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Improving the Efficiency of Production Process Organization in the Resource Saving System of Petrochemical Enterprises

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ABSTRACT

The relevance of this study is determined by the fact that the issues of resource-saving technology implementation in the petrochemical complex have not been fully addressed yet and require further study and systematization of the determining factors, which is especially important on the back of the emergence and development of "green" industries and the digital economy in Russia. The purpose of the article is to identify the factors of the resource saving system and the extent, to which digital technologies are used by petrochemical enterprises. The main research methods underlying the article include the method of description used to identify trends in the waste production and consumption in petrochemical facilities; Component analysis method, which helped to identify three groups of criteria factors affecting the resource saving system of the petrochemical industry, depending on the level of its digitalization; factor analysis method used to compile the indicators of digital technologies application in the petrochemical complex into three groups; And production function modeling for the petrochemical industry, taking into account the digital physical and digital human capital. The paper analyzes the resource saving system in the Russian petrochemical complex; The resource saving system of the petrochemical industry has been modeled, depending on the level of its digitalization; Also the study provides a production function model for the petrochemical industry, which may be used to model the parameters and the resulting indicators of the resource saving system in the petrochemical industry. The information contained in the article can be used to develop strategies and programs aimed at the improvement of the resource-saving system efficiency in petrochemical enterprises, taking into account the requirements for production digitalization and the ratio of digital physical to digital human capital.

Keywords: Resource Saving, Petrochemical Enterprise, Petrochemical Complex, Production Efficiency, Digital Technologies
JEL Classifications: D24; Q43; M31

1. INTRODUCTION

Today, the problem of resource saving and energy efficiency in the industrial sector of the world economy is one of the most urgent. According to OPEC data published in World Oil Outlook (OPEC https://www.opec.org/opec_web/en/), demand for petrochemical products in the medium term will only grow. To this end, the increasing production volumes require an in-depth solution of the resource and energy saving issues arising at petrochemical enterprises. The comparison of international data in the field of resource saving and energy efficiency shows that the Russian industry to a large extent falls behind that of other countries holding similar positions in terms of the share of petrochemical products output. For the purposes of comparative analysis, the industry data of the following states was used: USA (the petrochemical output accounts for 18.6% of the global production), China (14.9%), Japan (8.1%), Germany (7.1%), France (4.3%), and Russia (2.1%) (World Bank, from: http://data.worldbank.org/indicator).

One of the important objectives set out in the 2030 Energy Strategy of Russia is "to achieve sustainable results in the field of fuel and energy complex on the back of growing global competition for resources and markets; Rational reduction of the share of fuel and energy resources in the Russian export structure, the shift from exporting primary raw materials and energy resources to selling downstream value-added products, as well as the promotion of selling petroleum products produced at foreign refineries owned by Russian oil companies" (On Approval of 2030 Energy Strategy of Russia, from: https://www.garant.ru/products/ipo/prime/doc/96681/).

Today, on the back of technological modernization, industrial production is focused on innovative technological systems that can provide high economic efficiency, resource saving and quality improvement. In order to address the issue of the production system organization efficiency improvement, necessary mechanisms shall be identified and developed.

Production system is a resource conversion system, which has specific functioning features such as the nature of the links between the system elements, the degree of the production system content and components variability, the nature of production processes, and the type of links with the outer environment, etc., (Turovets and Chasovskikh, 2011).

The problems of resource saving and energy efficiency gain particular importance for those sectors of industry where the share of manufactured industrial products is high — these include the petrochemical complex. As of the end of 2018, the share of goods shipped in the coal, crude oil and natural gas production amounted to 15.3%, coke and petroleum products — 8.1%, chemicals and chemical products — 2.8%, rubber and plastic products — 1%, which together accounts for 27.2% of the total industrial goods shipped (Rosstat, 2018).

