DEVELOPMENT AND EVALUATION OF A SMALL-SCALE SHALE SCREENING MACHINE

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ABSTRACT

For decades, the shale screener has been used within side the drilling enterprise for putting off coarse debris from the drilling fluids. The overall performance envelopes of most of the shale shakers have been decided empirically. Systematic empirical research of complete shale shakers are not easy and are costly to develop because of the excessive rate of flow of drilling fluid and coarse debris conveyed via the screener. Beyond its use in the oil and gas industry, shale shakers could be utilized in agriculture separation of biomass and fluids. The present design considered operational parameters such as solid conveyance, spring length, amplitude and frequency of vibration, throw index and screen slope. The designed shale shaker comprises of a vibrating offset mass connected via a pulley system to an electric motor. An open V-belt, balata type material was specifically selected for effective grip. Four springs; two on each side that are encased by spring cups were attached to the shaker frame. Test and analysis carried out on the prototype showed that the oscillating motion of the mud bath caused the coarse masses to move upward and forward on the screen, while the fluid sift through the filter medium attaining filtration ratio to particle diameter of 4:1. As coarse particles size increased, the filter ratio increased. As vibration frequency increased, there was a corresponding increase in throw index which is an indication of the move activity of particles. There was a direct relationship of proportionality between the throw index, the vibration frequency, and amplitude of the mud particles. With attempt geared toward lowering the experimental costs while maintaining efficiency, the shale shaker was designed.

Keywords: drilling fluids, mud screener, mud shaker, shale
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INTRODUCTION

Drilling fluids gotten from a well in the course of drilling are conveyed sequentially through various solid/liquid separation equipment to ensure optimal expulsion of drilled solids from the fluid before making use of it again. A shale shaker as the initial stage solid containment device is a sort of vibration screen utilized broadly in the oil producing industry for solid/fluid partition [1]. The opening of the pore and particles of a shale shaker are little that an ideal method for exploring the issue to convey the solid is yet to be figured out. The Discrete Element Method (DEM) gotten from the 1970s, portrayed the development on a molecule scale, which assisted scientists with having a knowledge of the intricate screening interaction and fostering the movement law of particles on the screen. DEM has been applied generally in the investigation of molecule stream in mining industry and agribusiness vibration screen and ended up being exceptionally helpful in understanding the basics of the screening system [2 - 7]. Through hypothetical exploration and simulation, the DEM, the changing principles of direction inclination, tossing file and tossing speed along the screen deck are acquired and are in great concurrence with one another [8].

Research in the field of execution enhancement depend on utilizing various types of screen, separators and sorts of drilling fluid [9]. This work is centered on underlying changes of the structural design of the shale shaking machine, maintaining a high efficiency, and also ensuring that it is cost effective. Korostelkin *et al*. [10] Proposed an optimized design of shale shaker with a view to increasing the vibrational acceleration of the bed for increased efficiency of the machine. Results obtained showed that increasing the number of power vibrators also increased the vibration acceleration of the shaker bed, this however increased the bulkiness and electrical power requirement of the shale shaker. Utilizing diverse measure of vibrators or various motor powers is an undeniable choice to expand the outcome, so likewise an underlying enhancement and mass decrease of the shale shaker vibrating bed has been acted to build vibrational acceleration [10]. However, a shale shaker is somewhat simple to be controlled as far as drive systems are concerned [11]. Nascentes *et al*. [12] Carried out a design modelling of a shale shaker in a bid to predict the operational and geometrical parameters of its separation as well as to optimize and predict the screening efficiency of the sieves. Their result showed that there were losses that could be as a result of regional structural characteristics such as loss pressure profile in fractured formation. The research was however simulation based and no degree of deviation from practical shale shaker was established.

Inferences gotten from previous works on shale shakers as examined in the current work showed that bountiful shale shakers operation variables were simulated whilst their requirement real life practical shakers for validation and or check for degrees of deviation. In addition, the shale shakers as researched by many researchers are commonly modelled with respect to the oil industry formulations whereas, they could find use in non-oil sector such as agricultural sector for agro related separation.

This work was aimed at developing a shale shaker to have a low power consumption and be cost effective, so as to be easily acquired by locals in Nigeria that have need for it. The layout of the shale shaker in this work involved a belt-driven vibrator, a whimsically weighted shaft which is encased in a lodging and a sheave appended to one end. A sheaved electric motor was employed to drive the shaft with a drive belt. The electric motor was mounted on the foundation of the design underneath the mud bath.

