Ecological Approach in Managing the Technology of Oil Refineries

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ABSTRACT

The paper aims to analyze the problem of the complexity in managing of the environmental safety of an oil refinery. The possibility of using environmental monitoring methods for integrated regulation and the formation of optimal control parameters is noted. It's based on the principles of combining efficient production processes with environmental programs, which will be promotive of the production output with the technogenic impact minimization of oil refining technology on the environment.

Keywords: Environmental Management, Environmental Safety, Management Parameters at a Refinery, Oil Refinery
JEL Classifications: L71, Q35

1. INTRODUCTION

The intensification rates of the industrial development, the growth of demand on energy products leads to an annual increase of its production. The most material-intensive and huge enterprises of the energy complex include oil refineries, which provide the export market with a wide range of primary and secondary petroleum products. The problem of the such enterprises activity is connected with their significant potential of technogenic nature, which has an increased level of environmental hazard. Taking into account the deterioration of the people's socio-economic conditions, the problem of environment improvement becomes particularly important. Unfortunately, approaches aimed at pollution volume reducing are often made by cutting of the production level. Then an economic situation when the companies primarily seek ways to save their environmental costs is determined.

It should be noted that the share of the fuel and energy industry accounts for over 40% of total contamination among all economy sectors. At the same time, the oil refining industry is one of the most dangerous sectors of the economy. Complex, multi-stage production processes occur in conditions of high temperature and pressure, and are also characterized by high explosion and fire hazards, large pollutant capacity, including waste generation, significant amounts of hazardous emissions and substances. That has an adversely affect on the natural environment, disrupting its regenerative potential. Therefore, a complex combination of decisions directed at the reconstruction and modernization of a particular sections of the technological chain in the energy production process, so as to attracting investment in construction should be based on minimizing of the emission pollutants into the environment.

For quality management of the enterprise in the framework of compliance with national and international legislation in the field

of environmental protection and minimizing the man-made impact of enterprises, the international organization for standardization has created a series of ISO standard documents devoted to production quality management, labor and health protection system, energy and environmental management. In this regard, the priority and actual direction of the management program aimed at any technological process is the environmental approach implementation in it which can help to reduce environmental hazard.

The economic activity of the refinery leads to pollution of all objects of the natural environment (water basin, soil, atmospheric air). In this case, industrial emissions contain about 250 chemicals, one third of which belongs to compounds of I and II hazard classes (Sopilko et al., 2017; Stepanova et al., 2018). Highly hazardous emissions from oil refineries, up to 23% of C_1-C_4 hydrocarbons, more than 16% of sulfur oxides, up to 2% of nitrogen oxides, more than 7% of carbon oxide, and residual oxides of heavy metals (copper, manganese, chromium), cobalt, nickel, platinum) enter the atmosphere because they are used as catalysts. Chlorides, heavy metal sulphates, nitrogen compounds, phenols, mechanical suspensions were found in wastewater. It is noted that near the refinery, the concentration of harmful substances in the air and water bodies exceed the MAC by tens and hundreds of times (Gossen and Velichkina, 2007; Jayarathne et al., 2018). During some researches, the diversity of environmental risks of the oil industry was analyzed. Such situation is associated with a high environmental load throughout the entire life cycle, including production, transportation, oil process, the usage and disposal of emergency products. Insight, conducted in some studies, determines the need for rational parameters formation and their implementation to management of environmental problems technologies (Salim et al., 2018).

Also, experts have proposed the active development of high-tech scientific processes that combine production goals and environmental safety which can reduce the technogenic impact of industry on environmental objects (Nazarova et al., 2017; Mantaeva et al., 2018).

