Eng. Sci., 2023, **23**, 881

Engineered Science

DOI: https://dx.doi.org/10.30919/es8d881

Human Optimization of Drill Winch Brake Cooling System for Improved Working Process Parameter

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Abstract

The research aims to provide scientific reasons for the improvement of drilling process effectiveness by employing technical factors of working element lifespan improvement and parameter optimization, the braking system of drill winch, and decrease of production and non-production time. The article describes the results of experimental research on the determination of dimensionless parameters regarding constructive-geometric parameters of drilling winch brakes. By employing a full factorial experiment using the technique of central compositional orthogonal planning, regression equations were obtained, that characterize the mathematical model of the heat transfer process in the drill winch brake system, including additional cooling. Through the employment of computer experiments on the built mathematic-statistic regression model, the main optimal values for dimensionless parameters k_R, k_r, and ξ, according to the extreme values of the λR optimization criteria. Optimal values of $kR=9.6$; $kr=0.75$; $\xi=14.2$ factors are similar to the constructive-geometric parameters of drill winch brakes.

Keywords: Brake drum; Heatsink; Heat Conduction; Dynamic system; Drilling.
Received: 22 March 2023; Revised: 12 April 2023; Accepted: 05 May 2023.
Article type: Research article.

1. Introduction

Improvement of drilling process effectiveness is mainly related to the further modernization of machinery and drilling technology. Increased efficiency and a trend toward automation of the drilling process require the development of a mathematical model of the system as a whole. Moreover, with the same performance characteristics, different drilling rates can lead to different outcomes. In terms of efficiency, the resulting outcome assumes variable and fixed variables, while operational parameters can be easily adjusted. For example, in the work of V.S. Tikhonov *et al.*,[1] the authors proposed a model and method for dynamic analysis of a drilling system, where the mathematical model considers wave processes in a fluid, deformation of the cross-sectional area of a string, etc.

P. D. Cipek *et al.*[2], in their work, have developed an automatic drilling control system, the reliability of which was verified through simulation analysis. As such, it is necessary to develop a simple engine control system. The efficiency of the drilling process is evaluated by several factors, among which, in addition to geological and technological, technical ones also play an important role. For example, in the work of P.G. Talalay *et al.*,[3] the authors proposed a system of ice drilling with a cold circulation near the bottom of reservoirs, the results of which demonstrate that this technique can be used to avoid the influence of accumulation of various kinds of impurities.

Several parameters are used to evaluate drilling results, which include both the production time and non-production time. Picked and employed machinery demonstrates substantial influence on the balance of well drilling time, which reduced non-production time (time, spent on waiting, repairs, liquidation of malfunctions and complications) as well as time, spent on a complex of up and down operations.[4] During the deep well directional drillings, frequent accidents significantly increase the time to eliminate the accident, its complexity, and the cost of construction. Moreover, the drilling parameters, obtained from various projects, are affected by most of the factors that can lead to instability, and therefore it is a laborious process to find an obvious pattern.[5] As such, the effectiveness of drilling should be high to avoid complicated accidents, which may occur during the well production.

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During well production, there is a high risk of mechanical damage due to vibrations. The time of up and down operations, bit replacement, repairs, troubleshooting, and downtime due to organizational and technical reasons, in turn, is also affected by the performance and reliability of the drill primary brake, or rather, the operation of the band-shoe drill winch brake. Suffice it to note, that winch does not protect the drum from entanglement, while hydraulic elements are usually located outside of the operator's reach. L. Jiarong and R. Lingjie,[6] in their work, analyze various kinds of difficulties in deep drilling and the existing problems of deep-sea drilling rigs. In the work of T. Wilke *et al*.,[7] the authors provided a detailed overview of the potential disadvantages and advantages of new methodologies and analysis of deep drilling projects.

In turn, S. Li et al.[8] considers the influence of a magnetic field on the process of homogeneous dissipation. They found that an improvement in the suction variable leads to augments induced magnetic field. Reverse impact for velocity and thermal fields is observed with magnetic variables. Z. Liu *et al*.[9] was engaged in the calculation of Numerical bio-convective assessment using the Maxwell Fluid Model as a basis. On the other side, S. Li *et al*.[10] in their work studied the influence of a chemical reaction and activation energy on hydrodynamics and its thermal properties. As a result of the study, the authors came to the conclusion that the speed and temperature of the liquid increase as the plates approach each other.

