MODEL AND PROGRAM OF THE EFFECT OF INCOMPLETE COMBUSTION GAS ON THE ECONOMY

Rabim Alikulovich Fayziev
Professor Dept. Mathematical Methods in Economics
Tashkent State University of Economics, Tashkent, Uzbekistan
zktdiu@yandex.ru

Muzaffar Muhiddinovich Hamdamov
Phd. Institute of Mechanics and Seismic Stability of Structures of the Academy of Sciences of the Republic of Uzbekistan, Tashkent, Uzbekistan
kamina.0691@mail.ru

ABSTRACT

The article analyzes the impact of the issue on the economy of obtaining electricity in the energy system, which is now one of the topical topics and ensuring full combustion of the gas used by the population in everyday conditions, how much net income will come, and develops a model, algorithm, proposals for its improvement.

KEYWORDS

Electricity, production, electricity supply, net profit, Arrhenius law, finite differences, numerical algorithm, computational experiment, mathematical modeling, forecasting

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1 INTRODUCTION

Natural gas prices in Europe increased sixfold compared to the corresponding period last year. On October 5, 2021, the price of natural gas futures reached about 1200 dollars per thousand cubic meters. In the approaching heating season, the risk of gas shortages can pose a serious threat to the heating of apartments, electricity supply and industrial production. The reasons for the record rise of the nakhr in the European gas market and the consequences of this are considered one of the current topical topics.

A sharp increase in energy prices is affecting all sectors of the region's economy. In particular, the possibility of gas shortages in winter can pose a serious threat to the heating of apartments, electricity supply and industrial production.

This energy crisis is expected to suffer the most from the citizens of the region, especially those who have entered into variable-price contracts with power suppliers.

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It is noted that the rate of inflation in the eurozone in September, unlike the 2 percent rate of the annual inflation target of the European Central Bank, rose by 3,4 percent and energy price inflation exceeded 17 percent.

To date, natural gas prices in Europe have increased by 6 times compared to the corresponding period last year. The sharp increase in gas prices also has its impact on the situation in the electricity market. In the European Union (EU), a fifth of electricity is taken into account in natural gas.

In the European Union, natural gas consumption relies mainly on imports. According to Eurostat, almost 90 percent of the natural gas used in 2019 year had to be imported.

One of the largest gas suppliers is traditionally Russia, providing about 22% of total consumption, supplying 115-120 billion cubic meters per year. In January — August 2021, Russian exports amounted to 99 billion cubic meters, which is 19.3 billion cubic meters less than in the same period last year. And it's not that it's Gazprom, which suddenly stopped supplying in the right amount: the whole point is the desire of the European Union to reduce dependence on Russian gas, it is elementary to buy less than before. As a result, relying on other sources, such as LNG, renewable energy, the EU decided to use the so-called spot market: in fact, the principle of "here and now" instead of concluding long-term contracts with the same Gazprom, where you can safely fix the price for the future, even if the spot market breaks all records. All kinds of speculators have dispersed the exchange value to exorbitant levels. This will be a great lesson for those officials in the EU who are planning the development of the gas market. They were in a hurry and ran into a hard mine in the form of the very hand of the market.

In addition, the pandemic prevented some countries from carrying out repair work on their gas transportation infrastructure facilities. Most of the gas exporting countries to Europe, especially Norway (also a key supplier along with Russia), began repair and technical work this summer. Norway, as a result, reduced gas exports by 3.1 billion cubic meters in the first eight months of 2021 compared to the same periods of 2019-2020.

Gas prices in Europe began to rise in April of this year and have since risen eight times: gas futures quotes at the TTF hub in the Netherlands reached the level of 1969.2 dollars per one thousand cubic meters. For information: back at the beginning of the year, futures were trading at $265. Natural gas accounts for about 22% of electricity production in Europe, and, as a result, electricity tariffs for the population and industry have sharply increased: in Germany - up to 302.5 euros per megawatt hour, in Spain - up to 288 euros.

