoring and control of environmental condition of the area.

The reviewed complex of measures will identify hazards, assess and manage risks in the area of environmental safety and protection, and significantly reduce the impact of production on the country's ecology as a whole.

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