2. LITERATURE REVIEW

The topics of resource and energy saving system efficiency improvement in the petrochemical complex are touched upon in the works of Russian and foreign researchers, in particular, such problems as achieving the sustainability of petrochemical enterprises through the implementation of the strategy of innovative resource saving system development (Malysheva et al., 2016); institutional factors of the industrial complex innovative development at different management levels (Shinkevich et al., 2017); Computer simulation of production processes in petrochemistry (Meshalkin et al., 2017); Analysis of the environmental management system of chemical companies (Makarova et al., 2018); Integral indicators for resource saving system efficiency evaluation (Shinkevich et al., 2018); Energy-saving technologies implementation algorithms (Shiying et al., 2018); Strengthening of petrochemical materials in the process of production and disposal (Sheikh and Patnaikuni, 2019).

Modern engineering solutions in the resource saving system and industrial environmental safety improvement are covered in detail in the works of some authors; For example, Fuertes Ferrero and Sevilla propose methods of petrochemical product volumetric characteristics calculations to assess its security level (Fuertes, Ferrero and Sevilla, 2016); Gupta Ibrahim and Al Shoaibi developed a new method of using sulphur for acid gases treatment in the petrochemical industry, which improves production sustainability (Gupta et al., 2016); Zhang Lu and Yang conducted research on oxygen recovery in the petrochemical production process to reduce hazardous emissions and reuse petrochemical raw materials (Zhang, Lu and Yang, 2016).

Theoretical and practical aspects of the production processes organization and efficiency improvement through innovation and digitalization were covered and analyzed in detail in the works of a number of researches; Thus, a group of authors headed by Klimenko et al. (2018) proposed models for the development of environmental and industrial tourism; the aspects of digital technologies in the innovative activity of petrochemical enterprises to improve the environmental performance of production are covered in the article by Kudryavtseva et al. (2018); Meshalkin et al. (2018) focused on the development of approximate mathematical model of heat transfer in a complex thermal system consisting of several pipelines; problems of small petrochemical companies in the field of energy saving are reflected in the works of Khafizov and Mustafin (2017); A three-spiral model of innovation in the resource saving system is discussed in the works of a team of researchers under the leadership of Shinkevich et al. (2017).

Most of these studies have a controversial nature and require taking into consideration digital transformations of production processes in the petrochemical industry, including the integration of information systems, e-commerce and electronic communications that allow taking into account market and production requirements to the resource saving system in terms of its environmental friendliness, sustainability and reliability.

3. RESEARCH METHODOLOGY

We propose to use the following methods to build an analytical model of the resource saving system:
1. Component and factor analysis that are used to identify the most significant factors affecting the resource saving system of petrochemical enterprises in the context of its digitalization;
2. Production function model for petrochemical industry, based on two structural components — digital physical and digital human capital;
3. A predictive model of petrochemicals shipped.

The main objectives of factor analysis are the reduction of the number of variables (data reduction) and identification of the structure of links between variables, i.e., variable classification.

Combining two variables into one factor. The correlation between variables can be detected using a scattering diagram. The regression line obtained by fitting represents the dependency graphically. If a new variable is to be defined based on the regression line shown in this diagram, this variable will include the most significant features of both variables. Thus, the number of variables is reduced and two variables are replaced by one. The new factor (variable) is actually a linear combination of the two original variables.

Selection of the main components. Typically, the procedure for selecting the principal components is similar to the rotation maximizing the variance (Varimax) of the original variable space.

The production function model (Cobb-Douglas function) is obtained as a result of mathematical transformation of the simplest production function: Y=F (K,L), into a model showing the portion of the total product, which falls on the production factor involved in its production. It appears as follows:

$$Y=A \times K^{\alpha} \times L^{\beta},$$

where α varies from 0 to 1, and β=1−α.

The production function model is a model with two variable factors of production. A — a multiplier reflecting the level of technological productivity; it remains constant in the short term. α and β– output (Y) elasticity coefficients related to production factors, i. e., capital (K) and labor (L), respectively. In this context, if each of the factors is paid in accordance with its marginal product, α and β show the contribution of capital and labor to the total income.

