



Energy Delivery at Oil and Gas Wells Construction in Regions with Harsh Climate

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A B S T R A C T

Energy delivery at well construction in regions with hard climate is distinguished by variable demand in electric and heat power. Energy consumption of drilling equipment, production and living facilities varies greatly during the year, depending on power load charts and climate conditions. Power supply of remote well construction sites is mostly accomplished by operating autonomous power sources, such as gas turbine units. In this regard efficiency enhancement of power units is seen as relevant task. Thus combined heat and power structure for efficient power supply of well construction operations is offered by the authors. Required amount of electric and heat energy at well drilling in harsh climate is calculated in the paper. Also scheme of energy delivering structure based on gas turbine units with flue gases heat utilization for rig objects heating is developed in the article.

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NOMENCLATURE

APG	Associated petroleum gas	c	Air heat capacity at ambient air temperature, (J/(m ² ·K))
GT	Gas turbine	ρ	Air density at ambient air temperature (kg/m ³)
GRE	Gas reciprocating engine	ω	Velocity of air, penetrating through technological apertures (m/s)
MT	Microturbine	S	Square of technological apertures cross-section (m ²)
P_r	Rated power output (W)	$t_{in},$ t_{out}	Temperature of air in the rig and ambient air (K)
K_{tu}	Coefficient of technical usage	Q_{mc}	Heat losses of drilling mud chamber (W)
K_1	Coefficient of unit load	λ	Coefficient of chamber material heat transfer (w/(m·K))
K_{fg}	Coefficient, considering heat power losses with flue gases	t_r	Temperature of heat carrier inside the chamber (K)
Q_{cog}	Cogeneration heat power output (W)	t_o	Temperature of ambient air in the drilling mud chamber structure (K)
k	Coefficient of produced heat power on 1 kW of generated electrical power, for GT $k = 2$, for GRE $k = 1, 5$	d	Thickness of I chamber wall (M)
n	Number of operating power units	Subscripts	
COP	Coefficient of performance	r	Rated
Q_{ic}	Heat losses with heat transition of isolation constructions (W)	tu	Technical usage
k_i	Coefficient of isolation structure heat transfer, W/(m ² ·K)	l	Load
F_i	Square of separate isolation structures, (m ²)	fg	Flue gases
t_{in}	Temperature inside the rig (K)	cog	Cogeneration
t_{out}	Temperature of ambient air (K)	ic	Isolation constructions
n_i	Adjustment coefficient to calculated temperature difference	i	Number of corresponding value
Q_{inf}	Heat losses with cold air infiltration (W)	in	Inside
l_i	Length of opening, (m)	out	Outside
a	Coefficient, which considers time of operation with opened technological apertures during the working shift		
m	Amount of air, penetrating through 1 m of opening length (kg/s)		

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1. INTRODUCTION

Power supply of well drilling on oil and gas fields at ambient air low temperatures is characterized by increased requirements of electric and heat energy. Power costs for heating of production facilities, technological and living objects may several times exceed drilling equipment electric power consumption. While exploiting fields located in extreme north regions, heating should be done all year round, and in winter period on larger scale with higher intensity. But in recent time cases of power supply interruption in unified energy grid have become more frequent; electric power rates have grown, power lines construction costs have increased and power quality has declined [1]. In the meantime, satisfaction of production demands by unified power grid application in most places is not economically efficient due to substantial remoteness of constructed objects from existing power lines. Power supply of prospecting and exploitation drilling objects is usually done by means of local electric power structures based on diesel power stations. Heating is provided by electric power heaters and individual stoves, which raise the cost of generated power. Worth mentioning that question of drilling rig heating has not been paid much attention. While topic of electric power generation is quite developed, problem of heat production is usually not considered, which makes this issue actual.

At the same time, exploitation of oil fields is accompanied by vast quantities of extracted associated petroleum gas (APG), and while developing gas fields there are considerable amounts of natural gas and gas condensate. Worth noting that APG is valuable resource in both petrochemical and energy industry, but in many cases it is just flared away. With increasing costs in many countries for excessive APG flaring, oil enterprises are starting to be more rational regards to gas utilization. Therefore at cluster well drilling for purposes of electrical and heat supply, it is reasonable to use gas-driven power units, fueled by APG extracted from already exploited wells [2].

2. STATEMENT OF THE PROBLEM

Research made on the basis of geological survey in regions, situated beyond the Polar circle, which are characterized by extreme conditions of temperature and wind, showed fuel expenditure for heating of rig house and drilling mud tank is equivalent to 50-60 kW of heat power. This is mostly equal to electrical power which is needed to drive drilling equipment [3]. At the same time electrical power expenses at oil and gas exploitation

drilling are ten times higher than those at exploration works. Also due to large number of producing and living structures, required amount of heat power may several times exceed electrical power needs. With increasing requirements in electrical and heat energy at oil and gas field objects power supply, application of gas-powered units instead of diesel power stations, which are characterized by considerable consumption of expensive diesel fuel, is seen as more efficient.