MATERIALS AND METHODS

Materials selection

The shale shaker machine consists of the following components

i. Mud bath
ii. Spring guild,
iii. Screen.
iv. Spring
v. Frame structure
vi. Bearings,
vii. Pulley belt
viii. Electric motor
ix. Vibrating mass

Methods

In designing the shale shaking machine, the following design considerations were considered.

i. Amount in weight of mud to be screened
ii. Screen size
iii. Spring characteristics
iv. Angle of inclination of discharge chute
v. Batch or continuous process
vi. Ease of operation and maintenance
vii. Cost effectiveness
viii. Ease of material sourcing locally
ix. Vibrating motor capacity
x. The shaker collector, screen and bath should be non-reactive with the mud

Conceptual design

From the various design concepts of the mud shaker considered with respect to some design criteria and quantities, a comparative analysis of the concepts using a decision matrix was carried out. The design concept shown in Figure 1 was selected for fabrication.

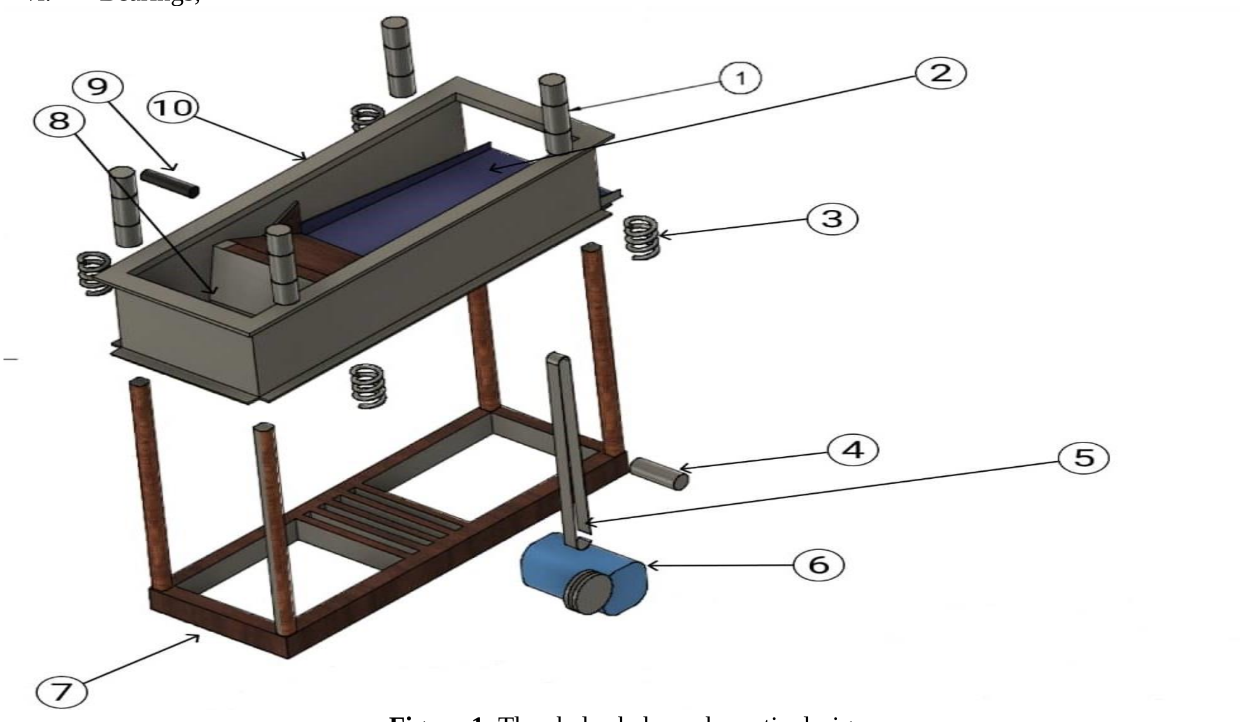

Figure 1. The shale shaker schematic design

LEGEND

PART NO	COMPONENTS
1	Spring guide
2	Screen
3	Spring
4	Frame
5	Pulley belt
6	Electric vibrating motor