The proposed production function model for the resource-saving system based on its digitalization will include the following parameters:

- Y – petrochemical products shipped per one enterprise, RUB million;
- K – "digital physical capital" as the share of organizations that used enterprise resource planning (ERP)-systems, percentage;
- L – "digital human capital" as the percentage of employees engaged in digital technology management, percentage.

To build the production function model, the initial dynamic series will be presented as a function of the logarithm: У=Ln F(X).

By varying the labor and capital values, we make a forecast for the dependent variable – output (Y). To this end, for the purpose of forecasting predictor variables, i.e., labor and capital, the simple geometric mean formula can be used, which allows extrapolating the trend of growth rates of the analyzed indicators:

$$X_{geom.} = \sqrt[n]{X_1 X_2 \ldots X_n}$$

$$X_1 = \frac{y_1}{y_0};\ X_2 = \frac{y_2}{y_1};\ X_n = \frac{y_n}{y_{n-1}}$$

Where,

- X_i — continuous growth factor;
- n — number of growth factors;
- y_0— value of the initial series level;
- y_n— value of the final series level.

4. DESCRIPTION OF DATA

Analysis of waste generation dynamics at petrochemical enterprises of the Russian Federation showed a declining trend, while untypical "jumps" in the petrochemical industry waste generation were observed in 2011 (up 57%, if compared to 2010) and in 2017 (3.6 times growth, if compared to 2016). The overall waste produced by petrochemical enterprises of the Republic amounted to 52.3 million tons in 2017, of which 13.5 million tons accounted for the production of oil products, and 38.7 million tons — for chemical production.

There is no pronounced trend in the ratio of the waste produced and waste consumed at petrochemical enterprises of the Russian Federation. Despite a sharp increase in the amount of generated waste in 2017, the ratio of waste consumed to waste generated reached the maximum point for this period and amounted to 43%, an increase of 12.4 percentage points compared to 2016 (Figure 1).

Along with the growth of waste generation at the petrochemical enterprises of the Russian Federation, the amount of unconsumed waste increases as well, reaching the peak in 2005 (34 million tons) and the minimum level in 2016 (10.2 million tons). In 2017, this amount made up 29.8 million tons, up 19.6 million tons in absolute terms, if compared to 2016, or 2.9 times in relative terms. At the same time, the minimum ratio of unconsumed to generated waste at petrochemical enterprises of the Russian Federation was observed in 2017 and amounted to 57%, while its peak fell on 2014 – 85.5% (Figure 2).

Analysis of the dynamics of the ratio of waste consumption per petrochemical enterprise to shipped petrochemical products per enterprise revealed a polynomial correlation between the two indicators with an average correlation degree. As of the end of 2017, waste consumption per 1 petrochemical enterprise amounted to 1.756 thousand tons, a 5.1 times increase compared to 2016 and a 6.3 times increase compared to 2010 (Table 1).

Thus, the dynamic analysis of waste production and consumption indicators in petrochemical enterprises has shown that the production system of the petrochemical complex tends towards semi-closed loop production processes that are characterized by fragmented processing and reuse of petrochemical raw materials. Consequently, the plant's environmental friendliness remains at a low level, which requires the development of new approaches to the production processes management in the petrochemical industry. As such, we propose to consider an approach to the resource-saving system organization based on its digitalization, which will increase the flexibility, transparency and efficiency of management decisions.