3. METHODOLOGY

Research made on the basis of several oil enterprises revealed that the most efficient way of power units operation is cogeneration mode- combined heat and power production (see Figure 1) [4].

Figure 1 illustrates the basic principles of energy conversion process in gas-powered units. Energy of the gas fuel (which is taken as 100%) is converted into heat and electricity through the turbine. Average efficiency of conversion process is about 60% for heat generation and about 30% for electricity production, 10% are the heat losses in gas unit junctions and low potential heat of the remaining flue gases.

For APG utilization as an energy carrier it is possible to implement gas turbines (GT) or gas reciprocating engines (GRE). Whereas in choosing the kind of required equipment, it is necessary to take into account complex parameters of power structure operation, such as rated power output of single unit (P_r), coefficient of technical usage (K_{tu}), coefficient of unit load (K_l) and coefficient, considering heat power losses with flue gases (K_{fg}). Rated power output is specified by device certificate. Coefficient of technical usage is defined by relation of unit operation time to operation time plus repair and idle periods. Coefficient of unit load shows actual level of generated power (according to rated power). Coefficient, which considers heat power losses with flue gases, changes when heat exchanger configuration is adjusted.

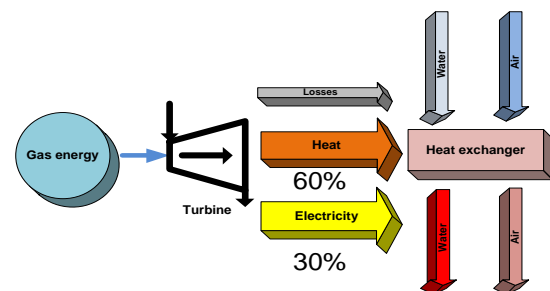


Figure 1. Cogeneration mode

Research, made on the basis of several oil enterprises, revealed that GT generates more heat than GRE while producing electricity, thus their application is seen as more rational [5]. Cogeneration heat power output can be calculated as follows:

$$Q_{cog} = k \cdot n \cdot P_r \cdot K_{tu} \cdot K_l \cdot K_{fg} \quad (1)$$

Among other advantages of GT in given conditions also may be noted: wide spectra of working modes, high unit capacity and ecological compatibility. One of the latest GT design are microturbines (MT). Their coefficient of performance (COP) at generating electrical power reaches 35%, which can be compared with those of diesel power plants and GRE [6]. This COP is achieved through very high speed MT shaft rotation - about 96000 rpm. More details on these machines and their implementation in the power supplying structure is presented elsewhere [7].

In conditions of ambient air low temperatures and high velocity wind, sufficient heat supplying is required for both technological process, specifically for drilling mud heating, and for maintaining comfortable working conditions at the rig. One of the main heat regime parameters are the heat losses. Drilling rig construction directly influences on heat quantity, which is dissipated into the atmosphere. At exploitation drilling rigs of precast or framed structure with height of 53-54 meters are used. One of the distinctive features of conducting operations in extreme northern conditions is drilling rig coating along the perimeter with layer of tarpaulin or tarpaper. Nevertheless, there are technological apertures in the rig structure with overall square about 2 m². Rig basement is built as a square of 10x10 m; at forward and back sides of the rig there are gates with height around 10.5-12 m. Due to structural peculiarities of the rig, most of the heat losses occur at cold air infiltration through the technological apertures and hatch ways and heat transition of isolation constructions. Heat losses with heat transition of isolation constructions may be defined as [3, 7]:

$$Q_{ic} = \sum_{i=1}^n (k_i F_i) (t_{in} - t_{out}) \cdot n_i \quad (2)$$

Heat losses with cold air infiltration are calculated as follows:

$$Q_{inf} = \sum_{i=1}^n l_i \cdot a \cdot m \cdot c (t_{in} - t_{out}) + \omega \cdot S \cdot \rho \cdot c (t_{in} - t_{out}), \quad (3)$$

In Equation (3) coefficient a considers time of operation with opened technological apertures during the working shift. If apertures are opened for no more than 15 min at one shift, heat losses are defined as infiltration through the openings with coefficient $a = 3$ [8].

