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Evaluation of Energy Efficiency, Energy Consumption and Energy Saving in the Production of Oil, Gas and Energy Sectors

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Abstract: Energy efficiency, energy consumption and energy savings depend on the performance of energy-technological equipment characterising the operational suitability of it. The operational suitability of the equipment determines the quality of it. Based on energy consumption, fuel consumption and reliability indicators as the formalised quality indicators in energotechnological equipment it is possible to determine the energy efficiency, energy consumption and energy savings of the equipment and therefore select the right production volume indicator (PVI). The aim in determining the fuel and power parameters (FPP) of the oil and gas production units and power sector is to get dependence influencing the energy efficiency (EE), power consumption (PC) and energy saving (ES) of those production units. To solve this problem it was necessary to choose the right (PVI). For that purpose, the issues concerning justifying the choice of the volume indicator for the oil, gas and power sectors using the gas turbine units (GTU) were examined. The correct choice of (PVI) it was possible to determine the available efficient power of gas turbine units which should meet the power consumption requirements for the gas compression by gas pumping units (GPU) on the compressor station (CS) of gas transmission systems for a given mode [4,5].

Keywords: Energy Efficiency of Equipment, Energy Consumption of Equipment, Energy Saving of Equipment, Production Volume Indicator, Oil and Gas Industry, Gas Pumping Unit, Pipeline Power Consumption, Effective Power of Machines

1. Introduction

The choice of (PVI) is quite essential in terms of assigned tasks. Analysis of the methods used of the determination of the (PVI) revealed shortcomings in the process. In one case it was due to the gross nature of (PVI), in other words, it was taken into account how much gas was transported at a predetermined distance but it was not considered how much power was consumed in that case. In another case, the work expended was taken into account but without proper accounting for the total energy losses. The correct assessment of the gas compression effectiveness associated with a specific energy consumption in production of the oil, gas and power sectors provided basis for determining (PVI).

On the value of (PVI) at compressor stations of gas pipelines with a gas turbine drive is influenced by both external and internal factors. External factors are mainly related to the outdoor temperature at the inlet of a gas-turbine drive at the compressor stations which are taken into consideration in the article. Based on the thermodynamic characteristics of a gas turbine drive derived are the effects of the outdoor temperature on the gas turbine drive of the gas pumping units of compressor stations.

In this regard, the article discusses regularities of outdoor temperature influence on the effective power of the gas-turbine drive of gas compressor units [1].

2. Materials and Methods

To assess energy efficiency (EE), energy consumption (EC) and energy savings (ES) production of the oil and gas sector (OGS) and energy sector it is necessary, first of all, to choose the (PVI). The article assesses the (EE), (EC) and

(ES) based on the (PVI) [1, 2].

The assessment of (POI) used in the industry is carried out on the basis of the commodity transport activities (CTA). The commodity transport activities are used as an indicator to characterise the productions volume of the (OGS) and energy sector, for example, the gas transportation pipeline system (GTS) and is a conditional work on the displacement of a unit of the volume of gas transported per length unit of a gas pipeline (gas pipelines) [3], [6].

The (CTA) are of the bulk nature and originates from the Ministry of Railway Transport (ton-kilometer) concerning the movement of goods and cargoes; it does not take into account a change in the physical properties of cargoes during transportation [3]. The pipeline transport is taken as an example. In the pipeline transport the physical properties of a working medium change, and the temperature, pressure, density of the working medium in the energotechnological equipment (ETE) do change as well, which greatly influences the (EE), (EC) and (ES). In this regard, using (CTA) it is impossible to assess the (EE), (EC) and (ES) of the considered (ETE) which is represented by gas pumping units (GPU) at the compressor stations (CS) along the pipeline in the pipeline transport.

The proposed equivalent commodity transport activities are based on determining the polytropic compression without considering all the losses of energy, in particular, the external energy loss determined by the mechanical efficiency of (GPU), a gas centrifugal compressor (CC) of the gas pipeline compressor station and the power spent for mechanical losses during the transmission of mechanical energy from the drive to the centrifugal compressor [4], [7]. It is mainly the gas turbine unit (GTU) that is used as the drive in the gas turbine system. Gas turbine units are also used in the power sector, i. e. thermal power plants (TPP), heat and power plants (HPP) to drive electric generators. Later we will mainly focus on the (GTU) used in the (GPU) to drive gas (CC).