It is known that the assessment of the enterprise ability to produce high-quality products that correspond to the cost index (investment intensity), the potential of value added, taking into account the complexity of processing technology, the secondary processes presence, organized and unorganized sources of harmful emissions, is carried out according to the Nelson coefficient. The complexity of each refinery set is calculated as an index consisting as the sum of the product of the cost values and the complexity coefficient for each piece of crude oil downstream equipment. This indicator is 4.8 for Russian refineries, with an average world level per 7.1 and an average level per 10.8 for the United States (Makov, 2007). Thus, according to experts, refineries with a Nelson index of less than 10 initially lose economically due to the insufficient combination of modern high-performance technologies (catalytic hydrocracking and catalytic reforming) with methods that are directed to control and regulate the negative impact on environmental quality. The European Union has developed and employed the best

available technologies guide to build management systems that are responsible for improving production efficiency and directly related with environmental requirements compliance (Directive 2010/75/EU, 2010). It's known as an information tool where best practices and approaches are described. In Poland, a program has been created to hazard assessment control the aerosol presence in the industrial atmospheric emissions based on the interpretation of satellite images (Chwastek and Dworak, 1990). The Mexican government, in light of the strategic principles improvement at industrial enterprises, provides strict control for the environmental protection system and periodic employees' training in risk prevention through courses and emergency situations modeling (firefighting, hazardous substances spills disposal, first aid), and financial resources investing for these purposes (Nieto et al., 2008). In Russia, the Ministry of Energy approved the information and technical reference for VAT "Oil refining" (Information and technical reference, 2017) for the harmonization of international programs. It's dedicated to greenhouse gas emissions reduction, environmental regulation for the enterprises of major economic sectors, including oil refining. According to this legislative act, enterprises are divided into categories depending on the level of environmental impact and established requirements for the introduction of "clean" technologies with minimal discharges and emissions to the environment.

Thus, an important task for industrial enterprises is still the searching for parameters of an optimal target management based on the principles, which combine efficient production processes with environmental programs.

2. METHODS

This study consists of the general scientific principles of approach forming to the management decisions system in the activities of an oil refining enterprise based on environmental monitoring methods aimed at reducing of the anthropogenic impact on the environment (Wright et al., 2018). Environmental monitoring uses modern analytical methods to determine the gross emissions of toxic substances into the atmosphere: Flame ionization, gas chromatographic analysis; to study the composition and concentration of wastewater elements contaminated with phenols, salts of heavy metals (X-ray fluorescence method). Such methods also include monitoring and control of technological processes, the formation and composition of gaseous emissions, wastewater, waste. It allows to assess the state of environmental components of both local and global objects.

Special research methods were also used, which include approaches to risk management, the warning system, the localization of accidents and the organization of measures to eliminate their consequences in the field of environmental safety (Korzhubaev et al., 2011; Redina and Haustov, 2016; Salim et al., 2018).

The main sources of environmental hazards are sites with a complex of equipment (diesel hydrotreatment unit; reflux purification unit; combined catalytic cracking unit; gas fractionation unit with high pressure tank fleet; combined gas desulfurization unit and recovery of spent sulfur). Therefore,

environmental risk assessment is based on a technological approach, which involves identifying the factor of hazardous events using computer technology.

To determine the probability of random events, failure (failures) and their consequences, three methods can be distinguished: Multiplicative, contingent valuation method of failure-free operation and the objective function method (Belskaya et al., 2014; Nusz et al., 2018).

The multiplicative method is based on the use of the Poisson formula for calculations, which gives a high degree of approximation. Poisson's law allows a discrete distribution of time between accidents. It is assumed that the occurrence of the accident forms a stream of random events (in this case it is used to determine the probability of one or more accidents occurring at the facility). The probability of accidents P (N,t) at a technical facility is calculated by the formula (1):

$$P(N,t) = \frac{(\lambda \cdot t)^N}{N!} \cdot \exp(-\lambda \cdot t), N = 0,1,2..., \lambda \cdot t > 0 \quad (1)$$

Where N is the number of accidents; t – time period of accidents; λ – the average value of the emergency situations intensity.

The probability of occurrence of one or more accidents at the object under consideration for the time interval of interest is calculated using the formula (2):

$$P(\geq 1, t) = 1 - P(0, t) = 1 - \exp(-\lambda \cdot t) \quad (2)$$

Thus, if there is information about the object under study, the use of the Poisson's law is possible to determine an accident initiation risk that is an environmental violation.