From these values we can say that the price of gas fuel has increased in the whole world. As a result of the increase in the population Year by year, the demand for electricity and gas in the national

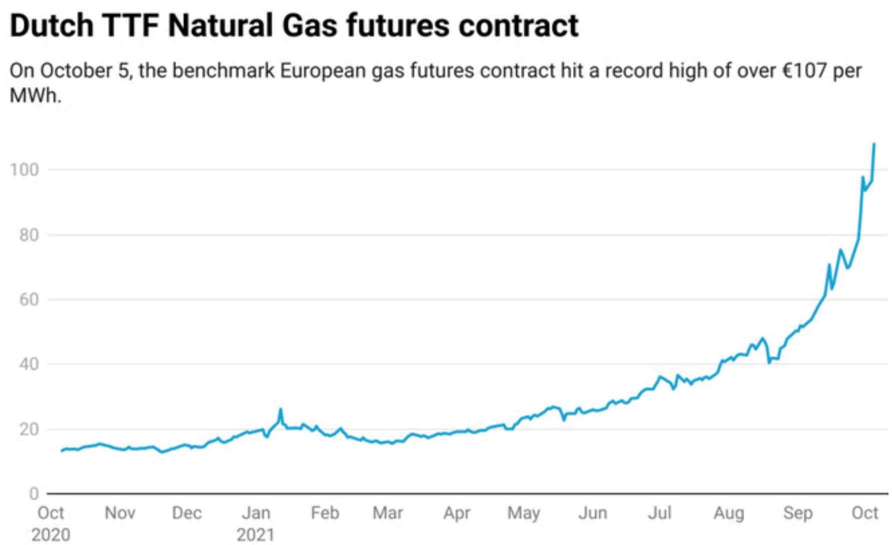

Figure 1: Dynamics of growth in the price of natural gas futures contracts

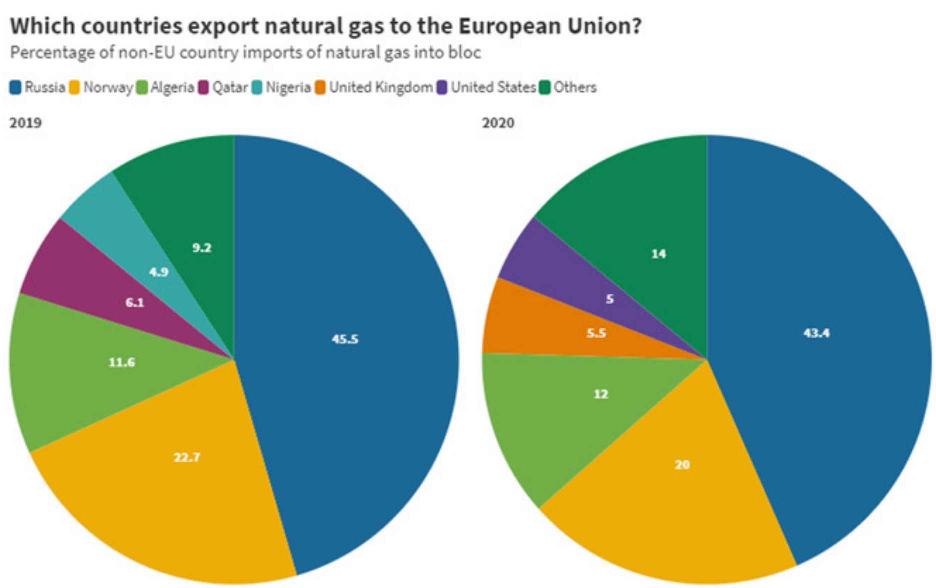

Figure 2: Distribution of natural gas imports in the EU by exporters.

economy is increasing. In the Republic of Uzbekistan, about 70% of the energy balance is obtained by activates gas. Despite the constant improvement of gas activate devices, their efficiency is still very low. It is therefore necessary to continue further research in this area. In [1-3], the problem of hydrogen combustion in a stream was solved, where a method of using the Schwab - Zeldovich functions and a method for solving the transcendental equation formed by the chemical equilibrium model were proposed. In a gas engine, depletion of the mixture in the optimal limit improves fuel, economic and environmental performance and thus has a positive effect on the effective efficiency [4, 5]. The increase in the effective Coefficient of Effectiveness is determined by the fact that the completeness of combustion of the gas-air mixture is most effective in the range α =1÷1.35, with mixed qualitative and quantitative regulation of the gas-air mixture. A further increase in the excess air ratio leads to a decrease in efficiency, with the most noticeable drop in engine efficiency occurring at α>1.3. Accordingly, it can be concluded that mixed regulation is necessary to ensure the maximum effective Efficiency in the entire range of engine speeds.