5. RESULTS

5.1. Systematization of Digitalization Indicators in the Production System of Petrochemical Enterprises and their Grouping Depending on their Degree of Contribution to the Resource Saving System

The main efficiency increase tools of the production system organization in the current conditions is deemed to be adherence to the 'just in time' system and 5S system of workplace

Table 1: Dynamics of waste consumption and products shipped at petrochemical enterprises (Rosstat, 2018)

Years	Waste consumption per one enterprise, thousand tons	Shipment of petrochemical goods per one enterprise, mln RUB
2010	277	286
2011	759	366
2012	193	419
2013	176	480
2014	128	546
2015	277	555
2016	341	728
2017	1756	855

Figure 1: Comparison of produced and consumed waste at petrochemical enterprises of the Russian Federation (Rosstat, 2018)

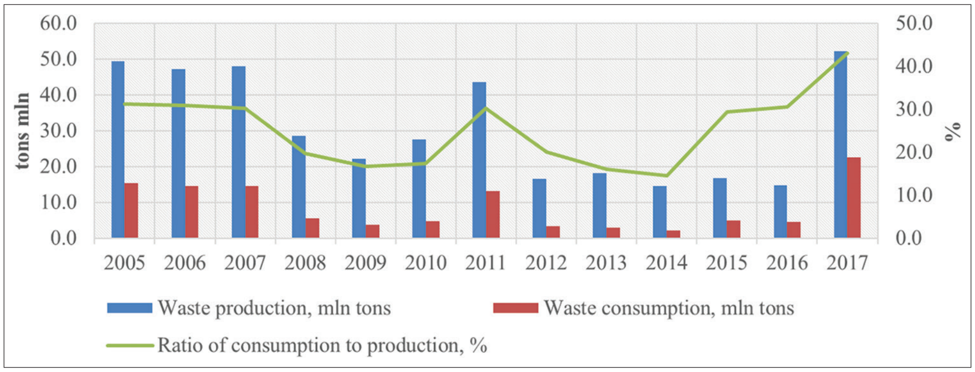
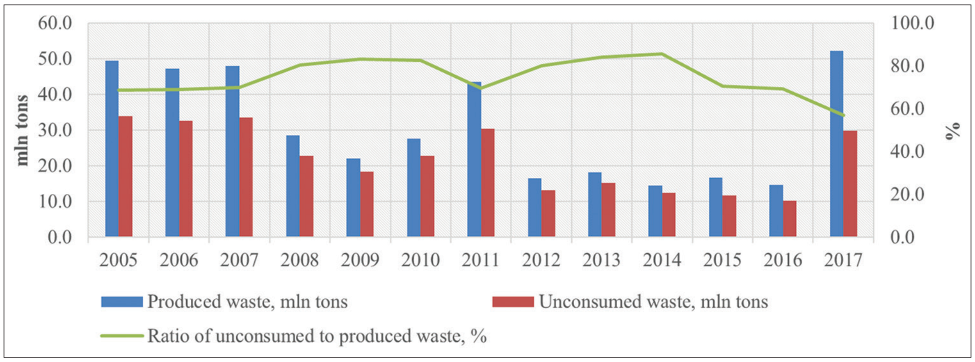


Figure 2: Comparison of produced and unconsumed waste at petrochemical enterprises of the Russian Federation (Rosstat, 2018)



rationalization, implementation of ERP, material requirements planning, supply chain management (SCM), (customer relationship management) (CRM) corporate information systems and other software applications for the purpose of production and management processes automation.

We believe that such an indicator as a volume of products shipped per one enterprise can be an outcome indicator of the petrochemical industry activity when modeling the production system of petrochemical enterprises; And the industrial enterprises digitalization intensity is intended to be used as an independent modeled variable, as being an explanatory factor, for integration in the delivery chain, formation of indissoluble contiguous knowledge, information and products chains among the suppliers, focus company, consumers and intermediaries, which allow to generate growth of petrochemical products output.

We will group the digitalization indicators into factors that influence the practical results of petrochemical enterprises, in particular, the growth of petrochemical products output per petrochemical enterprise through a factor analysis procedure in the Statistica software package.

Modeling performed concluded that representation of three factors characterized by a set of indicators of digital technologies application at the industrial enterprises is considered to be the most reasonable, as the characteristic values of the three factors are greater than one, and the rest are not so essential to be included in the analysis (Table 2).