The probability method of failure-free operation was used to determine the degree of the equipment reliability (installation). The probability is calculated by the formula (3) as the product of the reliable operation probabilities of a separate i-th unit element:

$$P_b(t) = \prod_{i=1}^{n} P_i(t) \quad (3)$$

Where $P_b(t)$ is the failure-free operation probability of the nth number of elements during the period t; $P_i(t)$ is the failure-free operation probability of the i-th unit element.

If we accept the failure of one of its elements for a failure of the installation (system), then the probability of failure of the installation can be calculated by the formula (4):

$$P_{\hat{i}}(t) = 1 - \prod_{i=1}^{n} P_i(t) \quad (4)$$

In this study, the equipment failure is taken as accident implementation with the subsequent negative impact on the environment.

If there is additional data about the technical system reliability, the probability of technical system failure, the cost rate for its safety ensuring and damage preventing. The environmental risk

determination is possible by calculating the objective function L(c) by the formula (5):

$$L(c) = \frac{c_0 \cdot W(c_k)}{S} + \frac{\left[(k \cdot M_v + g \cdot N_v) - m(c_1)\right] \cdot W(c_k)}{k \cdot M_{max} + g \cdot N_{max}} \quad (5)$$

Where c_0 – the technical object creating costs; $W(c_k)$ is the emergency occurrence probability which value is determined by the c_k means spent on warning an emergency; M_v is the forecasted damage of material values and the environment; N_v is projected human losses in the dimension of the selected financial resources; c_1 is the cost of ensuring system security (reduction of expected damage); c_k – funds allocated for accident prevention; k, g - coefficients of bringing cost indicators of damage and loss of population to a single measure; $m(c_1)$ is the function of eliminated damage, which value is determined by the allocated funds c_1.

From formula (5) it follows that as the probability of a potential accident tends to zero, the magnitude of the risk function L(c) tends to the first term, that is, the ratio of the costs of the technical system creating to the potential solvency of the responsible person. If the likelihood of an accident occurrence is one, the value of the indicator is determined mainly by the second term, that is, the relative damage.

The assessment of the environment damage (air, water, soil) in the result of refinery activities, is carried out by calculating the costs required to undertake measures to restore the potential of disturbed ecosystems, and is based on standardized methods for calculating the amount of payment for the negative impact on the environment (Resolution of the Government of the Russian Federation, 2017). Damage (W_{ECO}) is defined as the sum of damage from various types of harmful effects of the refinery on environmental components:

$$W_{eco} = W_a + W_w + W_s + W_b + W_{ws} \quad (6)$$

Where $W_a, W_в, W_п, W_б, W_о$ - damages from air pollution, water resources, soil, from the degradation of biological resources, from pollution of the territory with waste, respectively.

3. RESULTS

The modern organization and management level of production puts forward requirements for the development of new approaches to solving problems of chemical-technological processes managing based on the monitoring of technological indicators, new information technologies. Experience in managing complex, inertial, potentially hazardous facilities, which include the oil refining industry, shows that it is necessary to use methods and algorithms for optimal and operational management, timely control, collection and processing of information coming from technogenic sites, as well as to conduct a systematic assessment of the ecological state working objects. Trends in the development of modern technology management systems and systems that diagnose emissions show that they must be adaptive and effective. The adaptability of these systems is ensured by the ability and readiness to use the VAT rationing tools.

Many methods and algorithms of environmental management existing at process control systems of chemical plants are unsuitable for operational management, which is still carried out by the operator based on intuition, practical operating experience and a variety of instructions.

The methods of environmental monitoring, which include diagnosing, monitoring, predicting violations of the normal ecosystems functioning, determining the permissible level of technical load, are proposed as effective tools in the refinery.

