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Ecological Cybernetics of Oil Processing and Petrochemical Processes

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Abstract

Ecological cybernetics of technological processes, both as a scientific and educational subject, along with the improvement of theoretica1l knowledge in the application of technological processes improved by nanotechnologies, where the design technologies are intensively updated with new hardware and software of design technologies, will allow providing professional approach to the project development, ecological expertise as an environmental engineer. It is known that the performance of technological processes optimally reduces its impact on the environment. However, this does not answer the question of how much. In my view, studying ecological cybernetics of technological processes will provide the evaluation of ecological level in technological processes performed under complex technological, constructive design conditions. In other words, each optimum oil processing and petrochemical processes must be investigated as a research object, and technological and constructive parameters of the equipment, efficiency of the catalysts in the process, the composition of the raw material, processing depth must be studied, improved and brought to more advanced stages. It is known that re-refining of oil and petrochemical processes are performed in the combination of more complex conversions and more complex structural design of equipment and one of the useful ways of improving ecological condition is to determine a new level by increasing cybernetic bases of the process.

Keywords: ecology; industrial symbiosis; cybernetics; processes; wastes; by-products; pyrolysis; synthesis; acetic acid; methanol; mathematical modelling; management systems

Introduction

At the current development of computing technics and technologies, the importance of managing complex environmental and technological processes during designing production units in the design of a complementary system to ensure the global sustainability of the environment should be emphasized. Industrial symbiosis, environmental modeling, research, study, design of ecosystems, scientific researches in this area, all components studied separately to ensure at least the stability of CO_2 concentration in the atmosphere, which is a clear indicator of the current environmental situation, should be consolidated in a single system (Copenhagen forum could not solve this problem). Ecological cybernetics aims at developing theoretical and practical bases for the creation of single management systems that can create conditions for the reduction and elimination of atmospheric emissions, technical, chemical, thermodynamic, aggregative changes in the target facility within the intended physical parameters. The main purpose of the system is to collect, save, process and provide the data on the parameters that reflect the ecological characteristics of all devices and units that are part of the production process and lead to deviations, to provide environmentally optimal management with operational instructions to make the necessary corrections. One of the main stages of ecological cybernetics is the identification of the parameters that can compare, interact in the process, the transformation of these parameters into information, the possibility of their transmission, the creation of working conditions within the system. The concept of information, its formation, collection, transmission are of great importance as a key factor in ecological cybernetics as in all areas of cybernetics. The significant difference is harsh variables that arise from the processes which are observed with complex, sometimes unintended transformations in oil refining and petrochemical processes. At the same time, in the case of systematization of complex technological processes, in many cases, data frame interval is used, rather than single-digit data. Unlike abstract cybernetics, ecological cybernetics focuses on a known, existing subject. Therefore, this begins with the collection of data, their processing by mathematical methods, and the analysis of the environmental parameters of the technological process under consideration. If any parameter needs to be determined during studies, additional testing may be required. The main goal is to create mechanisms that allow implementing them in optimal management systems by directing the logical interactions of the individual elements of the parameters involved in the process to achieve the goal. The analysis of the ecological cybernetics of designed processes is carried out in contrast to the existing processes.

Applied researches, analysis of results

As it was mentioned during the creation of ecological cybernetics systems of oil processing and petrochemical process the technological parameters collected in database are given in the form of interval figures. This is related both to the process and equipment indicators. The mixed processes are also observed. The rectification process going with azeotropic drying in the same column, the rectification of diene hydrocarbons which goes with the delay of polymerization by adding special inhibitors into bottom of the column can be shown as a simple example. Both cases can be mathematically modelled as an ecological object and analyzed as a research object. But this will be one component of an industrial symbiosis. It will be an ecological component of the current technological process. In other words it is a part of an ecological system. Let's consider another example typical of the system. It is known that during methanol synthesis many additional reactions occur in parallel with the main reactions that results in the formation of other large amount of organic compounds together with a target product.