In this regard, it is proposed to use the efficient energy required to compress a predetermined volume of gas transported as the (POI) and, therefore the specific energy consumption in kW. h for the transport of the unit of a given volume of transported gas in million. m3 [5, 6]:

$$d = N_e / Q_k \,, \left[kw.h \middle/ million.m^3 \right], \qquad (1)$$

where N_e is the effective power of GPU of CS of GPS; Q_k $\left[million.m^3 \middle/ day \right]$ - volume (quantity) of the compressed gas of (GCU) of (CS) of (GPS).

3. Energy Efficiency of the Energy and Gas Pumping Units with the Electric Drive and Gas Turbine Drive

Untimely preventive maintenance to clean the pipeline from solids, crystalline hydrates and condensates as well as unreliable operation of the systems designed for gas cleaning, drying and stripping lead to overload (GPU) and increased (POI), i. e. an increase in the specific energy consumption for compressing. Based on the study of the modes of operation of gas transmission systems Urengoy - Chelyabinsk, NPTR (Northern Parts of the Tyumen Region) - Nizhnyaya Tura (N. Tura), N. Tura- Gorky in the first years of operation it was found that for gas pipelines in the normal state, the power consumption is up to 90-95 kWh / (million .m^3. km) with an average operating pressure in a gas pipeline of 5.6 MPa and up to 115-125 kW. h / (million. m^3. km) at 7.5 MPa. To prevent the formation of hydrates in gas and eliminate hydrate blocks, it is necessary to reduce the pressure of the gas transportation, raise its temperature, lower humidity and apply various inhibitors, condensate traps etc.

In turn, the poor technical condition of a gas-turbine gas-pumping unit leads to a fall in its productivity and ultimately a decrease in a certain amount of gas flow through the pipeline, or it causes an overload in the gas-turbine gas-pumping unit during the operation of the planned volume of gas transported. This causes an increase in specific energy consumption for transportation of gas, that is, an increase in the (POI).

An analysis of the mode of operation of the gas-turbine gas-compressor units of compressor stations of pipelines shows the impact from the technical state of the machinery and equipment on the (POI), deterioration of the overall performance, power performance of the gas-turbine gas-pumping unit and pipeline.

The research has shown that lowering the degree of compression in respect of (CS) is one of the most effective ways to reduce energy consumption including the fuel gas flow.

In the reporting practices of the gas pipeline systems (GPS) based on the recommendation of STO Gazprom 2-3.5-113-2007 [7], the energy efficiency of gas pumping units and that of compressor workshops, compressor stations and (GPS) are evaluated differently. If for (GPU) of (CS) with electric engines the efficiency is determined by the power consumption in specific values as $d_e = N_{ee} / Q_k$ or in absolute terms, the absolute energy consumption of (GPU) of (CS) of (GPS) - kW. h for the reporting period:

$$E_{ee} = d_e . Q_k \,, \qquad (2)$$

In the case of evaluation of efficiency of a gas-pumping unit with a gas-turbine drive compressor used is the fuel gas consumption of the gas pipeline system- in thousand. m^3 (million. m^3) for the reporting period. It should be noted that taking into account quality categories in the energotechnological equipment (ETE) fuel consumption can be characterised by the economical efficiency [8]. In this regard, to assess the energy efficiency of a gas-pumping unit with a gas-turbine drive, power consumption in calculations should be in specific terms $d_g = N_{eg} / Q_k$, or in absolute terms, i. e. the absolute power consumption of a (GPU) of (CS) of (GPS)- kW. h for the reporting period:

$$E_{eg} = d_g \cdot Q_k, \tag{3}$$

To assess the energy efficiency, energy consumption and energy saving of the production of (GPU) of (CS) of (GPS) according to [9, 10], it is proposed to divide the calculated flow rate of the fuel gas for the gas-turbine and gas-pumping unit (power consumption for the (GPU) with an electric engine) into perform useful work units. At the same time, the polytropic compression work is used as the useful work done by the gas pumping unit, compressor shop and compressor station. The proposed design ratio of the polytropic compression work with the work of gas-turbine and gas-pumping unit does not account for power losses that it is explained factors given below.