The system of reversible interrelation of environmental quality management tools (environmental management) and information data in the environmental field will be able to provide comprehensive economic regulation of the quantitative and qualitative parameters of the oil refining process, assessing the amount of harmful substances released into the environment. Regulation types include: Administrative (compliance with standards, restriction measures, control, production licensing, environmental impact assessment); economic (payments, taxes on pollution, fines based on pollution damage, subsidies, cost minimization, etc.); market (distribution of rights to pollution, compensation payments, etc.). The priority of the level programs, their goals, the tasks of the environmental monitoring system of an enterprise should be determined by criteria reflecting the harmful properties of pollutants (toxicity, radioactivity, carcinogenicity, etc.), the amount of their release into the environment, transformation features, the level of impact on living organisms.

Every year, Gazprom Neft makes payments for a negative impact on the environment, the main share of which is for the atmosphere emissions. The increase of environmental protection services costs, ensuring environmental safety and the environment protecting reduces the amount of payment for negative environmental impact in Figure 1.

According to the diagram in Figure 1, in 2016 the fee for the negative impact decreased by more than 3 times compared with the previous year.

As a result of the refinery's activities, the emission of harmful substances of hydrocarbons, hydrogen sulfide, sulfur oxides, mercaptans, nitrogen oxides, carbon dioxide and others into the atmosphere occurs both during normal operation of the process production and during accidental emissions. At the same time, it is more likely that there can be risk of emergency gaseous emissions of hydrogen sulfide and sulfur dioxide on refineries, which pose a serious threat to the environment.
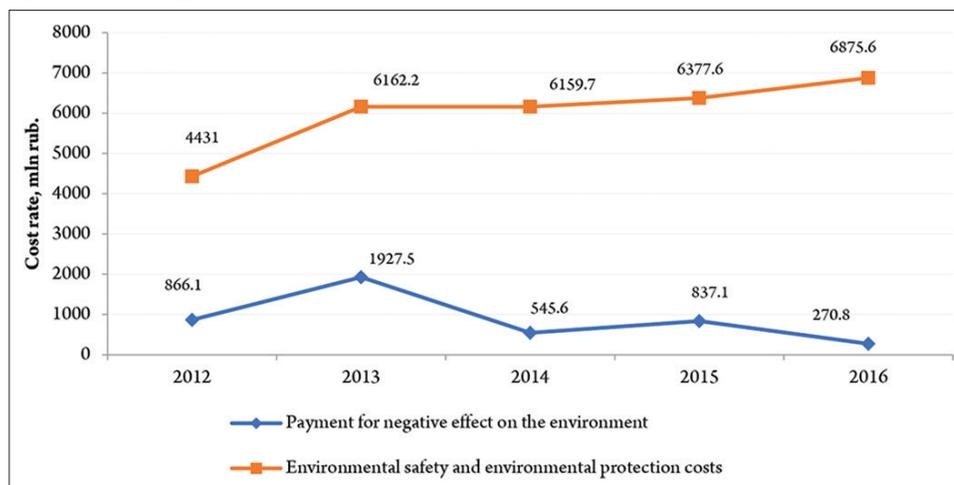
Considering that sulfur-containing compounds extracted from crude oil and petroleum products, in turn, are raw materials for the production of elemental sulfur, a new combined plant was introduced at the Moscow Refinery for the catalytic conversion of gas emissions of sulfur oxides, hydrogen sulfide, mercaptans. The work of the specialized unit is based on high-quality sulfur obtaining by the oxidative utilization absorption of sulfur emissions under strict adherence to the technological regime; rules and safety regulations; fire safety; control over the use of energy resources, reagents; at work and in good condition of the equipment, its timely shutdown and repair; adjustment of automatic control technology; for timely overhaul (every 4 years).

When analyzing the operation of the sulfur production unit (SPU), 25 potential sources of hazardous factors were identified, the implementation of which may result in the release of acid gases into the atmosphere. In this regard, the minimum frequency of modeling the calculation of the probability of hazardous emissions is taken 4 years, and the maximum 10 years.

The probability of occurrence of the investigated risk, calculated according to the Poisson's law, was 0.86. This value shows that the probability of at least one emission (one or more) of pollutants into the atmosphere over 10 years will be 86%.