a) Dimethyl ether $2CH_3OH \leftrightarrow (CCH_3)_2O+H_2O$

b) Organic acids $2CO+2H_2 \leftrightarrow CH_3COOH$

$CH_3OH+CO \leftrightarrow CH_3COOH$

$CO+H_2O \leftrightarrow HCOOH$

c) Alcohols $_nCO+2_nH_2 \leftrightarrow C_nH_{2n+1}OH+(n-1)\ H_2O$

d) Complex ethers $CH_3OH+CH_3COOH \leftrightarrow CH_3COOCH_3+H_2O$

e) Aldehydes $CH_3COOH+H_2 \leftrightarrow CH_3CHO+H_2O$

$HCOOH+H_2 \leftrightarrow HCHO+H_2O$

f) ketons $2CH_3COOH \leftrightarrow CH_3COCH_3+CO_2+H_2O$

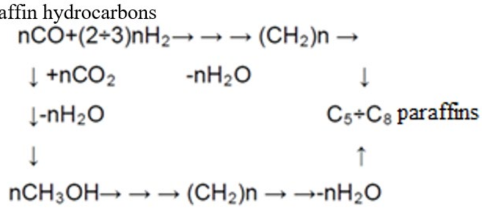
g) amines (can be obtained from ammonia, nitrogen and hydrogen)

$CH_3OH+NH_3 \leftrightarrow CH_3NH_2+H_2O$

$CH_3OH+CH_3NH_2 \leftrightarrow (CH_3)_2NH+H_2O$

$CH_3OH+(CH_3)_2NH \leftrightarrow (CH_3)_3N+H_2O$

h) saturated paraffin hydrocarbons



Based on the research of technological factors which impact on the obtaining of by-products: temperature, pressure, catalyst activity, reaction time, flow rate of reaction mass, construction of a reactor, communication design, automatic control system perfection, composition of a raw material, composition of recirculation components and functional ratio, equilibrium condition of the reactions, number of cycles of recycle gas, composition of a synthesis gas, efficiency of heat-exchange-cooling systems, composition of sewage and etc. advanced control algorithm can be developed by creating general mathematical model of the technological process, and according to it the process can be managed under optimum conditions in terms of high efficiency and eliminating the factors which impact on the environment. The process efficiency is characterized by its selectivity under general approach and can be calculated by the following equation:

$$I = \frac{S_1}{S_1 + S_2 + S_3}$$

Here, S_1-amount of a target product produced in the process; S_2-total amount of by-products for raw material produced during the process; S_3-amount of wastes released into atmosphere. As the technological process is improved theoretically, S_2 or S_3 approach zero and the selectivity increases and reaches up to 100%, the amount of wastes will be zero. In real processes in most cases it is impossible to get the amount of by-products or wastes down to zero. In most cases they become the elements of the process. We can only talk about optimizing their limits in the process. This means that there will always be a need for the improvement of the processes that we encounter on a large scale. The parameters affecting S_1 and S_2 which are the expression of variations in oil processing and petrochemical processes consist of numerous variations and have abovementioned wide ranges. These parameters can be identified by various experiments in the operating system or in its real physical model.

Let's review two-stage catalytic process of producing acetic acid and ethylacetate as a specific example [1]. At the first stage of the process a target product – acetic acid is formed from ethanol, acetaldehyde and carbon dioxide are formed. Acetaldehyde is recycled to the system, but carbon dioxide is released into atmosphere. In this case the selectivity is determined by the following way:

$$I = \frac{S_1}{S_1 + S_3}$$

At the second stage a target product – ethylacetate is produced from ethanol and acetic acid. Mathematical model for the first stage is given by:

$$\frac{dA_1}{dl} = S \cdot \frac{k_3 b_1 b_3 P_1 P_4}{\left(1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P_5\right)^2}$$

$$\frac{dA_2}{dl} = S\left(\frac{k_2 b_4 b_2 P_5 \sqrt{P_2}}{\left(1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P_5\right)^2} - \frac{k_3 b_1 b_3 P_1 P_4}{\left(1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P_5\right)^2}\right)$$

$$\frac{dA_3}{dl} = S\left(\frac{k_1 b_1 b_2 P_1 \sqrt{P_2} - k_2 b_2 b_4 P_5 \sqrt{P_2}}{\left(1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P_5\right)^2} - \frac{k_4 b_4 P_5 \sqrt{P_2}}{1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P_5}\right)$$

$$\frac{dA_4}{dl} = \frac{2k_4 b_4 P_5 P_2}{1 + b_1 P_1 + b_2\sqrt{P_2} + b_3 P_4 + b_4 P}$$

$$\frac{dT}{dl} = -\frac{\sum_{i=1}^{4} r_i \Delta H_i}{\sum_{i=1}^{8} n_i C_{pi}} - \frac{\alpha\left(T - T_x\right)}{\sum_{i=1}^{8} n_i C_{pi}}$$

