A mathematical model of the pulsator for cleaning paraffin deposits of pipelines and downhole equipment

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Abstract. An important task for the oil industry is considered the issue of cleaning paraffin deposits of downhole and surface equipment: Xmas tree, oil gathering pipelines, oil treatment plants. As a result of the paraffin blockage, there is a decrease in oil production, an increase in pressure drop in pipelines, disruption of the normal operation of oil collection and treatment devices, the field operation itself is still difficult, therefore preventing and removing paraffin deposits with various cleaning methods is a pressing problem in the oil industry.

1. Introduction

Paraffin deposits fall on the shank bore of the pipe. The depth of sediments varies from the mouth in the range of 300–750 m. For removal are used the following control methods: mechanical using rabbler; heat using hot oil, steam heating; chemical using solvents, modifiers, dispersers; non-traditional for periodic cleaning of technological equipment of the field. The use of a pulsator is recommended as one of the most effective methods of cleaning from paraffin deposits. The main parts of the pulsator are working parts that create a fluid vibration in the downhole equipment and pipeline; using the device, increases the efficiency of cleaning downhole equipment and pipelines from paraffin deposits [1–5].

2. Results and Discussion

The research work of scientists has established that the imposition of a vibration effect leads to the disintegration of the structural net of paraffinic hydrocarbons, while the oil sludge acquires the ability to flow [5–7].

The working elements of the pulsator are placed in the housing, which contains openings for the inlet and outlet of the liquid, the centralizer is mounted on the spring, which, in turn, rests on the stop. The rotary valve is mounted on the housing using an axis. The crank is connected to the valve with a wrist, with a centralizer - with a pin. The pulsator performs the work as follows. When fluid circulation is restored due to hydraulic forces, the valve and its associated components begin to perform oscillating motions. At the same time, the pass of the pulsator opens and closes, as a result, hydrodynamic waves are excited.

The study of the movement of the valve mechanism is carried out using the Lagrange equation of the 2nd kind. As the generalized coordinate of the mechanism is taken the turn angle φ of the AB link around the axis of rotation O.

In this case, the Lagrange equation is written as
\[
\frac{d}{dt} \left( \frac{\partial T}{\partial \dot{\varphi}} \right) - \frac{\partial T}{\partial \varphi} = Q_{\delta \varphi}, \tag{1}
\]

where \( T \) is the kinetic energy of the lever mechanism; \( \dot{\varphi} = \frac{d\varphi}{dt} = \omega \) - rotational speed of the link \( \text{AB} \); \( Q_{\delta \varphi} \) - the generalized force of the lever mechanism; \( q_i \) - the generalized coordinate of the lever mechanism is undoubtedly the main component of the mechanism at any time \( t \); \( \varphi \) - valve turn angle.

Based on the equation solution (1), an expression is obtained that relates the hydraulic force \( P_1 \) and the spring rate, i.e.

\[
P_1 \left( \frac{l_1}{2} - b \right) - c \left[ \lambda_0 - a(1 - \cos \varphi) - \frac{1}{4} l_2 \beta^2 (1 - \cos 2\varphi) \right] \times \frac{a (\sin \varphi + \frac{1}{2} \beta \sin 2\varphi)}{2} = 0, \tag{2}
\]

where \( l_1 = \text{AB} \); \( a = AO \); \( b = OB \); \( l_2 = AD \); \( \beta = a / l_2 \); \( c \) - spring rate; \( \lambda_0 \) - maximum spring compression.

From the expression (2) is determined by the value of the moving hydraulic force \( P_1 \), necessary for the mechanism operation:

\[
P_1 \geq \frac{2c \left[ \lambda_0 - a(1 - \cos \varphi) - \frac{1}{4} l_2 \beta^2 (1 - \cos 2\varphi) \right] \cdot a (\sin \varphi + \frac{1}{2} \beta \sin 2\varphi)}{l_1 - 2b}, \tag{3}
\]

Conversely, for a given force \( P_1 \), the spring rate is determined:

\[
c \leq \frac{P_1 (l_1 - 2b)}{2 \left[ \lambda_0 - a(1 - \cos \varphi) - \frac{1}{4} l_2 \beta^2 (1 - \cos 2\varphi) \right] \cdot a (\sin \varphi + \frac{1}{2} \beta \sin 2\varphi)}. \tag{4}
\]

The study of the pulsator work was carried out on a laboratory bench to establish the optimal spacing gaps between the mating parts; finishing and fitting elements; to determine the geometrical dimensions, establish a stable area of the pulsator; measurements of frequency response; running in to establish the wear resistance of the pulsator working parts.
Figure 1. The mathematical model of the pulsator: O - the center of rotation of the valve; AB - valve length; F_s - spring force; φ – the turn angle of the valve; OB - the length of the overhang of the valve; AD - the throw of crank; G_1 - valve gravity; G_2 - crank gravity; ω_1 - the angular speed of the valve; G_3 - centralizer gravity force; C_1 - valve gravity center; P_1 - the driving hydraulic force; C_2 - crank gravity center; C_3 – centralizer gravity center.

The laboratory bench consists of: pipeline; pulsator in different positions; gate valves; motor pump; working capacity; draw down gauge; a flow meter; pressure meter; sensor; commutator; power assist; analog-digital converter; vibration displacement sensor; computer.

When conducting laboratory researches of the pressure amplitude of the pulsator, measuring equipment was used consisting of a computer with an analog-digital converter board installed in it, and a strain gage sensor, power assist connected by the shank bore of the pulsator housing.

To determine the pulsator operation was used the Corsair device to measure and analyze vibration, which is considered to be a miniature compact independent portable vibration meter with memory. The device is used for recording, transforming and analyzing vibration signals with the potential of storing the totals of measurements in the computer's memory through the serial interface RS-232 using a software instrument.

