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DEVELOPMENT OF EQUIPMENT FOR PARAFFIN BUILD-UP PREVENTION

1. INTRODUCTION

The practice shows that the most complicated failures of pumping unit are the failures of its underground part, especially column of sucker rods. The column of sucker rods presents by itself a long bar, which consists of sucker rods, connected by the couplings and is intended for the transmission of motion from the pumping unit balancing beam to the plunger of oilwell pump. The behavior of the column of sucker rods is influenced by many factors that conduct to its corrosive-fatigue destruction, corrosion and abrasive wear. Except for this, sharp problem there are complications related to the paraffin deposits in the oilwell equipment [1].

To eliminate paraffin deposits expensive chemicals, thermal methods and unreliable mechanical methods are used. For example, in Oil Company "Dolynanaftogas" (West Ukraine) on oil wells next methods of deparaffinization are used:

- thermodeparaffinization by the hot petroleum or reservoir water with the surfactants three times or more per month – 236 oil wells;
- thermodeparaffinization by the hot petroleum or reservoir water 1–2 times per month – 63 oil wells;
- dissolution of paraffin by gas condensate three times per month – 7 oil wells;
- tubing and sucker rods rising for treatment by steam – 45 oil wells.

In connection with the higher indicated problems, in the present work we offer ways of development and improvement of equipment for the complex life increase of sucker rods column and fight with paraffin deposits.

Application of equipment, which includes sucker rod rotator, fiberglass sucker rods, scrapers-protectors, resolve deposit problems and corrosion, corrosive-fatigue failures, wear and buckling of sucker rods. However, in case of use of this equipment separately much problems arise up in complex. So, the existent design of protectors does not have

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enough universality and are appointed, mainly, for fight with wear or paraffin deposits. Existent constructions of fiberglass sucker rods need the improvement with the purpose of their life increase in the conditions of the great loading of compression and bending, which arise up in case of column application equipped by protectors.

The development of reliable complex of equipment for life increase of column of sucker rods and fight with paraffin deposits is the actual task which has an important value for national economy.

The aim of work consists in a life increase of sucker rods column by development of equipment, which comprises the fiberglass sucker rods, rotator, scrapers-protectors and protective couplings.

2. PARAMETRIC OPTIMIZATION OF PAWL AND RATCHET ROTATOR

Using the system of the automated planning on the basis of parametric three-dimensional design and finite elements method (FEM), the new type of device for the rotation of column of sucker rods was designed – rotator of continuous rotation.

The most responsible details, which require verification on durability and determine mechanism sizes are pawl and ratchet.

The basic principles of wheel optimization were developed. The following geometrical parameters of wheel were optimized: number of teeth, tooth width, tooth height, tooth curvature radius, angle of tooth base, size of tooth chamfer. Aim of optimization of initial construction is a reduction of maximal bending stresses after the Mises criterion in head and wheel ($_{max}$ or $_{min}$) tooth leg in case of maximal value of number of teeth, tooth radius, angle of base (z, R, f o $_{max}$), and minimum value of tooth width (B_{omin}). Ranges of legitimate values of the basic parameters are presented in the Table 1. The Table 1 explores parameters of the model corresponding to the objects, explore values, their ranges and dependent parameters.

Table 1

Model parameters, which are subjected to optimization specification

No.	Parameter	Description	Object in the three--dimensional model	Range and values	Dependent parameters
1	Number of teeth	z	CirPattern1	z 30 30, 32, 34	,
2	Tooth width	B	Boss-Extrude1/Sketch2	B 15 mm 10, 15 mm	r_c, r_u, b
3	Tooth height	h	Boss-Extrude1	2, 3,4 mm	–
4	Tooth radius	R	Cut-Revolve1/Sketch4	R 20 mm 20, 25, 30 mm	, r_u
5	Angle of base		Cut-Revolve1/Sketch4	= 35° 35°, 25°	–
6	Chamfer of tooth	f	Chamfer1	$f < h$ 0, 1, 2 mm	–

Initial model, which was subjected to optimization, had the following parameters: r_c = 53,5 mm, z = 32, B = 15 mm, h = 4 mm, R = 25 mm, j = 35°, f = 1 mm. That was the middle parameters of wheel of the most widespread models of rotators (Fig. 1). Others parameters were determined after formulas. Force, which operates on the ratchet, is equal to F = 3700 N. A wheel material is steel ($E = 2,1\cdot10^{11}$ Pa, = 0,28, $_y = 6,2\cdot10^{8}$ Pa).