α, %	5.96	6.7	7.6	7.8	9.35	14.1
Gy.к., kg/hour	2612	2649	2785	2785	3255	4914
Xк, %	20	21	22	22	27	40
CO2, kg/hour	675	788	874	896	1074	1619
Acetaldehyde (recycle)	1177	2292	3296	3654	3872	3423

Table 1: Results of theoretical optimization on the mathematical model are presented.

The table shows that as optimum values of ethanol conversion to oxygen at different ratios of ethanol increase the yield of by-product CO_2 which is released into atmosphere, increases. Due to the use of a new catalyst at the second stage by-products and emissions are not formed, i.e. the catalyst works with 100% of selectivity. In other words in the current case the solution of an ecological problem in the process which excludes emissions is solved through the improvement of a catalyst quality, i.e. the awareness of determining a proper direction of scientific study by using the results and developing the implementation of a technological process by stage. This is an example of the logical interaction of individual elements of the system to obtain a specific result, which is one of the elements of the logical basis of ecological cybernetics.

Let us review pyrolysis process of ethane with feedback [2-4]. Pyrolysis is a rather complex process, in which a large number of different components are involved, and, accordingly, its chemistry and kinetics are expressed by several hundreds of reactions and equations, that significantly increases the role of mathematical modeling of the optimum process modes. However, the methods of mathematical modeling are not considered in this work, but the possibility of using the results as a component of ecological cybernetics is investigated. Pyrolysis of ethane is accompanied by side conversions in parallel resulting in reduced yield of a target product of ethylene. Definite conversion level will conform to the maximum yield of ethylene during single processing of a primary raw material. Further deepening of the process in a single pass may lead to the increase in the yield of by-products. Therefore, the highly relevant for the most favorable process is to find that conversion level and share of recycled material in which the highest yield of a target product and the lower emissions into atmosphere can be achieved.

To study these problems first of all it is necessary to provide a mathematical description of the process which reflects the features of using recycling.

The kinetic model of the process developed in accordance with proposed stoichiometric diagram is presented by the following equations.

$$\frac{dn_1}{dl} = -u^{-1}\left[k_1 n_1 + k_7 n_1 \cdot \frac{n_2 P}{\sum n_i RT} - \frac{k_1}{k_{p1}} \cdot n_2 \frac{n_3 P}{\sum n_i RT}\right]$$

$$\frac{dn_2}{dl} = -u^{-1} n_2 \left[\begin{array}{l} k_1 \frac{n_1}{n_2} - \frac{k_1}{k_{p1}} \cdot \frac{n_3 P}{\sum n_i RT} - k_2 \left(\frac{n_3 P}{\sum n_i RT}\right)^2 + \frac{k_2}{k_{p2}} \cdot \frac{n^2 P}{n_1 \sum n_i RT} - k_3 - k_4 - \\ -k_5 - k_6 - k_7 \frac{n_1 P}{\sum n_i RT} \end{array}\right]$$

$$\frac{dn_3}{dl} = u^{-1}\left[\begin{array}{l} k_1 n_1 + \frac{k_2 n_4^2 P}{k_{p2} RT \sum n_i} + n_2 \left(\begin{array}{l} -\frac{k_1 n_3 P}{k_{p1} RT \sum n_i} - 2k_2 \left(\frac{n_3 P}{RT \sum n_i}\right)^2 + \frac{1}{8} k_3 + k_4 + \\ +k_5 + 2k_6 + \frac{93}{150} k_7 \frac{n_i P}{RT \sum n_i} \end{array}\right) + \\ \frac{n_{15} P}{RT \sum n_i} \left(k_8 n_{10} + k_9 n_{13}\right) \end{array}\right]$$

$$\frac{dn_4}{dl} = 2k_2u^{-1}\left[n_2\left(\frac{n_3P}{\sum n_iRT}\right)^2 - \frac{1}{k_{p2}}\left(\frac{n_4P}{RT\sum n_i}\right)^2\right];$$