To the value of the (POI) at the (CS) of pipelines from the gas-turbine and gas-pumping unit is influenced by two factors affecting the energy loss, i. e. the external and internal factors that determine the energy losses of (CC). Internal energy losses are assessed by the efficiency of the process which occurs in our machine across the flow part of the machine, from the inlet to the outlet of the machine. The gas (CC) is related to the flow impeller machinery and according to the theory of flow turbochargers the internal energy losses are evaluated by the adiabatic efficiency. The external factor relates mainly to the outdoor temperature at the inlet to an axial compressor (T_a) of (GTU). Known is the sensitivity of the gas turbine drive of (GPU), for which (CC) is used. According to the thermodynamic theory [5], on average every degree of Ta change changes the effective power of the (GPU) drive on average by 0.8 - 1.2% in the normal variation interval of T_a from -15 to 45°C.

In this regard, examines the regularities of influence of T_a on an effective power of the gas-turbine drive of (GPU). To evaluate (EE), (EC) and (ES) in addressing mode-related issues concerning the compression of a predetermined amount of gas transported, it is necessary to determine the available efficient power of the (GPU) drive that should not be less than the required power of (GPU) for gas compression of (GPU) of (CS) for fulfilling the assigned regime:

$$N_{e(gtu)} \geq N_{e(gcu)}. \tag{4}$$

Certain problems are related to the determination of power of the (GPU) drive ($N_{e(gtu)}$) in choosing the method to determine this power. The work [1] considers the sensitivity of the gas turbine unit to the change in temperature of the outside air Ta that enters at the inlet of the axial compressor (AC) of (GTU) and how in this case changes the available power efficient of drive of GPU- $N_{e(gtu)}$ using those or other methods. This subject is studied in a number of well-known works [1-3] etc.

Greater sensitivity of (GTU) to change in the temperature of air entering the compressor of (GTU) can be explained, firstly, by the fact that these units have constant passage sections of the gas turbine thus ruling out the possibility of regulating the air flow at constant parameters of the working medium and, secondly, the fact that modern gas turbine units are characterised by a high ratio of effective compression power of the axial compressor Nec of (GTU) and expansion of a gas turbine (N_{et}), respectively, for compressor and turbine ($p_e = N_{ec}/N_{et}$ – the characteristics of the power ratio, respectively, for compressor and turbine).

According to the conducted research [9], [11, 12], it follows that at low degrees of compression (C) for (AC) the effective efficiencies and power of (GTU) are less sensitive to the outdoor temperature. For example, when C = 2 the relative change in the effective efficiency and power are respectively on average 0.25 and 0.43% per 1 degree of change in temperature T_a relative to the value of the data sheet T_{a0} = 288.2°K. Hereinafter the index '0' refers to the nominal values of the parameters of the data sheet. With an increase in C for (AC), the sensitivity of (GTU) to changes in air temperature at the inlet to (AC) dramatically increases. Thus, at C = 6, the relative change in the effective efficiency and the gas turbine power per 1 degree of T_a, on average reaches 0.60 and 0.82% respectively. Greater sensitivity of (GTU) to changes in the temperature of the ambient air T_a entering the inlet of the axial compressor (AC) of (GTU) creates the problem of determining the available power of (GTU) for performing process-related tasks, for example, in the gas-and-oil-pipeline industry for the transport of gas or oil. In the industry known is a method of determining the available effective power of (GTU) based on the application of the formula of VNIIGAS (a leading Scientific Research Institute in Russia for gas) presented in [1], [3] taking into account the correction factors (K_N, K_{ai}, K_{re}, K_T)- as the empirical method:

$$N_{ea} = N_{e0} K_N K_{ai} K_{re} \left[1 - K_T \left(T_a - T_{a0}\right)/T_a\right]\left(p_a/p_{a0}\right), \tag{5}$$

where K_N is technical status index of the gas-turbine and gas-pumping unit; K_{ai} is the factor taking into account the effects of the anti-icing system; K_{re} is a factor which takes into account the work of recycling systems; K_T is a factor which takes into account the effect of outside temperature. The factors K_N, K_{ai}, K_{re}, K_T are presented in [1]. In calculating the available power of (GTU) and making other calculations relating to the mode of operation and determination of the technical condition of units of (CS) instead of the nominal power units according to the datasheet (N_{e0}), the power value according to the industry standards can be taken as the basic power of units.

The temperature coefficient K_m influencing the value of available power of the gas-turbine and gas-pumping unit (N_{ea}) is determined taking into account [3] is as follows:

$$K_T = 1 - k_T \left(T_a - 288\right)/T_a, \tag{6}$$

where T_a is the calculated temperature of air at the gas-turbine and gas-pumping unit; κ_T is the reduced temperature coefficient the values of which for various gas-turbine and gas- pumping units are presented in the annex [3] and are changed on average within the range of 1, 3 - 3, 7 (see Table 1). For estimations proposed is the value of $\kappa_т = 3.0$.