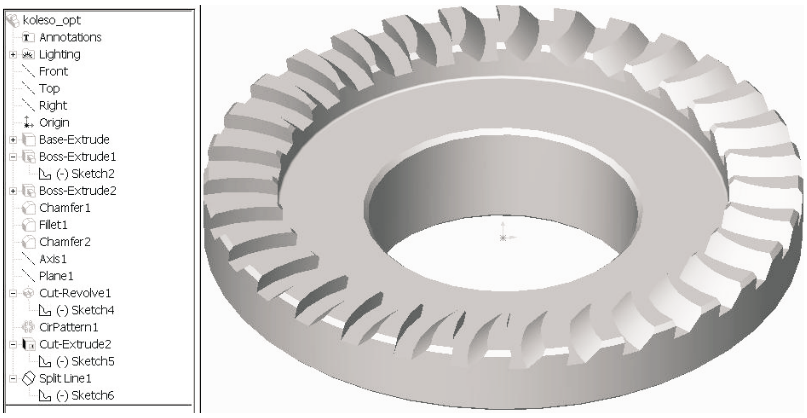

Fig. 1. Tree of parameters and model of rotator's wheel

The optimization algorithm consists in maximum stress values detection at the different positions of ratchet and values of one of parameters of initial model, construction of the proper dependences for all parameters and following their analysis. Such algorithm does not include all possible combinations of values of parameters, but allows to decrease a number of the long FEM computations and to find the influence of every parameter on the tooth durability.

Analyzing these data one can see, that the stresses in leg and tooth head substantially increase (435 MPa, 162 MPa accordingly) when number of teeth is equal to 34 (Fig. 2). Increase of tooth width from 10 to 15 mm decreases the maximal stress in the tooth leg to 50%, and in the tooth head to 2 times (Fig. 3). The least stresses in the tooth leg arise up at his height 3 mm, and in the tooth head – at the height 4 mm. Increase of tooth radius about 30 mm substantially promotes stress in the tooth leg. Reduction of tooth base angle about 25° does not almost diminish the maximal stress in the extreme positions of ratchet, however the thickness of working part of ratchet decreases. Size of tooth chamfer substantially affects the maximal stress in leg and tooth head in the extreme positions of the ratchet. Chamfer of 1 mm results in appearance the biggest stresses in leg, and in head – the least. The least stresses in the tooth leg, in the extreme positions of the ratchet arise up at chamfer equal to 2 mm. Coming this from, we will consider construction of wheel with the following parameters: z = 32, B = 15 mm, h = 3 mm, R = 20 mm, j = 35°, f = 2 mm. The computation results show the substantial reduction of stresses in the extreme positions of the ratchet.

The ratchet of rotator mechanism was designed by the similar method, as the most responsible and loaded details.

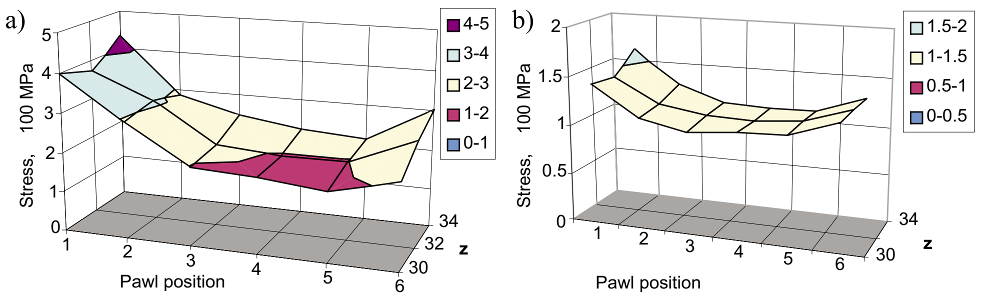

Fig. 2. Dependence of maximal stress in leg (a) and head (b) of tooth of rotator wheel from the pawl position and teeth number