$$\frac{dn_5}{dl} = u^{-1}k_3\frac{n_2}{4};$$

$$\frac{dn_6}{dl} = u^{-1}k_3\frac{n_2}{8};$$

$$\frac{dn_7}{dl} = u^{-1}k_3\frac{n_2}{8};$$

$$\frac{dn_8}{dl} = u^{-1}k_4\frac{n_2}{3};$$

$$\frac{dn_9}{dl} = u^{-1}k_5n_2;$$

$$\frac{dn_{10}}{dl} = u^{-1}\left[2k_6n_2 - k_8n_{10}\frac{n_{15}P}{RT\sum n_i}\right];$$

$$\frac{dn_{11}}{dl} = \frac{143}{150}u^{-1}k_7n_2\frac{n_1P}{RT\sum n_i};$$

$$\frac{dn_{12}}{dl} = \frac{57}{150}u^{-1}k_7n_2\frac{n_1P}{RT\sum n_i};$$

$$\frac{dn_{13}}{dl} = u^{-1}k_8n_{10}\frac{n_{15}P}{RT\sum n_i} - k_9n_{13};$$

$$\frac{dn_{14}}{dl} = u^{-1}k_9n_{13}\frac{n_{15}P}{RT\sum n_i},$$

Where k_i – reaction rate constant; k_{p1}, k_{p2} – equilibrium constants; n_i – number of moles of ethane, ethylene, hydrogen, methane, divinyl, butylene, butane, benzene, acetylene, carbon, propylene, propane, carbon monoxide, carbon dioxide and water; u – linear rate of a raw material; l – reactor length; R – gas constant.

The kinetic parameters of the proposed model have determined on the basis of experimental data of the unit EP-300 of Sumgait plant «Ethylene- Propylene».

In the present process the target products are ethylene + propylene; by-products are hydrogen, methane, divinyl, butylene, butane, benzene, acetylene, emissions are carbon, carbon monoxide and carbon dioxide. Table 2 shows the results of optimization of non-recycling pyrolysis process of ethane in the following variation intervals of plant output parameters: g_{ethane}=2÷5 t/hour; t_0=775÷850°C; the ratio of water steam: raw material – 1:1; 1.5:1 and 2:1; P_0=3÷4.2 atm. – depending on the water steam content. As a result of the optimization it was determined that at the beginning of the process primary reactions prevail, therefore, at the first section of the pipe from the beginning of the reactor, ethylene accumulation rate will be maximum, then as ethane is consumed it decreases gradually reaching minus values, in which consumption rate of ethylene in secondary and tertiary reactions begins to increase the rate of its accumulation. Therefore, up to this point (equilibrium point of accumulation rates and consumption of ethylene) the amount of C_2H_4 along the reactor length increases up to the maximum value of 826.4 kg/h. Further increase in consumption rate of ethylene to secondary and tertiary reactions reduces the amount of ethylene up to 692,1 kg/hour and increases emissions into atmosphere. However, due to the reversibility of the reaction, through which ethylene is partially formed from methane, the ethylene consumption rate decreases, but not so much as to result in an increase in the absolute yield of ethylene. Therefore, at the outlet of the reactor, the amount of ethylene is lower than in the previous sections, with the maximum ethylene values with an increase in charge for all temperatures reach near the end of the reactor. Therefore, starting from the loading of g_{ethane} = 3.25 t/hour, the yields of target products are maximized at the end of the reactor. Thus, with increasing loading for each temperature, the selectivity of the process rises and with increasing temperature - decreases. The selectivity of pyrolysis of hydrocarbon raw material is determined as a ratio ethylene + propylene to the amount of converted raw material, ethylene and propylene are formed as a result of primary reactions, increase of selectivity will contribute the suppression of secondary decomposition reactions of target products and thereby reduce, in separate cases, eliminate emissions into the atmosphere. This requires decreasing the residence time of feedstock in reaction zone and reducing partial pressure of hydrocarbons by selecting optimum level of dilution rate of raw material with water steam for each load, and transferring this command to the center of optimum control of technological processes in the context of ecological cybernetics. Data source for the command is the change in the output of by-products and the amount of carbon monoxide in it, obtained from flow chromatographs that provide the information to the technological process. In this mathematical model since the formation of carbon monoxide formed from the waste is dynamic, and the formation of deposited carbon layers on inner surface of coils in pyrolysis furnace where conversion processes occur, is static, the variation criteria in the amount of carbon monoxides in the flow are taken into account to give a quick ecological improvement command to the technological process. This means that ecological cybernetics of technological processes allows studying the flexibility and dynamic activity of the impact in management systems in depth, thereby reducing emissions by increasing the sensitivity of the management system as a whole. Each data delivered to intelligent management centers of technological processes must contain the information which allows managing the process to carry out environmental optimization. The comprehensiveness and completeness of carrier database is determined by local (at plant level), regional (territorial units where many plants operate), global environmental analysis of technological processes. When reviewing the global approach to environmental problems as an example of control over carbon monoxide, indicators that reflect the performance of all sectors, including transport and other utilities, should be included in the database. The research that we are reviewing will be an integral part of the global control and management system. The same approach applies to gases, liquids, solid wastes and sewage. This means that ecological cybernetics is a new direction that summarizes the results of scientific researches, studies, serves to improve intelligent management systems which aimed at solving environmental problems at different levels. This enables high-skilled engineers, mathematicians, programmers to work together creatively, to meet modern regulatory requirements in the field of environmental safety, to create more flexible management systems, to solve environmental problems through the improvement of technological processes in a new approach and scale.