2 INSERTING CONTENT ELEMENTS

For practical application, the system of Navier-Stokes equations in the viscous layer approximation, parabolized in the Mises coordinates, is used:

$$\frac{\partial(\rho ur)}{\partial x} + \frac{\partial(\rho\vartheta r)}{\partial x} = 0;$$

$$\frac{\partial u}{\partial x} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\vartheta r}{u\varphi}\frac{\partial P}{\partial \varphi} + \frac{1}{\varphi}\frac{\partial\left(\mu\rho ur^2/\varphi\right)}{\partial\varphi}\frac{\partial u}{\partial\varphi}$$

$$\frac{\partial H}{\partial x} = \frac{1}{\varphi}\frac{\partial}{\partial\varphi}\left(\frac{\mu}{Pr}\frac{\rho ur^2}{\varphi}\right)\frac{\partial H}{\partial\varphi};$$

$$\frac{\partial C_i}{\partial x} = \frac{1}{\varphi}\frac{\partial}{\partial\varphi}\left(\frac{\mu}{Sc}\frac{\rho ur^2}{\varphi}\right)\frac{\partial C_i}{\partial\varphi} + \omega_i;\ \ \mathrm{i} = 1\ldots\mathrm{N},$$

$$P = \rho RT\mu^{-1},\ \frac{\partial r}{\partial\varphi} = \frac{\varphi}{\rho ur};$$

$$H = \sum_{i=1}^{N} h_i\ (T)C_i + \frac{u^2+\vartheta^2}{2}.$$

Here and further u V is averaged longitudinal and radial components of the velocity vector ($m\,s^{-1}$) in cylindrical coordinates; φ is Mises coordinates is Mises coordinates ($m, (\frac{kg}{s})^{\frac{1}{2}}$); $\rho,\ T$ is density ($kg\ m^{-3}$) and the absolute temperature (K) gas mixture; p is hydrostatic pressure (Pa); Pr, Sc is hydrostatic pressure Turbulent analogs of the Prandtl and Schmidt numbers; C_i is mass concentration the i-th component of the gas in the mixture ($kg\ kg^{-1}$); ω_i is mass rate of formation or disappearance of the I isth gas component ($kg\ m^{-3}s^{-1}$); (h_i^*) is calorific value of the i-th component ($j\ kg^{-1}\ K^{-1}$), $\mu,\ \mu_t$ is kinematic coefficients of laminar and turbulent viscosity $\frac{m^2}{s}$; H is total gas enthalpy $\frac{J}{kg}$;

In this article, a methane-air mixture is considered as a combustible gas, and the one-stage kinetics of methane combustion in air is set through the gross reactions

$$CH_4 + 2O_2 \to CO_2 + 2H_2O + h_2^*.$$

The indices 1, 2, 3, 4 and 5 highlight the parameters of the components – oxygen, methane, carbon dioxide, water vapor and nitrogen, respectively.

Practice shows [3-7] that gas combustion in conditions of lack of air can cause incomplete combustion of combustible gas. If we consider the existing gas burners with preliminary mixing of gas and air, then the excess air ratio is 1.05–1.1 and combustion is consumed by 5-10% more air than the theoretically required amount.

The excess air factor α means the ratio of the amount of actually consumed air V for combustion to the theoretically required amount V_0:

$$\alpha = \frac{V}{V_0}$$

For the complete combustion of 1 gmol (16.043 g) of methane, the theoretically required amount of oxygen is 2 gmol (64 g). Suppose that a given amount of oxygen is taken from the composition of air, which has a molar mass

$$m_0 = \frac{1}{\frac{(c_1)_1}{m_1} + \frac{(c_5)_1}{m_1}};$$

Here $(c_1)_1,\ (c_5)_1$ is mass concentrations of oxygen and nitrogen in the air; m_1 and m_5 is their molecular weights. Under normal conditions (760 mm Hg), 1 gmol of gas occupies a volume. Let the air volume V_0 contains 2 gmol of oxygen. The mass of this volume of air is V_0m_0. Accordingly, 2 gmol of oxygen is $(c_1)_1$ part of this mass: $2m_1 = V_0m_0\ (c_1)_1$

Hence it follows that the volume of air required for complete combustion of 1 gmol of methane is

$$V_0 = \frac{m_0\ (c_1)_1}{V_0\ \ 2m_1}.$$

The mass of nitrogen in this volume of air is $m_{N_2} = V_0\ m_0(c_5)_1 = 211.81\ \ g$;

If the composition of the combustible mixture is stoichiometric, then its mass is $m_{sm}^* = m_2 + 2m_1 + 2m_1\frac{(c_5)_1}{(c_1)_1}$.