The probability of failure-free operation of SPU is defined as the probability of an accidental release of pollutants into the atmosphere. By qualitative analysis revealed 25 potentially dangerous factors. Under the influence of an unfavorable factor, there is a probability of an accidental release of acid gases into the atmosphere, which is taken as the probability of failure of

Figure 1: Amount of payment for the negative impact on the environment and the costs of environmental protection measures of JSC Gazprom Neft

one of the 25 elements of the installation. The calculation of the probability of failure-free operation of the installation is made every 4 years (the period of major repairs). It is assumed that the probability of failure-free operation of each element is 0.95.

It is obvious that the pressure factor is one of the most aggressive, which can lead not only to accidental release of hazardous substances, but also to depressurization and explosion. Therefore, the greatest probability of an accident is the release of the reaction mixture of acid gas and water vapor into the atmosphere due to a violation of the pressure standards in reactors and pipelines.

To calculate the payment for the negative impact on the environment, territorial bodies of supervision in the field of environmental management have developed standards for maximum permissible emissions (MPE).

In accordance with the technological regulations of the Moscow Refinery and the operating rates of SPU, the charge for the emission of pollutants for the year is 1 million 812 thousand rubles (27.5 thousand dollars). Most of the amount is paid for the emission of highly hazardous sulfur dioxide ($MAC = 0.5$ mg/m^3) and hydrogen sulfide ($MAC = 0.008$ mg/m^3).

Air emissions exceeding of the MPE standards or temporarily established limits in permits often leads to an increase in the concentration of these substances in the air of the working areas of the SPU in localities and entails additional financial responsibility of the enterprise.

So, up to 0.012 tons/year of hydrogen sulfide is emitted into the air during continuous operation of the SPU in normal mode in a year. If we take this number as the standard due to the technological capabilities of the equipment, then the single accident simulated in this case, during which emissions to the atmosphere occur - 2.514 tons of hydrogen sulfide, uniquely exceeds the permissible standard or temporarily established emission limit. At the same time, the charge for emergency emission of hydrogen sulfide into the atmosphere by the combined SPU is from 1245.9 rubles (18.9 dollars) to 37203.6 rubles (57 dollars), which does not incite to active actions.
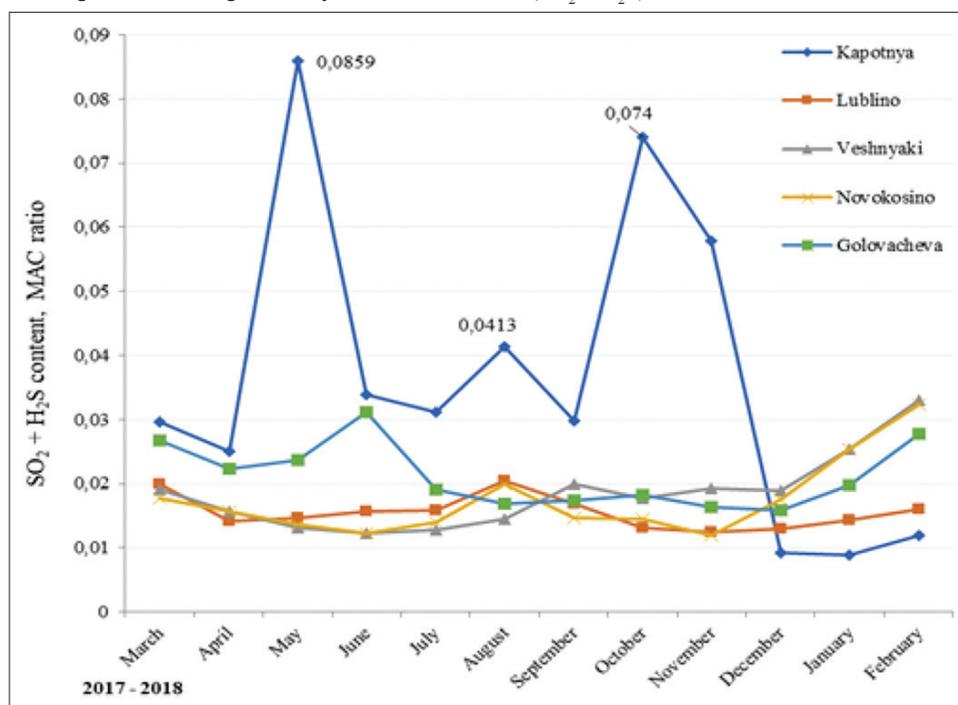
According to the data of the Moscow ecological monitoring, which registers the air pollutants amount on the permanent control points, graphs of changes in the average monthly concentration of hydrogen sulfide and sulfur dioxide during the year were plotted in different districts of Moscow adjacent to the refinery in Figure 2.