Advantages of using ADC:
- analog-digital converter is a device that converts a continuous signal from a strain gage sensor into a discontinuous (digital) one, it is possible to the registry and record the values of the measured parameter at ultralow times;
- the ability to registry and record the characteristics of the pulsator during the study in the computer's memory;
- the possibility of absolute automation of the measurement process, tracking the parameters of the study and their registration;
- ease of the parameters reading of the pulsator.

The signal is measured from sensor to power assist, from a power assist to an analog-digital converter, and from it to an individual computer equipped with a special program.

Figure 2 shows a flow chart for the vibration washing of downhole equipment of deep well pump units (DWP unit) and electrical submersible pump units (ESP unit). The scheme allows for normal and crossover circulation of the well. For normal circulation of the vibration cleaning system of the well from paraffin deposits with hot oil from a sucker rod pump must be torn off the suction valve of the...
noninserted pump or torn off the inserted pump the conical shoulders of the pump sitting nipple in order to depressurize the well.

![Figure 2](image)

**Figure 2.** The scheme of the vibration washing of downhole equipment DWP unit and ESP unit: 1 - pump unit; 2 - downstream line; 3 – back pressure valve; 4 – road tankers; 5 - pulsator; 6 - connecting line; 7, 8, 11, 12 - gate valves; 9 – oilwell tubing; 10 - annulus; 13 - controlled valve; 14 – deep well pump.

During crossover circulation of the downhole equipment of the electrical centrifugal pumping unit, the fluid circulates as follows: pump unit; downstream line; back pressure valve; pulsator; connecting line; gate valve; annulus; deep well pump; oil well tubing. Processing downhole equipment deep well pump unit also carried out in the same way. Treatment efficiency is determined by the increase in the well flow rate [8–10].

Vibration wells washing equipped with electrical submersible pumps, with direct flushing, is carried out by equipping with oilwell tubing above the pump controlled by the circulation valve. Existing valve circulation has a number of defects. As a result, a constructive scheme of a controlled circulation valve was developed. The device consists of a composite body, which is integral with the cylinder. The body is installed on the oil well tubing string with the help of subs. In the cylinder is a piston, which is equipped with a seal. The piston is supported by a sleeve, which contains a channel that communicates a sub-piston cavity with the annulus. The body has two holes. Chamber A is connected to the oil well tubing cavity, chamber B is connected to the oil well tubing cavity and the over-piston space.

3. Conclusion

Based on the equation analysis of the movement of the lever mechanism, analytical dependences are derived for determining the spring rate and the driving hydraulic force, which is important for optimal pulsator operation.

Experimental and theoretical studies have determined the optimal pulsator parameters: with a liquid flow rate of 0.012 m$^3$/s, the pulsator operates steadily with a rotary valve length of 135 mm, a cantilever length of 60 mm, a valve width of 58 mm, a crank length of 140 mm, a spring rate of 4.4 kN/m. With a liquid flow rate of 0.012 m$^3$/s, the oscillation body amplitude of the pulsator is 277 microns, the fluid pressure is 1.8 MPa, and the frequency is 8 Hz.

Using the pulsator were cleaned wells of paraffin deposits with hot oil. Vibration washing allowed reducing the cleaning time of paraffin deposits, increasing the cleaning quality, reducing the volume of hot oil per washing. Field tests showed the effective operation of the pulsator.

4. Acknowledgments

The use of a pulsator for flushing oil pipelines with hot oil from paraffin deposits makes it possible to increase the cleaning efficiency by 40 % as compared with the usual flushing in the Ural-Volga fields.
References

[1] Fan K, Huang Q, Li S and W Yu 2017 The wax deposition rate of water-in-crude oil emulsions based on the laboratory flow loop experiment J. Disper. Sci. Technol. 38(1) pp. 8–18

[2] Suleimanov R I, Zainagalina L Z, Khabibullin M Ya, Zaripova L M and Kovalev N O 2018 Studying heat-affected zone deformations of electric arc welding IOP Conf. Ser.: Mat. Sci. 327(3) 032053

[3] Fournanty S, Guer Y L, Omari K E and Dejean J-P 2008 Laminar flow emulsification process to control the viscosity reduction of heavy crude oils J. Disper. Sci. Technol. 29(10) 1355–66

[4] Ghannam M T and N Esmail 2006 Flow enhancement of medium-viscosity crude oil. Petrol. Sci. Technol. 24(8) 985–99

[5] Suleimanov R I, Gabdrakhimov M S, Khabibullin M Ya, Zaripova L M and Vasilyeva E R 2018 The study of hydraulic hammer device in the drilling tool assembly in hydraulic rotary drilling Int. J. of Engineering and Technology 7(2) 28–30

[6] Xu B 2018 Influencing factors governing paraffin wax deposition of heavy oil and research on wellbore paraffin remover Pet. Sci. Technol. 36(20) 1635–41

[7] Duan J, Liu H, Guan J, Hua W, Jiao G and Gong J 2016 Wax deposition modeling of oil/gas stratified smooth pipe flow AICHE Journal 62(7) 2550–62

[8] Khabibullin M Ya and Suleimanov R I 2018 Selection of optimal design of a universal device for nonstationary pulse pumping of liquid in a reservoir pressure maintenance system Chem. Petrol. Eng+ 54(3-4) 225–32

[9] Khabibullin M Ya, Suleimanov R I, Sidorkin D I and Arslanov I G 2017 Parameters of damping of vibrations of a tubing string in the operation of bottom hole pulse devices Chem. Petrol. Eng+ 53(5-6) 378–84

[10] Khabibullin M Ya and Sidorkin D I 2016 Determination of tubing string vibration parameters under pulsed injection of fluids into the well SOCAR Proc. 3 27–32