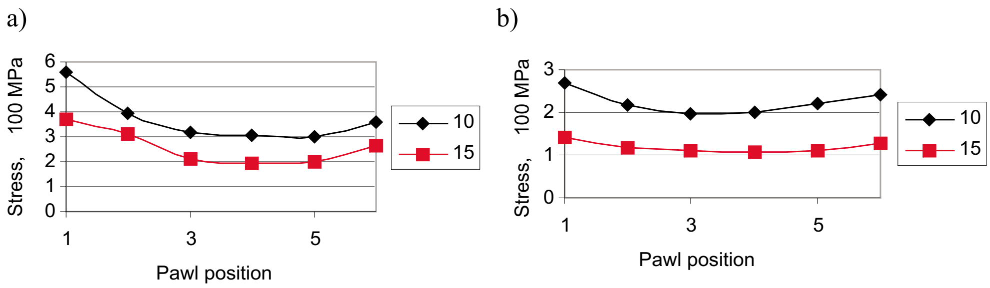

Fig. 3. Dependence of maximal stress in leg (a) and head (b) of tooth of rotator wheel from the pawl position for the 10 mm and 15 mm tooth width

3. OPTIMIZATION OF PROTECTOR

The optimization of protector construction consists in development of detail with the sufficient area of friction, minimum hydrodynamic resistance, stream turbulence and material volume. As the geometrical parameters of protector that affect these descriptions it is necessary to take into account: area and ditch form for flowing a liquid, protector length, hydrodynamic slope and radius of rounding blades.

The parametric three-dimensional computer model of protector was build, which was comfortable for optimization of construction to those, that allows to change a model by the change of one to the parameter, not changing, thus, others. So, it is possible to expose the influencing of separate parameters (Tab. 2) on the protector descriptions.

At first there was studied the dependence of hydrodynamic resistance from every parameter of initial model of protector: the area of the transversal cutting section, length, hydrodynamic slope and radius of rounding of initial model even by the mean value of the proper parameters of most spread protectors for the middle conditions of work: $R = 9$ mm, $L = 90$ mm, $a = 27°$, $R1 = 20$ mm, $R2 = 3$ mm. For reduction of hydrodynamic resistance and increase of friction area on the initial stage of abrasive wear it is necessary to design the ditches of the round transversal cutting with the R radius. The range of legitimate values of parameters got out from condition of model construction possibility, accordingly range of parameters of existent constructions and reasoning lead higher.

Table 2

Model parameters which are subjected to optimization specification

No.	Parameter	Description	Object in the three-dimensional model	Value	Range of legitimate values
1	Ditch radius	*R*	Cut-Extrude5/Sketch1 /radius circles R	from 7 to 13 mm with the step 1 mm	7 *R* 13
2	Length	*L*	Base-Extrude	from 60 mm to 120 mm with the 10 mm step	60 *L* 120
3	Hydrodynamic slope		Chamfer1	90°, 27°, 18°, 14°	90°
4	Radius of rounding elements of hydrodynamic slope	*R*1	Fillet 4	0, 5, 10, 20 mm	–
5	Radius of the blade rounding	*R*2	Fillet 6	0, 1, 2, 3 mm	–

It is necessary to emphasize, that the change of hydrodynamic slope, radius of ditch and radius of the blade rounding substantially affect a hydrodynamic resistance of protector. Last two parameters affect a size of area of the transversal cutting of protector, which, mainly, determines a size of hydrodynamic resistance.

For determination of dependence of S_{fr} friction area, the volume V and areas of the transversal cutting S_{tc} of protector from every parameter and size of protector wear of h_w we developed computer program in the VBA language (Fig. 4).

a) b)