t, 0C	***gC2H4, kg/h***	***gC3H6, kg/h***	***g(C2H4+ C3H6), kg/h***	***x***	***S2***	***τ***	***gC2H4, kg/h***	***gC3H6, kg/h***	***g(C2H4+ C3H6), kg/h***	***x***	***S2***	***τ***	***gC2H4, kg/h***	***gC3H6, kg/h***	***g(C2H4+ C3H6), kg/h***	***x***	***S2***	***τ***
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***	***13***	***14***	***15***	***16***	***17***	***18***	***19***
	$g_{\text{Í}_2\text{Î}} : g^0_{C_2H_6}$ =1:1																	
	$g^0_{C_2H_6}$ =2000 kg/h, $g_{\text{Í}_2\text{Î}}$ =2000 kg/h						$g^0_{C_2H_6}$ =2500 kg/h, $g_{\text{Í}_2\text{Î}}$ =2500 kg/h						$g^0_{C_2H_6}$ =2750 kg/h, $g_{\text{Í}_2\text{Î}}$ =2750 kg/h					
775	353.44	85.74	439.17	0.97	0.226	0.98	877.69	81.00	958.69	0.87	0.443	0.84	1101.55	71.33	1172.88	0.80	0.534	0.79
800	328.15	86.75	414.90	0.98	0.212	0.96	834.66	85.55	920.21	0.88	0.417	0.82	1071.65	76.58	1148.23	0.82	0.511	0.78
825	304.63	87.70	392.34	0.98	0.200	0.95	788.49	89.98	878.47	0.90	0.391	0.80	1035.86	82.03	1117.90	0.84	0.486	0.76
850	282.80	88.64	371.44	0.98	0.189	0.93	740.24	94.23	834.48	0.91	0.366	0.79	994.42	87.62	1082.04	0.85	0.460	0.74
	$g_{\text{Í}_2\text{Î}} : g^0_{C_2H_6}$ =1.5:1																	
	$g^0_{C_2H_6}$ =2000 kg/h, $g_{\text{Í}_2\text{Î}}$ =3000 kg/h						$g^0_{C_2H_6}$ =2500 kg/h, $g_{\text{Í}_2\text{Î}}$ =6750 kg/h						$g^0_{C_2H_6}$ =2750 kg/h, $g_{\text{Í}_2\text{Î}}$ =4130 kg/h					
775	435.47	76.52	511.99	0.95	0.269	0.78	930.50	67.12	997.62	0.83	0.484	0.67	1115.08	58.37	1173.45	0.76	0.564	0.63
800	408.73	77.81	486.54	0.96	0.254	0.76	899.20	71.15	970.35	0.84	0.461	0.65	1097.04	62.69	1159.73	0.77	0.544	0.61
825	383.33	79.00	462.33	0.96	0.240	0.75	864.27	75.19	939.47	0.86	0.438	0.64	1074.12	67.23	1141.35	0.79	0.523	0.60
850	359.32	80.13	439.45	0.97	0.227	0.74	826.23	79.21	905.44	0.87	0.414	0.63	1064.28	71.95	1118.23	0.81	0.501	0.59