7	Base
8	Mud bath
9	Bolt/nut
10	Mud bath reinforce

Detail design

Design nomenclature
Amplitude λ (mm), Vibration frequency (hz)
Coefficient of Restitution ek = 0.4 Excitation directions δ (degree)
Coefficient of Static Friction μs = 0.5 Density p (kg/m^3),
Parameter of Collision Screen slope α (degree)
Parameters of Collision Poisson ratio v = 0.3
Coefficient of Rolling Friction μr = 0.002 Throw Index D
Shear modulus G (Pa) Excitation directions, δ
Screen slope, α Gravitational acceleration g
Mean diameter of the spring coil D, Diameter of the spring wire, d

Mud bath sizing

Volume (cm^3) of slurry or mud = $\frac{mass\ of\ mud}{density}$ 1

Where; mass (kg) of batch load of mud = 50kg

The volume of the mud is expressed in dimension for a rectangular bowl plus an addition say 0.25 that volume to get the actual mud bowl volume to prevent spillovers. Therefore; Actual volume of mud bowl = V + 1.5V

Spring design

The spring elasticity is such that its elastic limit should not be exceeded at the largest amplitude of the spring during vibration to aid continuous vibration and sieving of mud. The spring is attached to the spring cup and the shaker frame structure

From hooks' law, $F = kx$ 2

Where F = load on the spring, k = constant of proportionality and it depends on the material of the spring, x = extension per unit length of the spring

The four springs connected in parallel are subjected to cyclic loading of repeated tension and compression, therefore;

$F = F_1 + F_2 + F_3 + F_4 = x(k_1 + k_2 + k_3 + k_4)$

Where; k = combined stiffness of the spring, x = deflection produced

The spring rate, k is given as;

$k = \frac{f}{x} = \frac{Gd}{8C^3 N_a (1+\frac{0.5}{C^2})}$ [13] 3

Where, N_a = the number of active coils; G = shear modulus, d = wire diameter.

The spring index, which is a measure of coil curvature, is expressed by the equation

$C = \frac{D}{d}$

For the compression helical springs, buckling effect is neglected since the free length (L_f) of the springs < 4x spring pitch diameter. The tensional stress in the springs is expressed as;

Tensional stress $ʈ1 = \frac{8WD}{\Pi d^3}$ 4

Direct shear stress $ʈ2 = \frac{4W}{\Pi d^2}$ 5

The maximum shear stress induced in the material of the spring = $K_s + \frac{8WD}{\Pi d^3}$ 6

W = axial load on the spring and K_s = shear stress factor = 1 + ($\frac{1}{2C}$), and C = $\frac{D}{d}$.

The energy stored in the spring (Es) is obtained from the equation

$E_s = \frac{1}{k_{eq}} x^2$ 7

By inference, it is presumed here that the elastic limit and yield point combined of the spring should be > the compression load for safe operation to prevent failure of spring.

Screening or solid conveyance of the shaker

The significan not process parameter of the shaker is the screening or solids-conveyance process which is a function of the vibrating effect of the springs. The oscillating motion of the mud bath causes particles to move upward and forward on the screen. The dynamics of the particles are hinged on the effect of particle-particle and particle-screen interactions what can be generalized as the throw index D_{index} [14] which is expressed as;

$D_{index} = \frac{\lambda(2\pi f)^2}{g cos\alpha} \sin\delta$ 8

Where; λ = amplitude (m), f = vibration frequency (hz), δ = excitation directions (degrees), α = screen slope (degrees), g = gravitational acceleration (/ms^2).

When throw index is greater than 3.3, the shale shaker will have a better performance [15]. Optimal values of these parameters which are varied for λ, 23Hz for f, 45^0 for δ, 5^0 for α and 10m/s^2 for g are asserted by [14, 16] and are represented in the Table 1 in results section.

Vibrating motor design and selection

The vibrating effect is caused by the vibrating motor. They come in compact type and are often imported. However; on availability due to cost of importation and other impediments, a vibrating mechanism comprising of an offset mass connected via a pulley system to an electric motor was designed. The centrifugal force F_c generated by the rotating unbalanced weight, causes the motor to vibrate in the Z axis and X axis and it is expressed as;

$$F_c = mr\omega^2 \quad 9$$

Where; m = mass of eccentric weight, r = mass offset distance, ω = 2π*f* = angular velocity of motor.