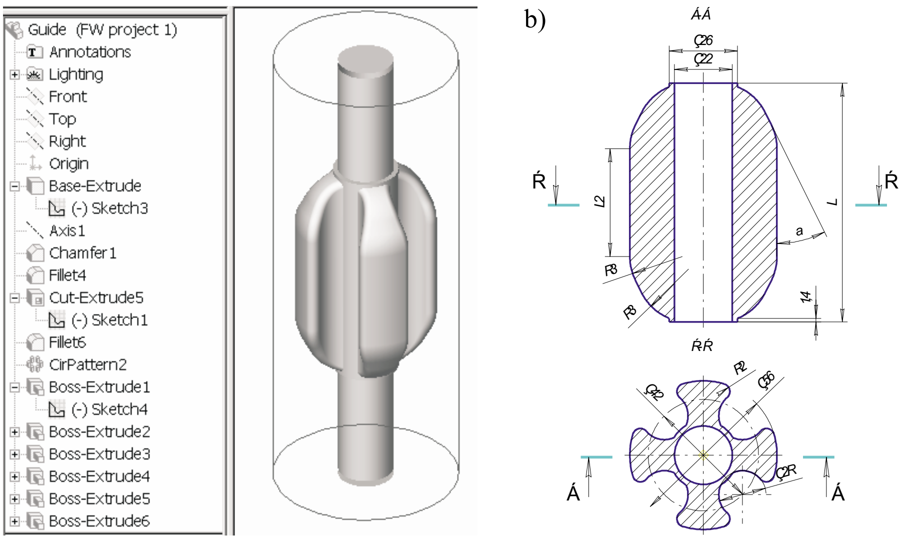

Fig. 4. Tree of model (a) parameters and geometrical parameters (b) of protector

This program, by means of SolidWorks Application Programming Interface (API), executes the change of model parameters from the initial value to eventual with the set step, determines S_{fr}, V, S_{ts} for every combination of parameters, and writes down them in database for the following analysis.

These data analysis shows, that ditch radius R in size of 9 mm and less substantially affects force of hydrodynamic resistance, with the increase of radius the dependence of area of friction from size of protector blade wear gets worse, the volume changes linearly: $V = -9840R + 167850$.

The increase of protector length L not substantially promotes a hydrodynamic resistance, but multiplies a friction area, the volume changes linearly: $V = 1084L - 18668$. Reduction of angle of hydrodynamic slope from 90° to 14° diminishes force of hydrodynamic resistance in 1.5 times, but thus the dependence of area of friction from size of blade wear gets worse substantially. Reduction of radius of the blade rounding about 0.1 mm promotes force of hydrodynamic resistance in 1.5 times, but makes better dependence of area of friction from size of blade wear. Taking into account this, it is necessary to choose an angle of inclination of hydrodynamic slope to maximal, and radius of the blade rounding – minimum, but such, that to secure impossibility of blows in case of protector motion in tubing (Fig. 5).

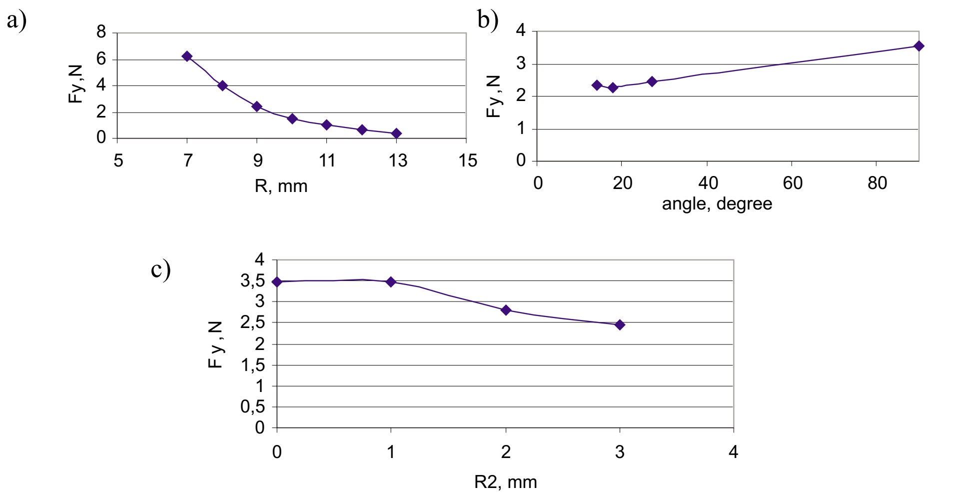

Fig. 5. Dependence of the geometrical parameters of protector on the force of hydrodynamic resistance: a) ditch radius;) hydrodynamic slope; c) radius of the blade rounding