Also, it is important to highlight the recent study by S. Li *et al*.[11] about the flow of a triple nanofluid behind a stretching sheet under Thomson and Trojan slip conditions, along with a temperature jump. In the context of the Drill Winch Brake Cooling System optimization process, it must be remembered that each machine can only process jobs that do not exceed its capacity. To optimize this process, X. Xin, M. Ijaz Khan and S. Li[12] explored ways to minimize the execution time of tasks or batches of tasks.

Most of the drilling rigs, designed for deep drilling, are equipped with a manual winch mechanical brake system, which is used to manually control the speed of descent of the drill string, thereby putting weight on the stone-cutting tool during the drilling operation.[13] Due to the inaccurate manual control of the brakes, the drilling performance and operational safety of such drilling rigs are less competitive compared to today's drilling systems. To improve the performance of older drilling rigs, which can also lead to longer operating life, these rigs need to be upgraded with more innovative winch control systems.

The fluid used in a cooling system plays a critical role in managing heat transfer and maintaining system performance. In the case of a drill winch brake cooling system, the fluid used would need to have good thermal conductivity to efficiently transfer heat away from the brake system.[14] Common fluids used in cooling systems include water, ethylene glycol, and propylene glycol, among others. Water is a widely used coolant due to its high thermal conductivity and low cost.

Ethylene and propylene glycol are also popular coolants due to their excellent heat transfer properties and ability to prevent freezing at low temperatures. In terms of physical applications, the choice of fluid used in a drill winch brake cooling system would depend on the specific requirements of the system, including operating temperature range, environmental factors, and fluid compatibility with system components. The use of an appropriate fluid can help to optimize the heat transfer process, ensure efficient system operation, and extend the lifespan of system components.[15]

The novelty of the study based on the provided information is that it employs a full-factor experiment using the method of central orthogonal compositional planning to optimize the system's heat transfer process in a dynamic system. The study compiles a matrix following highlighted factors to ensure a complete factorial experiment, conducts an experiment to acquire a regression equation, and builds a mathematical model of the second order after processing the experimental data.

The research aims to provide scientific reasons for the improvement of drilling process effectiveness by employing technical factors of working element lifespan improvement and parameter optimization, the braking system of drill winch, and decrease of production and non-production time. The hypothesis assumes that it is possible to identify dimensionless parameters related to the constructive-geometric parameters of drilling winch brakes and that these parameters can be used to characterize the mathematical model of the heat transfer process in the drill winch brake system, including additional cooling.

2. Materials and methods

This chapter presents the source materials and the methodology used in deriving a system focused on the control of a dynamic model of a drive for drilling traction. As such, a deep drilling device model is presented in the research. For this, at the first stage, a mathematical model was built, which considered the advantages, required for the successful solution of the main problem during the selection of the main factors that have the most influence on the process of heat removal from the zone of biggest heating of the brake drum. This implies, that the method was tested through the simulation in the field on a drilling machine. As a result, simulation analysis and calculations were carried out with the values of the parameters of the process model.

Overall, the winch itself is a powerful structure, where the hydraulic motor control parts are located on the bulkhead directly in front of the winch. The main threat to safety systems comes from two issues – when the winch does not protect the entanglement of the drum and it is out of reach. Also, during the study, attention was paid to the importance of the valve, which controls the rotation of the winch, while shutting off the flow of hydraulic oil to the winch motor. Several factors, simultaneously and in conjunction with each other, influenced the heat removal process. Therefore, to obtain the result of the experiment, which describes the real physical meaning of the ongoing process of cooling the brake system, the selected factors were considered in complete interconnection.

At the next stage of the research, to determine the optimal design-mode parameters of the device based on the methodology given in,[16-22] a complete factorial experiment was carried out using the method of central compositional orthogonal planning. Analysis of the drilling strategy is a necessary condition for achieving effective results. In some cases, it may be necessary to adapt the drilling strategy to effectively address specific scientific issues or deviant lithological intervals. As such, it was accounted for, that several criteria may influence the drilling strategy.

Detailed characterization, including case-specific information and the collection of site-specific information such as seismic sediment structure data and lithological characteristics from pilot surveys. This analysis can be used to create a drilling strategy, which later may be evaluated following the scientific needs. During the research, an analysis of geological formation depth was concluded by lowering instruments into the well. The logistical effort, related to the transportation and installation of logging equipment at a well site, can be high, especially when the equipment must be transported to a floating drilling barge. The final decisions on wells, which need to be made in time or at the end of the drilling process, can change rapidly and depend on the overall progress of the drilling operation.