In the second stage of the analysis, indicators of digital technologies application were compiled into three groups of factors depending on the degree of their influence on the outcome indicator, which is the volume of products per petrochemical enterprise. A factor analysis was based on the method of Varimax raw rotation, the variables were included in the factor if their correlation with it exceeded 0.7 (Table 3).

The first integral factor provisionally titled "information systems integration" is formed by five indicators: The percentage of enterprises that used to have special software tools for goods (work, services) sales management, percentage of enterprises that used ERP systems, percentage of enterprises that used CRM systems, percentage of enterprises that used electronic data interchange among their peripheral information systems in terms of interchange formats and percentage of enterprises that used SCM systems characterizing potential of industrial enterprises to use integrated management systems for supply chain practices. Such indicators as the percentage of enterprises that used electronic data interchange among their peripheral information systems in terms of interchange formats (the correlation coefficient with an integral factor was 0.90) and percentage of enterprises that used ERP systems (0.89) showed a strong link with this factor. Total variance percentage explained by the effective sign was 43% for the information systems integration factor.

The following two indicators form the second integral factor provisionally titled "Electronic Commerce": The percentage of enterprises that used to place orders for goods (work, services) on the Internet (the correlation coefficient with an integral factor was 0.97) and the percentage of enterprises that used to have special software tools for goods (work, services) sales management (0.76). Total variance percentage explained by the effective sign was 22%

Table 2: Characteristic values of the factors singled out

No.	Characteristic values	Total variance percentage	Cumulative characteristic values	Cumulative percentage of total variance
1	4.986750	55.40833	4.986750	55.4083
2	1.918930	21.32145	6.905680	76.7298
3	1.329530	14.77256	8.235210	91.5023
4	0.652528	7.25031	8.887738	98.7526
5	0.070636	0.78485	8.958375	99.5375
6	0.041625	0.46250	9.000000	100.0000

Table 3: Factor analysis results

Independent variables	Factor 1	Factor 2	Factor 3
	Information systems integration	Electronic commerce	Electronic communications
The percentage of enterprises that used to have special software tools for goods (work, services) sales management	−0.873649		
The percentage of enterprises that used ERP systems	0.893157		
The percentage of enterprises that used CRM systems	0.806225		
The percentage of enterprises that used electronic data interchange among their peripheral information systems in terms of interchange formats	0.909160		
The percentage of enterprises that used SCM systems	0.822166		
The percentage of enterprises that used to have special software tools for goods (work, services) sales management		0.769680	
The percentage of enterprises that used to place orders for goods (work, services) on the Internet		0.977284	
The percentage of enterprises that used an electronic document management system			0.956434
The percentage of enterprises that used opensource operating systems (e.g. Linux) provided by a third party			0.746826
Total variance	3.904762	1.980982	2.349466
Total variance percentage	0.433862	0.220109	0.261052

CRM: Customer relationship management, SCM: Supply chain management

for the electronic commerce factor.

The following two indicators contributed to the formation the third integral factor provisionally titled "electronic communication": The percentage of enterprises that used electronic document management system (the correlation coefficient with an integral factor was 0.95) and the percentage of enterprises that used opensource operating systems (e.g., Linux) provided by a third party (0.74). Total variance percentage explained by the effective sign was 26% for electronic communication factor.

Cumulative variance percentage explained by the effective sign was 91% according to all integral factors.

5.2. Production Function Modeling for Petrochemical Industry based on the use of Digital Physical and Digital Human Capital

We will use production function models, in which petrochemical products shipped per one enterprise, million RUB (Y) will be used as a response dependent variable, "digital physical capital" as being the percentage of enterprises that used ERP systems, which showed one of the closest correlations with the integration, and "digital human capital" as being the percentage of employees engaged in digital technology management will be used as independent explicative variables, to evaluate the effectiveness of digital technologies application in the organization of petrochemical production. Based on official statistics data for these indicators published in the Development Monitoring of the Information Society in the Russian Federation (Rosstat, 2018).