It should be noted that a change in the available power of (GTU) depending on the ambient temperature in the station conditions, determined can also be, along with the above methods, according to the formula proposed by Professor N. I. Belokon. A known method for determining the available power of a unit based on the well-known equation proposed by Professor N. I. Belokon [5]:

$$N_{ea} = N_{e0}\left\{\left[1-\left(T_a - T_{a0}\right)/T_a\right]*\left[\lambda_e/\left(1-\lambda_e\right)\right]*\left(T_a - T_{a0}\right)/T_a\right\}. \quad (7)$$

In calculating the mode of the gas-turbine and gas-pumping unit at (CS) on the condition of the example under consideration it is necessary that the effective power supplied for the (CC) operation does not exceed the available power of the gas turbine unit (4).

In this formula, the ratio of the power consumed by the axial compressor of (GTU) and produced by the gas turbine (λ) depends on the ambient temperature (T_a). The effective power of (GTU) becomes equal to (1- λ) relative the power of the axial compressor.

Table 1. *The λ values depending on the temperature.*

T_a [°C]	-15	0	15	30	45
λ	0.520	0.540	0.572	0.615	0.668

The results of calculations to determine the relative value of the available power of (GTU) N_{ea}/N_{e0} depending on the ambient temperature according to the formula of Professor N. I. Belokon and the formula of VNIIGAS at different values of the temperature coefficient (K_T) are given in Table 2.

Table 2. *Relative available power of GTU of various types at: $K_N = 1$; $K_{ai} = 1$; $K_{re} = 1$; $P_a = P_{a0}$; $T_{a0} = 288$ °K.*

T_a [°K]	*According to the formula of N. I. Belokon*			*According to the reduced formula of the Russian Research Institute for Natural Gases and Gas Technologies (VNIIGAS) at values K_T*					
	ΔT=T_a-T_{a0}	λ/(1-λ)	N_{ea}/N_{e0}	1.3	2	2.8	3.2	3.4	3.7
				GPU-C-6.3	GTK-10I	GPU-C-16	GTN-16	GTN-25	Other GTU
258	-30	1.083	1.22	1.15	1.23	1.32	1.37	1.39	1.43
273	-15	1.174	1.11	1.07	1.11	1.15	1.17	1.19	1.20
288	0	1.337	1.00	1.00	1.00	1.00	1.00	1.00	1.00
303	15	1.596	0.86	0.93	0.90	0.86	0.84	0.83	0.82
318	30	2.012	0.70	0.87	0.81	0.73	0.70	0.68	0.65
333	45	2.448	0.53	0.82	0.72	0.62	0.56	0.54	0.50

From the data it follows that the value of N_{ea}/N_{e0} by the formula of VNIIGAS varies within a wide range for various types of gas turbine units. This variation in the temperature range T_a from -15°C to 15°C comes to 18 - 20%, while for the other temperature values it reaches 35% or higher; with an increase in coefficient K_T the ratio N_{ea}/N_{e0} in the range of negative temperatures increases, and it decreases in the range of positive temperatures. The value N_{ea}/N_{e0} by the formula of N. I. Belokon is stable for all types of gas turbine units, and is approximately 1% in the range of positive temperatures T_a. This gives a considerable spread of power of the gas-turbine and gas-pumping units by the formula VNIIGAS. It should be noted that the method of determining the effective power of (GTU) by the formula of Professor N. I. Belokon is based on the analytical method and may indicate the most accurate results of calculations (see Table 2).

Calculation of the available power of units has a great importance in the study of modes of the gas-turbine and gas-compressor units of (CS) of pipelines makes it possible to determine the shortage of power of units in summer and the value of underutilising it in the winter time at (CS), the load factor of units etc. When calculating the load factor of the gas-turbine and gas-pumping units, the actual effective capacity of a unit is referred to as the effective base power, and at the same time, various values, i. e. nominal, nameplate power, regulatory or available power are taken as the latter one. It is difficult to achieve the nameplate power under operating conditions not only on the units that are in operation for a long time but also on a number of new units. Therefore, various types of units in use, set the industry standard for the power of (GPU), which is far below the nominal one. On average, the decrease is 15%.