Using the obtained results, it is possible to choose necessary parameters of protector depending on conditions of his work. For example, it is necessary to find the parameters of protector for the heavy conditions of work with the friction area on the initial stage of wear (h_w = 2 mm) S_{fr} = 7300 mm^2, minimum volume and area transversal cutting. By means of facilities of data Ms Excel or Ms Access analysis we have found an optimum variant: R = 10 mm, L = 120 mm, a = 45°, $R3$ = 15 mm, $R2$ = 2 mm, V = 108599 mm^3, S_{ts} = 820 mm^2. By comparison to the CondorTM protector, at that volume, friction area on the initial stage of wear is increased on 23%, area of the transversal cutting is decreased on 25%, and force of hydrodynamic resistance – on 40% (Fig. 6).

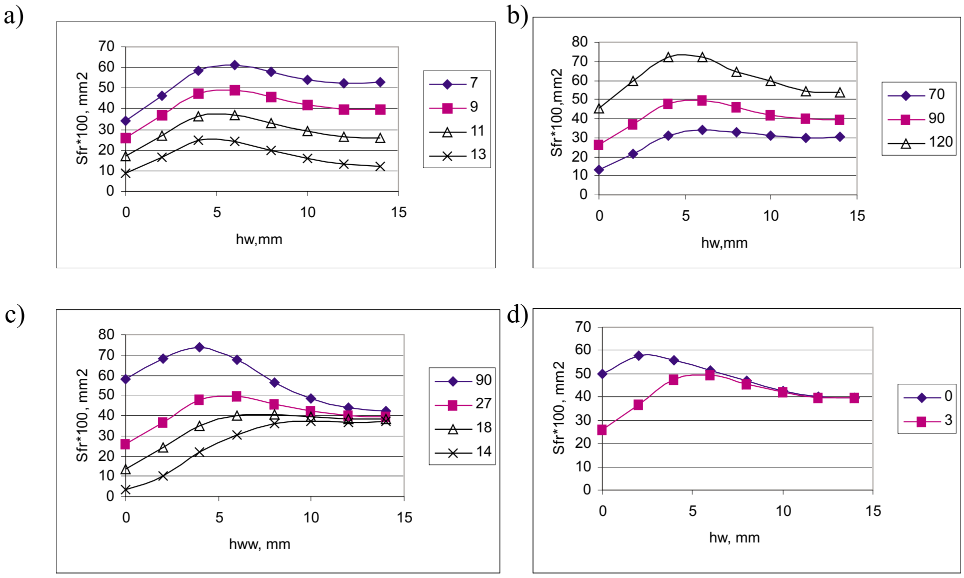

Fig. 6. Dependence of total area of friction S_{fr} on wear size h_w of protector blade for parameters: a) ditch radius, mm; b) protector lengths, mm; c) hydrodynamic slope; d) radius of the blade rounding, mm

For protectors for the easy conditions of work with the friction area on the initial stage of wear (h_w = 2 mm) S_{fr} = 4300 mm^2, minimum volume and area of the transversal cutting was found: R = 12 mm, L = 90 mm, a = 45°, $R3$ = 15 mm, $R2$ = 1 mm, V = 59671 mm^3, S_{ts} = 731 mm^2. By comparison to the Turbulence BreakerTM protector volume was decreased on 30%, friction area on the initial stage of wear was increased on 46%, area of the transversal cutting was decreased on 40%, and force of hydrodynamic resistance – on 60%.

For the life increase of sucker rod column and fight with paraffin buildup we have developed the complex of equipment, in which the fiberglass sucker rods [2], preventive device for the fiberglass sucker rods, scrapers and protectors of hydrodynamic construction and roller protectors [3], protective the bushing for the tubing [4], protector couplings and rotator of continuous rotation [5] are proposed (Fig. 7).