Having used a regression analysis module for an exponential function from the Statistica software package a regression equation has been worked out, an equation protocol is specified in the Appendix.

As can be seen from the above, a production function model characterizing the effectiveness of digital technologies application in the organization of production appears as follows:

$$Y=176 \times K^{0.98} \times L^{-1.41}$$

The obtained production function model is deemed to be probably significant as confirmed by:

1. Model determination coefficient 0.95;
2. P-value of independent variables <0.05;
3. Fisher's variance ratio of the model <0.05;
4. Standard error of the model which is equal to 0.1 made 1.6% of the average value of the independent variable, which is within the range of permissible norms up to 5%.

The diagram below shows the surface diagram for a production function model (Figure 3).

Interpretation of the production function model obtained leads to the following conclusions. The effectiveness of digital technologies application showed as an increase in the volume of petrochemical products shipped per one enterprise, is more dependent on the "digital human capital" variable − the percentage of employees engaged in digital technology management, as the elasticity coefficient for this indicator exceeds the elasticity coefficient of dependence on the "digital physical capital" variable, which is

Figure 3: Surface diagram for a production function model

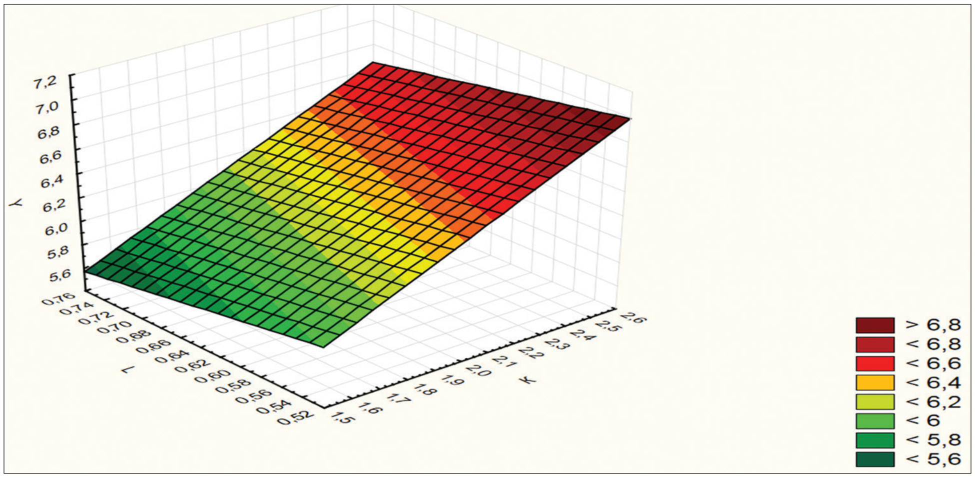
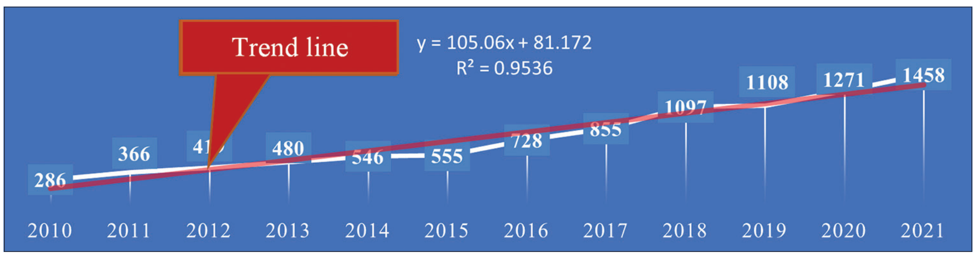


Figure 4: A forecast of the petrochemical products shipped per one enterprise, mln RUB



the share of organizations that used ERP systems, –1.41 versus 0.98 respectively. It is significant that the elasticity together with "digital human capital" is represented in the production function model with a negative sign, which is explained by the unstable dynamics of this indicator and its decrease in the last 2 years.