Optimization of a drill winch brake cooling system requires a combination of materials and tools. Here are some common materials and tools used in the process:

- heat transfer fluids: These fluids are used to transfer heat from the brake system to the cooling system.
- heat exchangers: Heat exchangers are used to transfer heat from one fluid to another.
- pumps: Pumps are used to circulate the heat transfer fluid through the heat exchanger and brake system.
- temperature sensors: Temperature sensors are used to monitor the temperature of the brake system and cooling system.
- computational fluid dynamics (CFD) software: CFD software is used to simulate the flow of fluids through the cooling system and brake system.
- finite element analysis (FEA) software: FEA software is used to simulate the stress and deformation of the brake system and cooling system components.
- machining tools are used to fabricate and assemble the brake system and cooling system components. These tools include lathes, milling machines, drill presses, and welding equipment.

The full factorial experiment included linear, quadratic, and synergistic dependencies of the factors as a function of the optimization criterion. During the computer experiment setup and studies of the analog model, the method of orthogonal compositional planning of experiments was used, where several factors were previously selected. They, according to a priori information, influence the thermal conductivity coefficient of the working surface of the pulley of the drill winch belt brake λ_R the most.

3. Results

3.1. Calculation of the thermal conductivity coefficient, the cross section of the main and auxiliary pulleys k_R, the angle between the heat-conducting ribs of the auxiliary pulley ξ

At the first stage, it became apparent, that the thermal conductivity coefficient largely depends on the ratio of the cross-sectional thickness of the main and auxiliary pulleys k_R, the angle between the heat-conducting ribs of the auxiliary pulley ξ, the ratio of the reduced thickness of the ribs to the size of the heat-removing surface of the auxiliary pulley (Fig. 1).

Following Fig. 1, coefficient k_R is calculated from the formula (1):

$$k_R = (R_H - R_B)/(R_B - r'_b), \tag{1}$$

this, from the physical standpoint, determines the process of heat transmission between the primary and secondary pulleys.[1] Coefficient k_r is calculated by the formula (2):

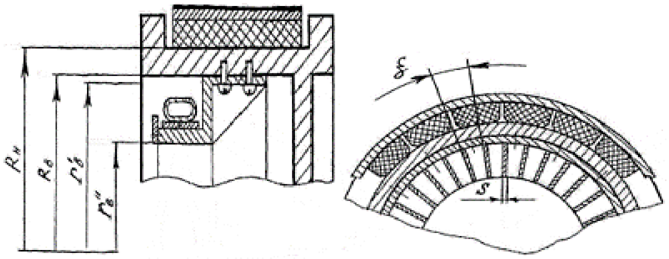
$$k_r = Sn/(r'_B - r''_B), \tag{2}$$

where: n – is the number of heatsink ribs.[1]

The goal of the factorial analysis of the experimental research results is to acquire a mathematical model of the formula (3).[1]

$$\lambda_R = f(x_1; x_2; x_3) \rightarrow max. \tag{3}$$

However, this type of formula is relevant for the boundaries 40 W/(m K)≤λ_R≤80 W/(m K). Exceeding the set boundaries of the λ_R does not have a positive influence. Moreover, it makes the system functionless and useless.



a) b)

Fig. 1 a) To the determination of factors and dimensions of the secondary heatsink; b) to the determination of the distance between heatsink ribs.

Table 1. Factors and level of their variation.

Level of variation	Factors			Names and their average values of optimization criteria
	X_1	X_2	X_3	$\bar{Y}$
	Relation of the cross-sectional thickness of the main and auxiliary pulleys, k_R	The angle between heatsink ribs, ξ	The ratio of the set thickness of the ribs to the size of the heat-removing round surface of the auxiliary pulley, k_r	Coefficient of thermal conductivity of the working surface of the drill winch belt brake pulley, λ_R, Vt/(м*K)
Upper +	24	15	2.5	
Main 0	16	10	1.5	-
Lower –	8	5	0.5	
Variation interval	8	5.0	1.0	-

It can be seen from formula (3) that to achieve the goal, it is necessary to find such values of the factors x_1, x_2, and x_3, at which the maximum thermal conductivity of the most heated sectional surface, i.e., the rim of the drill winch brake pulley, would be ensured. To construct a mathematical model of a heat-removing component as a function of the optimization criterion of significant parameters, an orthogonal experiment planning matrix was constructed. A mathematical model of the second order was made after the process of the experimental formula (4):

$$y = a_0 + \sum_{i=1}^{n} a_i\, x_i + \sum_{i=1}^{n} a_{ii}\, x_i^2 + \sum_{i=1}^{n} a_{ij} x_i\, x_j, \qquad (4)$$

where: y – optimization criteria; x_i, x_j – independent variable factors; a_0, a_i, a_{ii}, a_{ij} – theoretical coefficients of regression.[6]