Accordingly, the mass concentrations of the components in the stoichiometric composition of the methane-air mixture are:

$(c_1)_2 = \frac{m_2}{m_{sm}^*}$- oxygen, $(c_2)_2 = \frac{2m_1}{m_{sm}^*}$- methane, $(c_5)_2 = \frac{m_{N2}}{m_{sm}^*}$ - nitrogen.

Stoichiometric composition, $(c_1)_2 = 0.0550$, $(c_2)_2 = 0.2192$, $(c_5)_2 = 0.7278$ methane-air mixture, which corresponds to the case $\alpha = 1$ In this case, the density of the combustible mixture relative to the density of methane increased 1.7225 times.

At $\alpha \neq 1$ the composition of the gas-air mixture is determined as the ratio of the molar composition $CH_4 + \alpha(2O_2 + m_aN_2)$, which, in the transition to the mass composition, take the form: (m_2) : $(2\alpha(m_1)) : (2\alpha(m_1))\frac{(c_5)_1}{(c_1)_1}$.

The total mass of the mixture in volume V is $m_{sm} = m_2 + 2\alpha m_1 + 2\alpha m_1\frac{(c_5)_1}{(c_1)_1}$,

and the concentration of the components $-(c_2)_2 = \frac{m_2}{m_{sm}}$, $(c_1)_2 = \frac{2\alpha m_1}{m_{sm}}$, $(c_5)_2 = \frac{2\alpha m_1}{m_{sm}}\ \frac{(c_5)_1}{(c_1)_1}$;

We introduce the Schwab-Zeldovich functions. With a known value of the reaction rate of the fuel, the rates of chemical transformations of the remaining components in dimensional form are represented as

$$\omega_1 = \frac{\upsilon_1 m_1}{\upsilon_2 m_2}\omega_2;\ \omega_3 = -\frac{\upsilon_3 m_3}{\upsilon_2 m_2}\omega_2;\ \omega_4 = \frac{\upsilon_4 m_4}{\upsilon_2 m_2}\omega_2;\ \ \omega_5 = 0.$$

The rate of the combustion reaction of methane with oxygen in the fuel mass conservation equation, according to the proposals of works [8], in dimensionless Mises coordinates has the form:

$$\omega_2 = -A_{r1}\ \frac{c_1c_2\rho^2}{u}\ exp\left(-\frac{A_{r2}}{T}\right),$$

where $A_{r1} = 1.35 * 10^{20}$, $\frac{E_a}{R} = 15.05\ K = A_{r2}K$.

Method of casting N differential equations of conservation of components to two equations (with respect to the combustible component and the Schwab-Zeldovich function) for *n=1..5* and the formulas for the reverse transition to mass concentration are given in the article [5-7].

At the entrance *x=0* the following conditions are imposed on the calculation area:

$$0 \le \varphi < 1:$$

$$u = 1,\ H = 1, C_2 = (c_2)_2, k = 1,\ \varepsilon = 1.$$

$$1 \le \varphi < \varphi_\infty:$$

$$u = u_1,\ H = 0, C_2 = (c_2)_1, k = k_1,\ \varepsilon = \varepsilon_1.$$

By $x > 0$ we have by $\varphi = 0$:

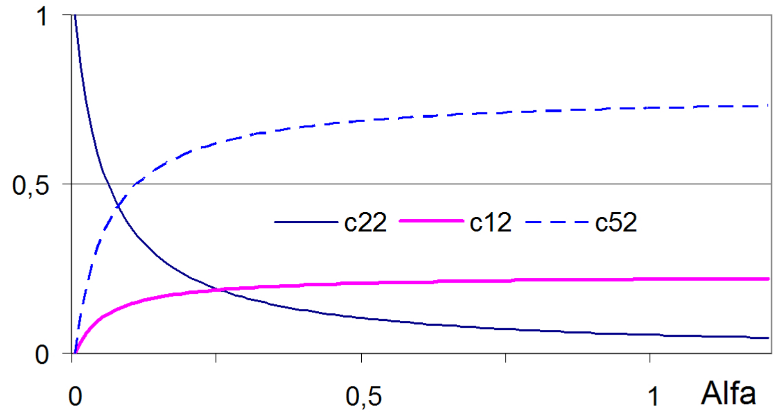

Figure 3: Changes in the mass concentrations of fuel, oxidizer and nitrogen in the composition of the combustible mixture, depending on the excess air ratio