	$g_{Í_2Î}$: $g^0_{C_2H_6}$ =2:1																	
	$g^0_{C_2H_6}$ =2000 kg/h, $g_{Í_2Î}$ =4000 kg/h						$g^0_{C_2H_6}$ =2500 kg/h, $g_{Í_2Î}$ =5000 kg/h						$g^0_{C_2H_6}$ =2750 kg/h, $g_{Í_2Î}$ =5500 kg/h					
775	502.48	68.30	570.78	0.93	0.307	0.65	960.11	56.21	1016.33	0.79	0.516	0.55	1114.93	48.20	1163.13	0.72	0.590	0.52
800	476.04	69.80	545.84	0.94	0.291	0.63	938.08	59.71	997.80	0.80	0.496	0.54	1105.50	51.79	1157.29	0.74	0.572	0.51
825	450.40	71.20	521.61	0.94	0.276	0.62	912.55	63.29	975.84	0.82	0.475	0.53	1022.08	55.57	1147.65	0.75	0.554	0.49
850	425.72	72.52	498.24	0.95	0.262	0.61	883.72	66.92	950.64	0.84	0.454	0.52	1074.53	59.54	1134.07	0.77	0.534	0.48

gC2H4, kg/h	gC3H6, kg/h	g(C2H4+ C3H6), kg/h	x	S2	τ	gC2H4, kg/h	gC3H6, kg/h	g(C2H4+ C3H6), kg/h	x	S2	τ	gC2H4, kg/h	gC3H6, kg/h	g(C2H4+ C3H6), kg/h	x	S2	τ
20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
$g_{Í_2Î}$: $g^0_{C_2H_6}$ =1:1																	
$g^0_{C_2H_6}$ =3000 kg/h, $g_{Í_2Î}$ =2000 kg/h						$g^0_{C_2H_6}$ =3000 kg/h, $g_{Í_2Î}$ =2500 kg/h						$g^0_{C_2H_6}$ =3250 kg/h, $g_{Í_2Î}$ =3250 kg/h					
1263.86	62.54	1326.40	0.74	0.601	0.75	1381.46	55.46	1436.92	0.68	0.649	0.71	1469.84	49.84	1519.68	0.63	0.684	0.68
1249.58	67.78	1317.35	0.76	0.581	0.73	1380.64	60.48	1441.12	0.70	0.631	0.70	1480.05	54.64	1534.69	0.66	0.669	0.66
1229.18	73.39	1302.57	0.78	0.559	0.72	1374.35	65.94	1440.29	0.72	0.613	0.68	1485.49	59.90	1545.39	0.68	0.653	0.65
1202.28	79.55	1281.63	0.80	0.536	0.70	1361.97	71.85	1433.83	0.74	0.593	0.67	1485.56	65.54	1551.21	0.70	0.635	0.63
$g_{Í_2Î}$: $g^0_{C_2H_6}$ =1.5:1																	
$g^0_{C_2H_6}$ =3000 kg/h, $g_{Í_2Î}$ =4500 kg/h						$g^0_{C_2H_6}$ =3250 кг/ч, $g_{Í_2Î}$ =4880 kg/h						$g^0_{C_2H_6}$ =3500 kg/h, $g_{Í_2Î}$ =5250 kg/h					
1246.82	50.81	1297.64	0.69	0.623	0.59	1341.97	44.70	1386.67	0.64	0.666	0.56	1412.89	39.78	1452.67	0.59	0.698	0.53
1242.09	55.04	1297.13	0.71	0.606	0.58	1348.54	48.74	1397.28	0.66	0.651	0.55	1428.91	43.62	1472.53	0.61	0.685	0.52
1232.65	59.57	1292.23	0.73	0.587	0.57	1350.95	53.11	1404.06	0.68	0.635	0.53	1441.29	47.80	1489.10	0.63	0.671	0.51
1218.15	64.41	1282.56	0.75	0.568	0.55	1348.74	57.84	1406.57	0.70	0.618	0.52	1449.59	52.37	1501.96	0.65	0.656	0.49
$g_{Í_2Î}$: $g^0_{C_2H_6}$ =2:1																	
$g^0_{C_2H_6}$ =3000 kg/h, $g_{Í_2Î}$ =6000 kg/h						$g^0_{C_2H_6}$ =3250 kg/h, $g_{Í_2Î}$ =6500 kg/h						$g^0_{C_2H_6}$ =3500 kg/h, $g_{Í_2Î}$ =7000 kg/h					
1223.41	41.45	1264.86	0.65	0.644	0.48	1300.36	35.97	1336.32	0.60	0.684	0.46	1356.06	31.48	1387.54	0.55	0.715	0.43
1225.69	44.90	1270.58	0.67	0.628	0.47	1312.54	39.21	1351.75	0.62	0.670	0.44	1376.61	34.53	1411.14	0.57	0.703	0.42
1224.28	48.59	1272.86	0.69	0.612	0.46	1321.51	42.73	1364.23	0.64	0.656	0.43	1394.40	37.86	1432.26	0.59	0.690	0.41
1218.88	52.53	1271.42	0.71	0.595	0.45	1326.93	46.52	1373.45	0.66	0.641	0.43	1409.10	41.47	1450.58	0.61	0.677	0.40