To study the response surface of the target function, regression coefficients were determined, and calculated by the formulas (5-10):

$$a_0 = a_0' - \frac{1}{N_0}\sum_{i=1}^{N_0} a_{ii} \sum_{i=1}^{N_0} x_{in}^2, \qquad (5)$$

$$a_0' = \frac{1}{N_0}\sum_{n=1}^{N_0} \bar{y}_n; \qquad (6)$$

$$a_0\, a_i = \frac{\sum_{n=1}^{N_0} X_{in}\bar{y}_n}{\sum_{n=1}^{N_0} (X_{in})^2}, (i \neq 0), \qquad (7)$$

$$a_{ij} = \frac{\sum_{n=1}^{N_o} X_{in}X_{jn}\bar{y}_n}{\sum_{n=1}^{N_o} \left(X_{in}'\right)^2}, \qquad (8)$$

$$a_{ii} = \frac{\sum_{n=1}^{N_0} X_{in}'\bar{y}_{in}}{\sum_{n=1}^{N_0} \left(X_{in}'\right)^2}, \qquad (9)$$

$$X_{in}' = X_{in}^2 - \frac{1}{N_0}\sum_{n=1}^{N_0} X_{in}^2, \qquad (10)$$

where: n – case number; i – factor number.[6-10]

Parallel case dispersion was determined by a formula (11):

$$S = Y_i - \bar{Y}/m - 1, \qquad (11)$$

where: $\bar{y}$– an average value of criteria optimization in parallel cases; m – repetition number.[9]

Dispersion consistency was evaluated by the formula (12):

$$K_p = \frac{S_{max}^2}{\sum_{i=1}^{N} S_i^2}, \qquad (12)$$

where: K_p – calculated Cochran criteria value Cochran; S_{max}^2 – max depression of parallel cases; $\sum_{i=1}^{N} S_i^2$ – a sum of depression of parallel cases.[16]

A critical value of Cochran criteria was determined per.[17;18] Under this, the number of degrees of latitude was determined from the formula (13):

$$\xi_1 = m - 1,\ \xi_2 = N - 1, \qquad (13)$$

where: N – number of cases.

The dispersion was considered uniform if $K_p < K_{table}$. Reproducibility dispersion was determined by formula (14):

$$S(y) = \sum_{i=1}^{N_0} S_i^2\, / N. \qquad (14)$$

The number of degrees of latitude dispersion of reproducibility was calculated following the formula (15):

$$Z_{\bar{y}} = (m-1)N. \qquad (15)$$

Adequacy dispersion was calculated by formula (16):

$$S_{ад}^2 = m\sum_{i=1}^{N_0}\left(\bar{y}_i - \bar{y}_i\right)/(N - \chi), \qquad (16)$$

where: χ – number of substantial equation coefficients; $\tilde{y}$ – Y theoretical value, calculated by the formula (4).[17]

3.2 Calculation of mathematical model

Mathematical model adequacy was determined by the Fisher-Snedecor criteria, calculated by the formula (17):

$$F_p = S_{ад}^2 / S^2(y), \qquad (17)$$

Table 2. Levels of variation and intervals of highlighted factors.

Factors	Explanation	Levels					Intervals
		-1.215	-1	0	1	1.215	
Relation of the cross-sectional thickness of the main and auxiliary pulleys, k_R	X_1	2.84	8	16	24	29.16	8
The angle between heatsink ribs, ξ	X_2	1.77	5	10	15	18.23	5.0
The ratio of the set thickness of the ribs to the size of the heat-removing round surface of the auxiliary pulley, k_r	X_3	-0.04	0.5	1.5	2.5	3.04	1.0
		-β				β	

with the following boundaries $F_p < F_{table}$.[18] The fulfillment of condition $F_p < F_{table}$ was a satisfying fact of the adequacy of the developed model to the real process. The previously identified so-called dominant factors varied at five levels during the experiments. Intervals and levels of variation are presented in Table 2.

To ensure a complete factorial experiment, a matrix was compiled following the highlighted factors. An experiment was conducted to acquire a regression equation. The planning matrix and results of experimental data of the heat transfer coefficient are presented in Table 3.