A number of methods of determining the effective power of (GPU) depending on the outdoor temperature (T_a) [5], [9]. In this regard, we consider the problem of determining the effective driving power of (GPU) depending on T_a varying ways for comparative evaluation. The effects of other factors on the value of the available power (use of various recycling systems, anti-icing systems, the technical condition of units etc.) thus treated the same for different ways depending on temperature.

Then, taken as an example is a unit of the type GTK-10-4 with the known characteristics according to the datasheet, and the temperature of the outside air at the inlet of (AC) of (GTU) is taken as T_a = 0°C for the following calculations. In determining the available power of the unit is used in different ways as input a set of known reference values and specifications for the unit datasheet in doing sums.

3.1. Determination the Available Power of the Gas-Turbine Unit

To determine the available power of the unit type GPU-C-6, 3 at the nominal temperature before the high-pressure turbine with the following values, N_{e0} = 6,300 kW; K_N = 0.95; K_{ai} = 1.0; K_{re} = 0.985; K_T = 1.3; T_a =273°K; p_a = 0.099 MPa.

Solution: The determination of the available power of N_{ea} is carried out by two ways.

At first according to the formula VNIIGAZ taking into account the corrective coefficients according to (5) we have:

N_{ea1} = 6300*0, 95*1, 0* 0,985[1 – 1, 3 (273-288)/273] (0,099/0,1013)= 6173 Kw.

We obtained $N_{ea}<N_{e0}$ i. e. the available power of the unit by the condition of the example under consideration is understated relative to the nominal power of (GTU) on 127 kW, which is 2%.

Then, the determination of the available power N_{ea} is conducted using formula (7) taking into account the auxiliary coefficients by the formula (5), the values of which are adopted as in the above example:

$N_{ea2} = N_{e0}\, K_N\, K_{ai}\, K_{re}\ \{[1- (T_a - T_{a0})/T_a] * [\lambda_e /(1-\lambda_e)] * (T_a - T_{a0})/T_a\}(p_a / p_{a0})$.

After substituting the numerical values we obtain the final result:

N_{ea2}=6300*0,95*1,0*0,985{[1- (273 -288)/273] * [0.54/(1-0.54)]*(273-288)/273}(0,099/0,1013)=7135 Kw.

We obtained $N_{e0} < N_{ea}$ i. e. the available power of the unit according to the condition of this example is greater than the nominal engine power of (GTU) on 835 Kw, which is 13,3%.

The obtained result of comparing two methods of determining the N_{ea} indicates that the method of determining the effective power of the (GTU) following Professor N. I. Belokon's formula is based on the analytical method and may indicate the most accurate results of calculations relative to the first empirical method.

3.2. The Problem of Choosing the Available Power of GTU–N_{ea}

On the basis of the technical documentation of the manufacturer concerning servicing (GTU) it is not allowed to exceed the maximum power of the engine by 10% higher than the rated power according to the datasheet, $N_{e(max)}$ = 1.10 N_{e0}. An analysis of the results of the calculations show that in the first and second cases, N_{ea} exceeds N_{e0} by 2% and 13.3%:

$N_{ea1} = 1{,}02\ N_{e0}$; $N_{ea2} = 1{,}133\ N_{e0}$.

The calculations according to the 1st empirical method allow running gas turbine units, and according to the 2nd analytical N_{ea2} exceeds N_{e0} by more than 10%. If we take the results of the 1st method, then (GTU) will operate overloaded as the result is incorrect and in fact overload will not be 2% but 13.3% relative to N_{e0} according to the analytical method of calculation by Professor N. I. Belokon. Therefore, the conditions faced with the task to reduce the overload of up to 10%. For this purpose, it will be necessary to develop a method for reducing the air temperature T_a at the (GTU) inlet [9].

4. Conclusions

The article describes the validity of choice for assessment of the volume of production in the oil and gas industry as well as the energy sector that use gas turbine units. As a production volume indicator in enterprises with gas turbine units given is the specific energy consumption at compressor stations of gas pipelines for the transport of a given volume of gas transported in the gas pipeline system, allowing an objective evaluation of the efficient use of energy consumed.

Taking into account the influence of temperature of the ambient air on the available effective power of the drive, considered are various ways to determine this power when the temperature of outside air is changed in the range of 258°K to 333°K. In this context, the method of determining the available effective power of the gas turbine drive based on the equation proposed by Professor N. I. Belokon is proposed as the most suitable one.

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