gC2H4, kg/h	gC3H6, kg/h	g(C2H4+C3H6), kg/h	x	S2	τ	gC2H4, kg/h	gC3H6, kg/h	g(C2H4+C3H6), kg/h	x	S2	τ
38	39	40	41	42	43	44	45	46	47	48	49
$g_{Í_2Î}$: $g^0_{C_2H_6}$ =1:1											
$g^0_{C_2H_6}$ =4500 kg/h, $g_{Í_2Î}$ =4500 kg/h						$g^0_{C_2H_6}$ =5000 kg/h, $g_{Í_2Î}$ =5000 kg/h					
1681.80	35.97	1717.77	0.50	0.763	0.56	1747.07	31.79	1778.86	0.45	0.786	0.51
1722.23	40.21	1762.44	0.52	0.753	0.55	1798.59	35.87	1834.46	0.47	0.776	0.50
1759.70	44.91	1804.62	0.54	0.742	0.54	1847.62	40.43	1888.05	0.49	0.767	0.49
1793.73	50.15	1843.88	0.56	0.730	0.52	1893.72	45.53	1939.26	0.51	0.756	0.48

$g_{Í\ 2Î} : g^{0}_{C_2H_6}$ =1.5:1											
$g^{0}_{C_2H_6}$ =4500 kg/h, $g_{Í\ 2Î}$ =6750 kg/h						$g^{0}_{C_2H_6}$ =5000 kg/h, $g_{Í\ 2Î}$ =7500 kg/h					
1573.11	27.08	1600.18	0.46	0.775	0.43	1614.51	9.61	1637.52	0.41	0.798	0.39
1616.11	30.33	1646.44	0.48	0.766	0.42	1667.55	10.87	1693.60	0.43	0.790	0.38
1656.88	33.95	1690.83	0.50	0.756	0.41	1718.84	12.29	1748.28	0.45	0.781	0.37
1695.10	37.96	1733.06	0.52	0.746	0.40	1768.05	13.88	1801.29	0.47	0.773	0.36
$g_{Í\ 2Î} : g^{0}_{C_2H_6}$ =2:1											
$g^{0}_{C_2H_6}$ =4500 kg/h, $g_{Í\ 2Î}$ =9000 kg/h						$g^{0}_{C_2H_6}$ =5000 kg/h, $g_{Í\ 2Î}$ =10000 kg/h					
1462.69	19.47	1482.16	0.42	0.793	0.33	1471.22	15.41	1486.63	0.36	0.820	0.29
1507.51	21.86	1529.37	0.43	0.785	0.32	1524.02	17.49	1541.51	0.38	0.813	0.27
1550.87	24.51	1575.38	0.45	0.777	0.31	1575.65	19.83	1595.47	0.40	0.807	0.26
1592.56	27.45	1620.01	0.47	0.769	0.30	1625.80	22.44	1648.24	0.41	0.800	0.25

Table 2: Study of the impact of the temperature on the output of target products at various loads and similar ratio of steam: raw material (L=138.24 m).

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