Matrix, compiled in Table 3, provides a full factorial experiment with several cases, equal to 15, calculated under the formula (18):

$$N_0 = 2^n + 2n + 1, \tag{18}$$

where N_0 – number of cases; n – number of factors.[7]

Table 3 shows the values of the thermal conductivity coefficient in percent y_i and their average values $\bar{y}_i$ for the repetition of experiments i=3. During the experiments, the remaining factors, which were not included in the planning matrix, were fixed at optimal levels. Under the average experimental values of the degree $\bar{y}$, the regression coefficients were determined. Substituting the latter into (4), the regression equation was acquired formula (19):

$$y = 51.45 + 5.98X_1 - 1.805X_2 + 0.615X_3 - 5.625X_1X_2 - 10.875X_1X_3 + 2.95X_2X_3 - 10.445\,X_1^2 - 14.592X_2^2 - 2.711X_3^2 \tag{19}$$

The correspondence of the obtained regression equation to the real physical process was determined by evaluating the adequacy dispersion under the Fisher-Snedecor criterion. The results of calculating the adequacy variance made it possible to determine the calculated values of the Fisher criterion for

Table 3. Planning matrix and results of experimental data of the heat transfer coefficient.

No. of cases	X_0	X_1	X_2	X_3	X_{12}	X_{13}	X_{23}	$X_1^2 - \alpha$	$X_2^2 - \alpha$	$X_3^2 - \alpha$	Heat transfer coefficient λ_R			
											Y_1	Y_2	Y_3	$\bar{Y}$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	+	0	0	0	0	0	0	-0.73	-0.73	-0.73	78	76	76	76.6
1	+	-	-	+	+	-	-	0.27	0.27	0.27	38	47	36	40.3
2	+	-	+	-	-	+	-	0.27	0.27	0.27	22	25	31	26.0
3	+	-	+	+	-	-	+	0.27	0.27	0.27	50	58	59	55.6
4	+	+	-	-	-	-	+	0.27	0.27	0.27	69	65	67	67.0
5	+	+	-	+	-	+	-	0.27	0.27	0.27	45	41	38	41.3
6	+	+	+	-	+	-	-	0.27	0.27	0.27	47	48	49	48.0
7	+	+	+	+	+	+	+	0.27	0.27	0.27	37	32	35	34.6
8	+	-	-	-	+	+	+	0.27	0.27	0.27	20	22	21	22.0
9	+	β	0	0	0	0	0	0.745	-0.73	-0.73	62	59	61	60.6
10	+	-β	0	0	0	0	0	0.745	-0.73	-0.73	4	70	62	45.3
11	+	0	β	0	0	0	0	-0.73	0.745	-0.73	45	44	47	48.6
12	+	0	-β	0	0	0	0	-0.73	0.745	-0.73	58	60	61	59.6
13	+	0	0	β	0	0	0	-0.73	-0.73	0.745	70	73	74	72.3
14	+	0	0	-β	0	0	0	-0.73	-0.73	0.745	71	74	77	74.0
The square sum of the column	15	10.95	10.95	10.95	8	8	8	4.73	4.73	4.73				
Regression coef.	51.98	5.98	-1.80	0.615	-5.62	10.875	2.95	-10.445	-14.592	-2.711	in(Y)			

Note: α = 0.73; β = 1.215.

the regression equations: F_{po}=1.92 и $F_{p\text{э}}$=2.17.

The comparison of the latter with the table values F – a criterion on the 5% level of substantiality, has shown the equation adequacy. Table values F – criteria acquired for values of latitude degree values of the numerator f_1=2 and f_2=14.[6] To determine optimal values of factors in conditional coordinates, separate derivatives of the function of the formulas (20-22) are determined 1.14:

$$dY/dX_1 = -20.89X_1 - 5.625X_2 - 10.875X_3 + 5.98 = 0, \quad (20)$$

$$dY/dX_2 = -5.625X_1 - 29.184X_2 + 2.95X_3 - 1.805 = 0, \quad (21)$$

$$dY/dX_3 = -10.875X_1 + 2.95X_2 - 5.422X_3 + 0.615 = 0. \quad (22)$$

Values of independent optimization factors were deducted by solving formula (21) on the formula (23):

$$X_1 = 0.06, X_2 = 0.32, X_3 = 2.38. \quad (23)$$

3.3 Computing the coordinates of the objective function response surface

The deducted conditional coordinates of the response surface of the target function characterize the shift of the physical values of the factors from the zero level of variation. These coordinates also determine the location of critical points in two-dimensional sections of the response surface of the model. Two-dimensional sections of the objective function are of great interest as, by processing them, it is possible to acquire any required dependence of the heat transfer coefficient from the primary design-operative parameters. An objective function is more acceptable for practical calculations and evaluation of indicators, which shows a mathematical model of the heat conduction process with decoded physical variables than in conditional coordinates. Translation of conditional coordinates, per Table 2, is done by the following formula (24)[16;17]

$$X_1 = (k_R - 16)/8; X_2 = (\xi - 10)/5;\ X_3 = (k_r - 1.5)/0.5, \quad (24)$$

which will result in formula (25):