Significant amount of heat is also required for drilling mud working temperature sustaining. Violation

of circulation thermal regime may lead to ice build-up on well surfaces and ice blockages in armature elements. That is why it is important to ensure heating of the drilling mud chamber according to ambient air temperature. Needed heat power will be defined by heat losses of the chamber. Stationary model is considered for discussed system calculations. Specifically, the temperature of the whole drilling mud mass inside the chamber is considered permanent. Thus heat losses of drilling mud chamber may be calculated through the following equation:

$$Q_{mc} = \sum_{i=1}^n \frac{\lambda (t_r - t_o)}{d_i} \quad (4)$$

where

λ – coefficient of chamber material heat transfer, W/(m·K);

t_r – temperature of heat carrier inside the chamber, K;

t_o – temperature of ambient air in the drilling mud chamber structure, K;

d – thickness of i chamber wall, m.

4. RESULT AND DISCUSSION

Noting heat power required for drilling structure functioning, it is possible to create combined heat and power complex based on MT for satisfying consumer power needs and at the same time lowering power generation costs. As a result, combined power supplying scheme for multiple well drilling utilizing heat of MT flue gases was developed (see Figure 2) [10-12].

Scheme is functioning in the following way. MT I generates electrical energy to supply drilling equipment. Flue gases of the gas turbine 1, that have high temperature, are going to heat exchanger 2 and transfer part of their high-temperature potential to the air, circulating in the air heating system 4 by means of fan 3. Heated air is directed to the drilling rig structure II and raises the temperature of air in the working area through the convectors. Flue gases coming out of the heat exchanger still have substantial temperature potential; they are going to coiled pipe 5, situated in drilling mid chamber III, heating the drilling mud.

Possible heat losses can be viewed on example of drilling rig VB-53-320, consisting of nine sections, with upper base size of 2x2 m and lower base size of 10x10 m. Working area coating is done by isolation panels on height of 8 m from the floor of the lower base. To calculate possible heat losses following parameters are assumed: ambient air temperature is -20°C, at that temperature of working area in cold climate should not be less than +10°C, velocity of cold air penetrating isolation structures is 2 m/s, overall square of technological apertures is 2 m². Whereas defining heat losses of mud chamber by volume of 50 m³ (used for

wells with depth of 2000 m) made from carbon steel is considered (coefficient of heat transfer is $50 \text{ W}/(\text{m}\cdot\text{K})$) with wall thickness 7 mm and temperature of ambient air in the drilling mud chamber structure is taken as 0°C . Heat losses through the isolation constructions (working area coating) are 30 kW, defined by (2), heat losses with cold air infiltration are 1105 kW, calculated by (3), analyzing Equation (4), mud chamber losses through the walls and bottom are 7 kW without taking into account possible heat losses through the open upper chamber part. This way, sum of heat losses for drilling rig and drilling mud chamber is 1142 kW. In the meantime it is necessary to heat unit of mud preparation and cleaning, various production and living quarters. In this regard, needed amount of heat energy may increase 1.5-2 times [3].

At well drilling from 1500 to 3500 m needed electric power varies between 800-2000 kW. For example, while drilling upper intervals of the well with projected depth of 2500 m, 1600-1800 kW is required, as drilling is joined by operation of two mud pumps (power consumption of each is 600 kW) providing high rate of drill mud, removing the sludge from the borehole bottom. After the casing column is lowered into the borehole, drilling is conducted with the help of only one pump thus reducing the need in power in half. In the drilling process sustaining of optimal load onto the bore bit is done through feed control regulator, which consumes 50-90 kW. It is also necessary to note power needed for drilling fluid purification system, what

usually is about 250 kW. Whereas performing round-trip operations, most of the power is required for the work of drilling gun with consumption of 700 kW.

It can be seen that electrical power output needed to drill upper intervals of the borehole is 1450 kW, to manage casing column operations on the later stages of well construction is 850 kW. Electrical power required for drilling equipment at different depths of well construction is shown in Table 1.

Comparative analysis of power units, which may be used for power supply at well drilling is presented in Table 2. At combined power supply of well drilling operations, GT and MT are most efficient types of power units, capable of stable and reliable functioning using APG as fuel. Moreover, implementation of MT with rated power of 1000 kW allows generation of 2000 kW heat energy, which is enough to cover power requirements at cluster well drilling with depth to 2000 m.

TABLE 1. Drilling equipment electrical power drive

Drilling depth, m	to 2000	to 5000	more than 5000
Drilling rig class	3	7	9
Power drive, kW	to 1000	to 2200	to 3400