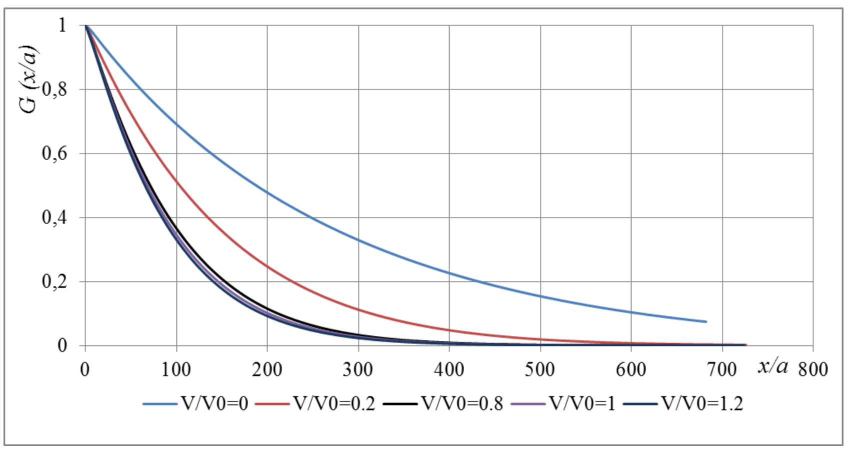

Figure 4: Curves of fuel burnout depending on the excess air at the radius of the fuel nozzle a=0.0002 м

$$\frac{\partial u}{\partial \varphi} = 0, \ \frac{\partial H}{\partial \varphi} = 0, \ \frac{\partial C}{\partial \varphi} = 0, \ \frac{\partial k}{\partial \varphi} = 0, \ \frac{\partial \varepsilon}{\partial \varphi} = 0.$$

when $\varphi \to \varphi_\infty$

$$u = u_1, \ H = 0, C_2 = (c_2)_1, k = k_1, \ \varepsilon = \varepsilon_1.$$

The right-hand sides of the equations involve the square of a dimensionless radial coordinate r^2. Let's calculate it with the second order of accuracy

$$\left(r_{i,j}^{s}\right)^2 = \left(r_{i,j-1}^{s}\right)^2 + 2\frac{\varphi_j^2 - \varphi_{j-1}^2}{\rho_{i,j-1}^{s-1} u_{i,j-1}^{s-1} + \rho_{i,j}^{s-1} u_{i,j}^{s-1}}.$$

3 RESULTS AND DISCUSSION

According to the presented material, a program was compiled and calculations were carried out. The mass composition of the air was set as $(c_1)_1 = 0.232$, $(c_5)_1 = 0.768$. Methane without impurities was considered as a fuel. The speed of the main flow was *61 m/s*, a of the satellite stream – *18.3 m/s*. Air temperature – *T=293.15K*

Numerical results are obtained for the total enthalpy, longitudinal velocity, concentration of components, and temperature along the length of the flame. Individual calculation results are presented in the form of graphs in Fig. 3. mass concentrations of methane, oxygen and molecular nitrogen depending on the excess air ratio in the range 0-1.2. It can be seen that with an increase in the value of the excess air ratio, the proportion of methane, respectively, the calorific value of the combustible mixture, decreases according to the hyperbolic law. The proportions of oxygen and nitrogen, as well as the molar mass (and density) of the combustible mixture, increase according to the hyperbolic law. It should be noted that the ratio of the molar mass of the combustible mixture to the molar mass of methane in this range of the excess air ratio increases from 1 to 1.7341, and the graph of this ratio is similar to the graphs of the concentration of nitrogen and oxygen (Figure. 3).