$$X_1 = 0.125k_R - 2;\ X_2 = 0.2\xi - 2;\ X_3 = 2k_r - 3. \quad (25)$$

Substituting (25) into dependence (23), the coefficients of physical variable factors from Table 2 were calculated, as a result of which, a mathematical model of the heat conduction process was obtained in the form of a dependence of the main optimality criterion, i.e., the heat conduction coefficient on the design and operating parameters of the drill winch band brake formula (26):

$$\lambda_R = -160.54 + 11.447k_R + 11.21\xi + 73.43k_r - 0.14k_R\xi - 2.72k_Rk_r + 1.18\xi k_r - 0.17{k_R}^2 - -0.58\xi^2 - 10.8{k_r}^2. \quad (26)$$

Using the results of the solved equation (24), two-dimensional sections were constructed, with the help of which the dependences of the optimization criterion on pairwise (synergetic) coordinates were constructed, which made it possible to determine the optimal values of the three selected factors, i.e. $k_{R,}$=9.6; ξ=14.2; k_r=0.75. This, in turn, allowed the distribution of optimal values of working parameters in proportion to selected calculation values. By using values of the k_R, k_r, and ξ coefficients by formulas (1) and (2), constructive parameters of the auxiliary heatsink pulley of the braking system of some existing drill winches were calculated. Calculation results are presented in Table 4.

Table 4. Constructive parameters of heatsink pulley.

Winch brand	Parameters, mm	
	$r'_{\text{в}}$	$r''_{\text{в}}$
LB-750	240	107
У2-5-5	290	157
LBU-1100	265	132

A graphical demonstration of an overall mathematical model process, which characterizes a surface of heat transfer surface coefficient changes in dependence on investigated factors, is presented in Fig. 2.

However, it is also necessary to point out the fact that the use of the objective function with decoded physical variables helps to provide a better understanding of the simulated physical system, which can help in making practical decisions based on the optimization results. the use of conditional coordinates of the response surface of the target function in the study is an effective approach to characterizing the shift of the physical values of the factors from the zero level of variation and determining the location of critical points in two-dimensional sections of the response surface of the model. This approach enables the acquisition of any required dependence of the heat transfer coefficient from the primary design-operative parameters.

4. Discussion

The drilling performance of rigs can be further improved by using advanced drill string dynamics controls to actively suppress rotational vibration. These installations are based on a linear approach to control. The advantage of a mechanical brake-based drilling control system is the ability to make it mostly fail-safe. It is the brake that is usually activated when the servomotor fails (the lifting force of the lever is not applied) under the weight of the level and the additional force of the return spring. A quick stop of the winch drum can be made easier in critical conditions, but it should be noted, that in