As can be seen from the above, the required level of digital technologies application effectiveness in the organization of production can be modeled by varying independent variable parameters, being digital human capital and digital physical capital, for the outcome parameter which is an increase of the volume of shipped petrochemical products per enterprise.

5.3. Creating a Forecast of Shipped Petrochemical Products Based on Production Function Modeling

A middle-term forecast of the volume of petrochemical products shipped per one enterprise was created based on the production function model and parameters. While forecasting an independent variable, which is the percentage of organizations using ERP systems, a middle-term increase of 15% was used as a whole for this industry market and for the average growth rate of this indicator for 2010-2018; the other variable, which is percentage of employees employed in digital technologies, was taken into consideration as unchanged and equal to 1.7%, since in the production function model it showed a negative relationship with the outcome parameter and reasoning from this fact we assume that the average value of "digital human capital" will remain unchanged in the forecast period from 2019 until 2021. So, according to forecast, the independent variable value, which is the percentage of enterprises that used ERP systems, will increase from 12.2% in 2018 to 18.6% in 2021. Using independent variables values of the production function model, we created a forecast of the petrochemical products shipped per one enterprise (Figure 4).

According to the calculations, the volume of petrochemical products shipped per one enterprise will increase from 855 million rubles в 2017 to 1458 million rubles в 2021.

6. DISCUSSION

As can be seen from the above, the increase of the volume of manufactured chemical products makes minimization of production toxicity, processing, and disposal of petrochemical industry waste an urgent problem. Development of resource and energy saving technologies in the manufacturing processes and logistics chains, improvement of environmental safety of petrochemical enterprises, and output of innovative and environmentally friendly products stipulates companies' competitive capacity and their position in the market. In this context, advanced technology product development and expensive environmental protection measures implementation require extensive investments in technological and environmental innovations. The decrease of an ecological burden on the ecosystem is only possible by "greening" of all its functional areas. "greening" of the production process includes a full range of measures to ensure a product life cycle from raw materials and materials used for implementation of the manufacturing processes to the finished product and production waste generation. A product life cycle also includes further disposal of waste or provision of safe storage in the ecosystem.

A period of a petrochemical product life cycle posing a certain environmental hazard includes the hydrocarbon production process, technological process of finished products manufacturing, and technological process of production and consumption waste disposal. These processes complement such logistics procedures as storage and transportation of raw materials, semi-finished products, finished products and production, and consumption waste disposal.

In our opinion, the logistical aspects of production "greening" concerning the supply chain represented, shall include resource-saving technologies, production waste management, and consumption waste management in the logistics chains.

Thus, environmental safety organization and observance of behavior standards by manufacturers, suppliers and consumers imply the transformation of traditional approaches to logistics system management guiding enterprises on safe environmental technologies application in the supply chains.

7. CONCLUSION

To summarize, the production system of a soundly operating enterprise is subject to constant quantitative and qualitative changes caused by market demands and technologies development. In connection therewith, the efficiency enhancement mechanism of the production system organization shall implement the functions of development, selection, and implementation of measures that will ensure the achievement of system efficiency from the perspective of resource saving, using the means and methods of production organization through its automation.

Thus, integrated programs implementation of production processes automation at the largest oil companies contributes to:
- Increase in technology process performance;
- Improvement of product quality;
- Time cutting of transient processes;
- Increment of time for optimum technological mode maintenance;
- Reduction of energy resources consumption;
- Increase of runtime process efficiency and oil refinery operating capability;
- Operating cost reduction and production automation level development.

Environmental security and behavior standards observance by manufacturers, suppliers and consumers implies the transformation of traditional approaches to logistics system management guiding organizations on safe ecologic technologies application to supply petrochemical products, including based on the use of digital technologies.

This article can be used to develop strategies and programs of resource saving system efficiency improvement at petrochemical enterprises, taking into consideration the requirements for production digitalization and the ratio of digital physical and digital human capital.

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