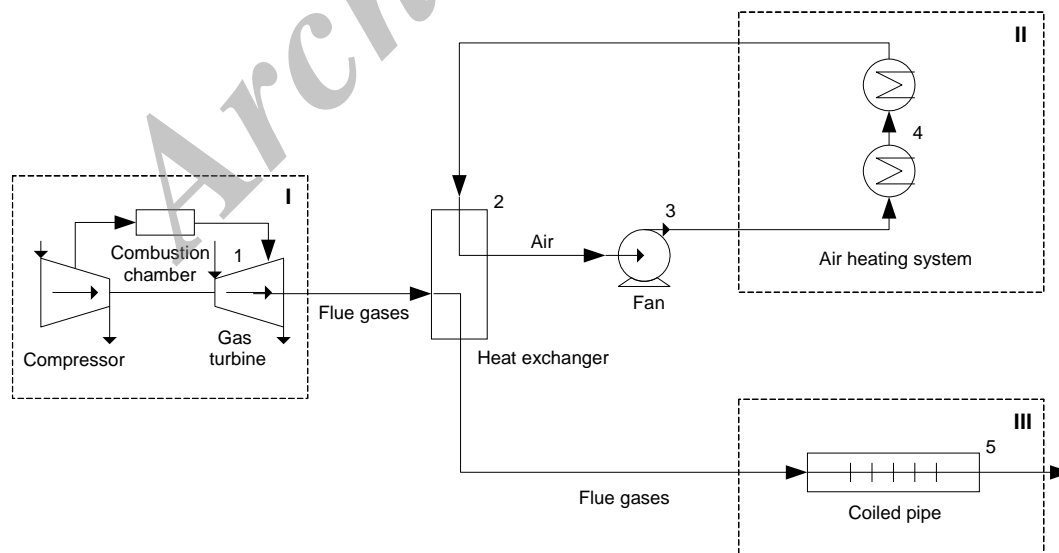


Figure 2. Basic scheme of drilling rig objects power supply

TABLE 2. Power plants for well construction

Parameters	Diesel Cummins C1400D5	GRE FG Wilson PG1250B	MT Capstone 1000
Electrical power output, kW	1000	1000	1000
Heat power output, kW		1363	2000
Electrical COP, %	40,9	38	33
Fuel consumption, l/h (diesel fuel), m ³ /h (gas)	196 (diesel fuel) (75 % load)	276 (gas)	325 (gas)

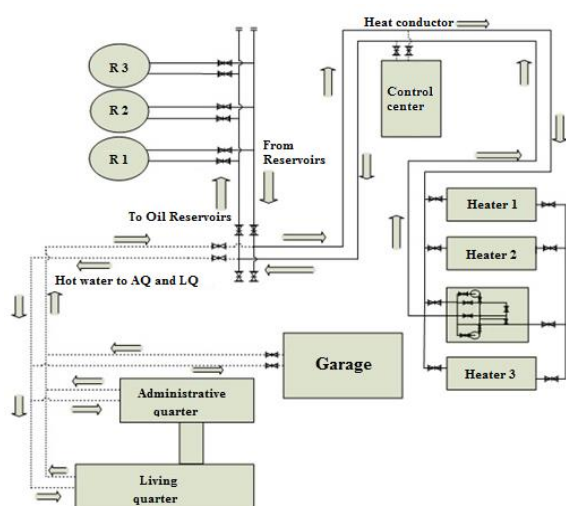


Figure 3. Structural scheme of oilfield objects heating

5. CONCLUSIVE RESULTS

Elements of the investigated power supply system were used to develop heating complex (see Figure 3), utilizing associated petroleum gas to warm objects of the actual oilfield, located beyond the Polar circle. This system works as follows: APG is used as a fuel for heaters, which heats water circulating in the heating circuit. Hot water flows through the control center where technicians and operators are located, oil reservoirs (R1, R2 and R3) with crude oil and also through the administrative and living quarters where personnel works and lives, and then goes back to the heaters to be heated again what forms so-called closed loop. Detailed description of the system is presented in the literature [13]. Further research is aimed at experiments on drilling rigs located in harsh environmental conditions. It can be concluded that introduction of such autonomous combined heat and power units is justified in remote regions with no access to unified power grid where heat energy is required.

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تامین انرژی مورد نیاز ساخت چاه در مناطقی با آب و هوای ناملاّیم با نیاز به نیروی الکتریکی و گرمایی متمایز می شود. مصرف انرژی در وسایل حفاری، تولید و در امکانات زندگی در طول سال با توجه به شدت تامین نیرو و شرایط آب و هوایی به شدت تغییر می کند. نیرو در مناطق دور دست ساخت چاه معمولاً به وسیله منابع مستقل تامین انرژی نظیر توربین های گازی تامین می گردد. در نتیجه افزایش بازدهی واحد های تولید انرژی ضروری می نماید. بدین منظور ساختار ترکیبی گرما و نیرو در جهت تامین بهینه نیروی مورد نیاز عملیات ساخت چاه به وسیله نویسندگان پیشنهاد می گردد. در این مقاله مقدار انرژی گرمایی و الکتریکی مورد نیاز در عملیات حفاری چاه در مناطق با آب و هوای ناملاّیم محاسبه شده است. همچنین مدل ساختار تامین انرژی بر اساس عملکرد توربین های گازی جهت تامین گرمای ساختارهای دکل توسعه یافته است.

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