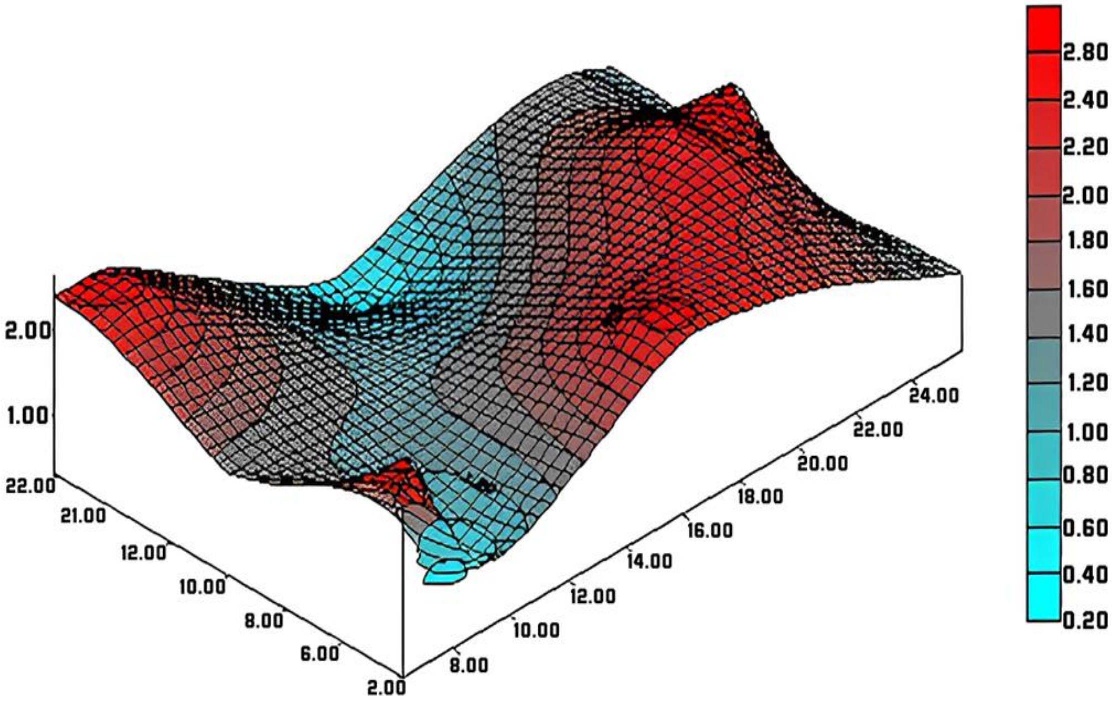


Fig. 2 Graphical demonstration of the mathematical model of heat transfer model in dependence on primary parameters.

certain cases, an adaptation mechanism is necessary to achieve the optimal rate of penetration regardless of the drilling parameters. However, the performance of the control system, based on the mechanical brake, is limited, as it can only assist in running the drill string. Moreover, in the process of positioning, the winch drum, positioned on the brake, a slight slip of the winch drum may occur due to the transition from static to Coulomb friction.[23]

During the design of the winch, the brake valve can be distributed between the manual valves that control the rotation of the winch, as well as the winch drive motor, which limits the flow of hydraulic oil to the winch motor, which makes it possible to instantly block the drum.[24-26] In other words, when the electro-hydraulic valve is blocked, the spool extends to the second default position to block oil to and from the winch motor. In general, the normal function of the manual valve precludes the presence of a self-centering coil.

However, additional auxiliary buttons can be connected in parallel with the emergency stop button of the winch, while neglecting the reset switch on the manual control of the winch. For example, in the work of J.M. Lincoln *et al*.,[27] the authors developed a system of engineering control or physical modification to protect against dangerous cases when the winch is malfunctioning, the results of which show that this technology is effective as protection in dangerous cases. In the work of A.M. Tripathi *et al*.,[28] an innovative classifier for recognizing various types of well-drilling activities in the drilling process is proposed.

Precise prediction of geological peculiarities and description of drilling environment factors, basic data for modeling. As the exploration and development environment for oil and gas resources becomes more complex, the need for extended-reach wells, especially extended-reach horizontal wells and extended-reach horizontal cluster wells, increases, while the associated technical challenges become more apparent.[29,30] Numerous drilling cases have shown that the accuracy of prediction and description before drilling is relatively low due to the extrapolation of errors. If certain conditions are present, such as soil and borehole loads, a boundary limit value for the depth of the well is determined for any well with extended reach, which is called the limit of drilling with extended reach. During the drilling process, the geological features and factors of the drilled formation environment can be updated, while the geological features and factors of the drilling environment of the drilled formation cannot.[31]

In the work of W. J. Huang and D. L. Gao,[32] the authors developed a drilling complexity assessment and expert judgment model that provides a framework for complexity assessment and optimization of drilling design. Basically, for drilling blast holes, rigs with two to four rods are used as basic equipment. The most important element of the drilling rig is the impact drilling rig, which is mounted on rods. Moreover, drilling operations have an enormous impact on the further course of excavation. Through configuration improvement, system integration, and parameter optimization based on existing drilling platform designs, lead projects are developed, including hydraulic control drive and communication network structure.

The drilling performance of a percussion drilling rig is reflected in the speed of the design and, accordingly, in the planned economic feasibility of the project.[33] Drilling speed, which most often serves to determine the degree of productivity of drilling rigs, is mainly characterized by the depth of penetration achievable per unit of time. At constant production rates, different values of drilling intensity make it possible to evaluate different parameters of the rock. Drilling speed is controlled by setting operating parameters, while the adjustment of indicators does not exceed the allowable limit, which may cause drilling failure.[34] Repeated descents in both directions lead to additional production costs. Specific energy is also one of the parameters for the analysis of the drilling efficiency. Specific energy is characterized by the consumption of thermal energy per unit volume of the extracted rock and is a parameter of the crushing of rocks.[35] A large number of analytical models have been developed to predict energy consumption. However, for the most part, they are designed for a rotary non-percussion drilling rig.

The Q. Shen *et al*.[36] study is aimed at analyzing the influence of drilling parameters on its efficiency, the results of which show that there is a relationship between drilling speed and its parameters. In the work of H. Wang *et al*.[37] the authors provide a detailed review of well-drilling technologies, which demonstrates their main points and prospects for the future. Since the well is drilled in 3D space, it is necessary to control the well trajectory to accommodate planned changes in its direction or to compensate for unwanted wellbore deviations. It is also worth paying attention to the fact that when a well leak occurs during the drilling of geothermal wells, a redistribution of the well temperature may occur.