The negative impact of emissions from refineries with a capacity of 12 million tons per year can occur up to a distance of 20 km from the plant. The over-limit air pollution of sulfur-containing gases is periodically recorded in summer and autumn in the micro-districts of the Southeast Moscow district, adjacent to the refinery, – Marino, Kapotnya, Lyublino, Brateevo. In remote areas, the concentration of SO_2 and H_2S is within the normal limits of the MPC.

4. DISCUSSION

Currently, the problem of air pollution with sulfur-containing gases arises primarily in large industrial metropolitan areas. Substances emitted into the atmosphere separately or together with other sulfur compounds undergo a series of chemical transformations, forming highly toxic compounds. Interacting with atmospheric moisture or as a result of utilization by phototrophic bacteria, sulfur oxides and

Figure 2: Changes in the average monthly total con centration ($SO_2 + H_2S$) in the districts of Moscow during the year

hydrogen sulfide form acid precipitation (rain, fog, snow), which have a negative impact on the environment (acidity of rivers and lakes increases, which reduces the species diversity of animals and plants; quality deteriorates agricultural products, drinking water, air, accelerated destruction of construction sites, corrosion of metals). In addition, SO_2 molecules are actively adsorbed on the developed surface of atmospheric aerosols, along with molecules and radicals of oxidizing agents, which is accompanied by undesirable photo stimulated reactions.

The negative impact of atmospheric air polluted with sulfur-containing compounds on the health of the population is expressed in varying degrees of diseases severity. For example, the Moscow Southeast district is at the top in terms of high overall primary incidence of adolescents, running second in children non-infectious incidence, general primary incidence and high prevalence of the nervous and circulatory system diseases.

A system that combines the linking of the structural elements of an environmental monitoring system with economic management tools allows not only to control the degree of xenobiotic emissions into the environment, concentrated gas emissions, in effluents, waste of a particular enterprise, but also to form timely preventive solutions that reduce environmental risks.

If it is impossible to eliminate the causes of risks formation, the distribution of environmental risks between the enterprise and the insurance company is noted as effective decision (hedging).

5. CONCLUSIONS

The analysis made it possible to identify the inherent environmental risks for the oil refinery that depend on industrial, technological, financial activities. During the study, the priority was given to the formation of a management approach based on environmental monitoring. It allows controlling the qualitative and quantitative inputs of pollutants into the environment and creates a global environmental problem accumulating in time.

It was noted that the process of the environmental situation monitoring and assessing is of fundamental importance for creating an effective response system and is carried out in stages. At the initial stage, the performance of a qualitative analysis is reduced to the identifying procedure, systematizing, identifying, modeling risk situations, retrospective or predictive assessment, prioritizing environmental risks, comparing the consequences and probabilities of their occurrence.

When forming management decisions on an environmental basis, special attention should be paid to: Internal control of processes, timely implementation of measures to reduce accidents and technological failures, improvement of legal regulation, and staff qualifications. It is shown that a quantitative assessment of the level of environmental risk for each accident scenario within the framework of determining the severity and severity of the hazard is defined as the probability of the occurrence of this event and the damage magnitude.

It was emphasized that for the development of options and actions for production risks minimization and elimination, the environmental monitoring methods are of fundamental importance, allowing not only to assess the state of the environment (gross emissions of pollutant spectrum; waste; sewage), but also to predict the consequences (adverse effects on biota), determine the environmental reserve (allowable load level) by calculation in accordance with regulatory requirements.

6. ACKNOWLEDGEMENT

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