On the basis of conducted researches we recommends to apply a complex of equipment for the life increase of sucker rods and fight with paraffin buildup in such configuration:

– rotator of continuous rotation (if frequent there are failures as a result of uneven wear elements of column, unscrew of the couplings, fatigue of sucker rods in the dog-leg of hole);
– fiberglass sucker rods with the press joint of body with head in the lower part of column (if frequent there are failures of the joints of body with head);
– preventive device for the fiberglass sucker rods on depth, which answers a maximum of failures as a result of tensile loading;
– scrappers-protectors, protective bushings for tubing in places of intensive paraffin buildup;
– scrappers-protectors of hydrodynamic construction for fiberglass sucker rods in places of intensive paraffine buildup and wear;
– protective coupling.

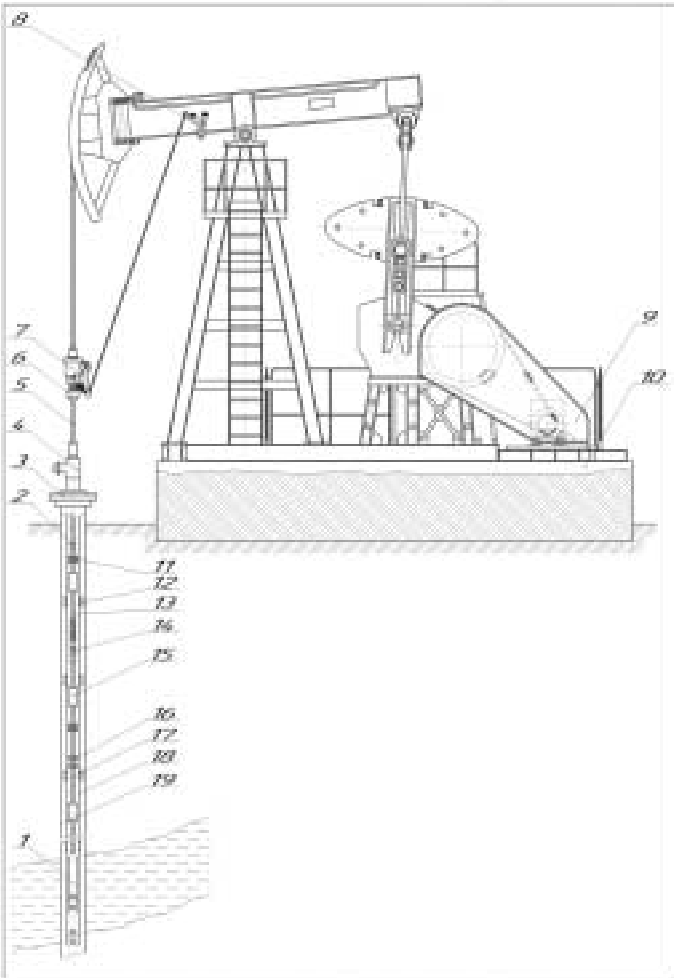

Fig. 7. Pumping unit with the equipment for complex life increase of column of sucker rods and fight with paraffin buildup: 1 – oilwell pump, 2 – coupling, 3 – tubing suspension, 4 – wellhead equipment, 5 – polished rod, 6 – polished rod suspension, 7 – sucker rod rotator, 8 – preventive clamp, 9 – pumping unit, 10 – foundation, 11 – scrappers, 12 – protective bushing, 13 – fiberglass sucker rods, 14 – hydrodynamic protector, 16 – protective coupling, 17 – steel sucker rods, 18 – tubing, 19 – casing

4. CONCLUSIONS

This complex of equipment gives the following advantages:

- prevention of paraffin build-up on tubing and sucker rods, especially on fiberglass rods;
- decrease of friction forces and wear of couplings during sucker rod displacement in tubing, more uniform abrasive wear of coupling and tubing;
- minimization of torsion stresses in fiberglass and steel sucker rods;

– decrease of load on surface equipment due to fiberglass sucker rod column lighter weight;
– economy of electric energy consumption of prime movers;
– increase of sucker rods fatigue life due to their less buckling in the hole, decrease of corrosive fatigue crack initiation and propagation in sucker rods;
– decrease of workovers number on hole deparaffinization;
– decrease and distribution of pushing forces in elements of rotators, that helps to rise reliability of rotating mechanism.
– minimum the loss of pressure during rising of crude oil through new protector-scrappers.

The production of mentioned complex of equipment is organized in Ukraine.

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