To understand the law of temperature distribution in the well, it is necessary to carry out several works, where a simulation model is also needed. For example, in the work of Z. Zhang *et al*.[38] the authors created a model of temperature distribution in a well under difficult operating conditions when drilling geothermal wells. Z. Li *et al*.[39] propose technology for improving the rate of well drilling, i.e., increasing production in terms of continuous localization of drilling technologies.

In their study, D. Khatiwada *et al*.[40] to increase productivity, it is proposed to optimize the tool path, for example, reduce the time spent in the air on the tool path, and drill all holes along the shortest path. This kind of optimization can not only help save time but will significantly reduce the cost of processing, while the cost of computation will remain high. The process of optimizing the operation of a drilling rig directly depends on technical progress in the materials market. From this point of view, the hybrid scheme of electricity sharing is a rather relevant, but difficult to implement initiative, according to A. Castellano *et al*.[41] In their study, the scientists present a first-of-its-kind electrical hybridization of a power-sharing drilling rig.

D. Pavković *et al*.[42] in turn, consider modernizing the control system, suitable for drilling deep wells using outdated mechanical braking equipment of the winch. The authors believe that this technology will help facilitate a fully automatic drilling operation, as well as improve well production efficiency and meet the increasingly stringent drilling control system performance requirements.

Based on the experience of researchers, it would be correct to confirm the fact that the drilling process is associated with high costs and complications. Advances in technology are driving the introduction of modern drilling equipment, and sensor-enabled monitoring infrastructures to reduce drilling costs and complications. An optimized and trouble-free drilling process requires continuous monitoring of many hydraulic and mechanical parameters, which are measured using integrated sensors.[43] Each of the existing systems in the world has certain limits. As such, drilling and pumping of oil and natural gas still have major challenges to overcome. In the various sources reviewed, the authors highlight the recurring truth that, in order to optimize the drilling process, Additional measures should be taken to address the lack of safety and integrity of the wellbore, low productivity of rock breaking, limited adaptability of equipment and tools to increase speed and efficiency, as well as the lack of new technologies. In drilling technology, efficiency is one of the key metrics to control the total cost of operation in a survey.

5. Conclusions

To reduce the number of cases and optimize the design and mode parameters, a full-factor experiment was implemented using the method of central orthogonal compositional planning. To ensure a complete factorial experiment, a matrix was compiled following the highlighted factors. An experiment was conducted to acquire a regression equation. A mathematical model of the second order was made after the processing of the experimental data. An objective function was employed for practical calculations and evaluation of indicators, which shows a mathematical model of the heat conduction process with decoded physical variables in conditional coordinates.

Through the employment of computer experiments, based on a built mathematic-statistic regression model, the main optimal values for dimensionless parameters k_R, k_r, and ξ, according to the extreme values of the λ_R optimization criteria. Optimal values of k_R=9.6; k_r=0.75; ξ=14.2 factors are similar to the constructive-geometric parameters of drill winch brakes. A graphical demonstration of an overall mathematical model process, which characterizes a surface of heat transfer surface coefficient changes in dependence on investigated factors, is also presented. Advances in technology are driving the introduction of modern drilling equipment, and sensor-enabled monitoring infrastructures to reduce drilling costs and complications.

The use of central compositional orthogonal planning in the full factorial experiment to obtain regression equations to optimize the system's heat transfer process is novel. The results of the study provide scientific reasons for improving the drilling process's effectiveness by optimizing the braking system of the drill winch and may be useful for researchers and practitioners working with similar dynamic systems.

The scientific value of the research is in developing and demonstrating the use of primary parameter calculation methods for the braking system of a drill winch, including the implementation of an additional coolant device, that can improve the effectiveness of the drilling process. At the same time, the practical value of the research is in providing recommendations for the optimization of the braking system of the drill winch to improve the efficiency and effectiveness of the drilling process, and reduce production and non-production time.

One possible area for further investigation could be to explore the impact of different fluids on the heat transfer properties of the drill winch brake cooling system, and how the choice of fluid could be optimized to improve system performance. Another potential avenue for research could be to conduct experiments to validate the optimal values of dimensionless parameters k_R, k_r, and ξ determined in this study, under different operating conditions and with different types of drill winch brakes. This would provide valuable insights into the generalizability and applicability of the results.

Conflict of Interest

There is no conflict of interest.

Supporting Information

Not applicable.

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