In the course of the calculations, the indicator of the completeness of combustion of the combustible gas was analyzed, which was presented in an integrated form $G(x/a)$. Figure 4. the curves are shown depending on the excess air at the radius of the fuel

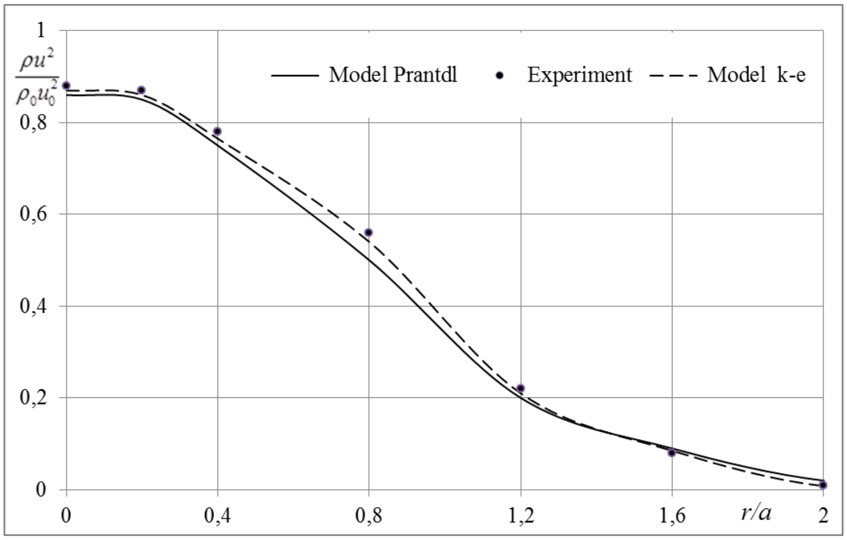

Figure 5: Comparison of the distribution of the pulse flux density in the flow field with the experiment [2]. When $\frac{x}{d} = 6$, $T_2 = 600\ K$, $c_{22} = 0.085 \frac{kg}{kg}$.

nozzle a=0.0002 m. The results showed that at low values of the excess air ratio, the flame shrinks and the fuel reacts faster.

4 CONCLUSION

The measure of the saturation of the combustible mixture was the excess air in the methane-air mixture, which has a zero value for pure methane and a single value for the stoichiometric composition of methane with air. The conditional torch length is taken as $(H_{axis} - H_1)(H_2 - H_1) = 0.01$. Cases of different values of the excess air coefficient at fixed values of the radius of the fuel nozzle are studied. It was revealed that at small values of α, a high temperature is formed and a more complete combustion of the gas occurs, i.e. the efficiency of equipment using a gas burner increases.

For the numerical solution of the combustion problem according to the Arrhenius law, an approximation with the second order of accuracy in the calculated coordinates is used. This made it possible to significantly reduce the calculation time as a result of using a large calculation step for the longitudinal coordinate. A computational experiment was used to study the influence of the radius of the fuel nozzle, the addition of air to the fuel, and the air temperature on the parameters of an axisymmetric jet and torch. It was found that with a decrease in these indicators, a decrease in the highest value of the gas temperature is observed, which leads to an increase in the underburning of fuel and a decrease in the efficiency of the burner. The results of this work were used in the implementation of a fundamental grant for the modeling of complex objects, as well as in the development of burners with high efficiency.

The adequacy of the results was verified by the implementation of the laws of conservation of mass, momentum and total enthalpy, as well as by comparing the results with experimental data from other authors with the largest 5% deviation. This means that the previously presented algorithm and calculation program can be used for practical purposes. The results obtained with both turbulence models were compared with experimental data. Analyzing the results, one can notice that the $k - \varepsilon$ model coincides more qualitatively with the experiment than the Prandtl turbulence model (Figure. 5).

This makes it possible to determine how much gas is needed and how much gas goes out into the environment without burning, depending on the population with the help of a structured software tool. When activated in the process of gas combustion in devices through the model we offer, up to 2-5% of gas is saved. This is a very large sum, if we look at the indicator in relation to the entire population. The proposed models, software tools will help improve the power supply of the country and create a basis for significant growth of the economy.

As for forecasts, the International Energy Agency (IEA) predicts that the current price level will remain at least until the end of the first quarter of 2022. The agency's report says that in 2022, Henry Hub prices will increase by 5%, TTF - by 10%, and spot LNG prices in Asia - by 6% compared to this year's levels. After the end of the heating season, prices will drop. In the second half of 2022, Henry Hub prices will be on average 18% lower than in the second half of 2021, while prices on TTF and on the spot LNG market in Asia will decrease by 40%.

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