But f = frequency of vibration of the motor = $(\text{motor RPM})/60$

From the equation 3.9 it can be inferred that the mass with a bigger offset from the shaft will produce more force and hence more vibration amplitude. It follows that increasing the voltage supplied to the motor will increase its speed, and therefore the vibration frequency, as well as the vibration amplitude. The power of the motor can therefore be expressed as;

$$P = \frac{2\pi NT}{60} \ (\text{Nmm}^2/\text{s}) \quad 10$$

Where; T = tension in belt N = speed of motor pulley,

For maximum power transmitted by the belt,

$$T = 3mv^2 \quad 11$$

Where; m = mass of belt = area x length x density and v = velocity of belt = $\frac{\pi dN}{60}$.

Where; d = diameter of driver pulley.

Belt selection

The open V-belt, balata material type was specifically selected for effective grip, its length was expressed as;

$$L = \frac{\pi}{2}(d_1 + d_2) + 2x + \frac{(d_2 - d_1)^2}{4x} \quad 12$$

Where; d_1 = diameter of driver pulley, d_2 = diameter of driven pulley and x = center distance between pulleys.

Shaft design

The shaft diameter D_2 was expressed as;

$$D_2{}^3 = \frac{16}{\pi s_s}[(K_b M_b)^2 + (K_t M_t)^2]^{1/2} \quad 13$$

Where; Ss = allowable stress MN/m^2 for mild steel, K_b = Shock and fatigue factor for bending moment, K_t = shock and fatigue factor for torsional moment. K_b and K_t = 2 for suddenly applied shock loads

M_b = bending moment, N_m and M_t = torsional moment, N

Filter ratio

It is expected that the mud particles will be of varying diameter and that the filter pores can only allow fluid with particles diameter lesser than the area of the filter pores. This follows that a quantity expressing the particle diameter as a ratio of the filter pores can be used to evaluate the efficiency of the shaker. This can be described as the filter ratio. The aim is to extract as much fluid as possible from the mud while the also collecting bulk of the coarse materials in a separate collector. The filter ratio ɳ is expressed as;

$$ɳ = \frac{d_i}{a_p} \quad 14$$

Where; d_i = average particle diameter, a_p = filter pore area

RESULTS AND DISCUSSION

The Table 1 shows the results of the quantitative evaluation of variables for the mud shaker design.

Table 1: Design parameters and quantities for the mud shaker

Variable	Notation	Quantity	Unit
Mud density	$\boldsymbol{\delta}$	1906	Kg/m^3
Volume of mud	v	0.026	m^3
Volume of mud bath	V	0.065	m^3
Spring wire diameter	d	5	mm
Spring coil diameter	D	35	mm
Spring coil curvature	C	7	
Number of spring active coils	N_a	6	
Shear modulus of spring material	G	80000	N/mm^2
Spring rate	K	8.2x10^{-6}	kg/m
Total load on spring	F	65.2	kg
Extension/unit length of spring	x	0.7	mm
Torsional stress of spring	τ_1	46.4	N/mm^2
Direct shear stress of spring	τ_2	3.3	N/mm^2
Maximum shear stress induced in spring material	τ_{max}	50.68	N/mm^2
Throw index of shaker	D_{index}	variable	
Vibration frequency	f	23	Hz
Screen slope	α	5	degree
Excitation directions	δ	45	degree
Amplitude	λ	variable	mm
Power of motor	P	2	kw

Length of belt	L	400	mm

Effect of design parameters on the performance of the mud shaker

The mud shaker performance is hinged on many variables, however in this work some crucial parameters are discussed and they include the followings;

i. Particulate nature of the mud and filter ratio

The mud separation is more effective when there is a wide margin between the mud coarse particle size and the mud fluid. Considering the mathematical expression for the filter ratio, it can be inferred that if the ratio of the mud particle diameter to filter pore area increases, that is greater than 1, then the "hard to pass through" particles will flow through the filter bed down to the coarse material collector while the lighter mud fluid percolates and passes through the filter by gravity into the fluid collector. Considering a varied amount of particle sizes as shown in Table 2, a graphical analysis is shown in Figure 2 to depict the effect of the larger and lower diameter particles on filter ratio.

Table 2: Effect of particle diameter on filtration ratio

d_i	0.1	0.2	0.3	0.4	0.5
a_i	0.25	0.25	0.25	0.25	0.25
η	0.4	0.8	1.2	1.6	2

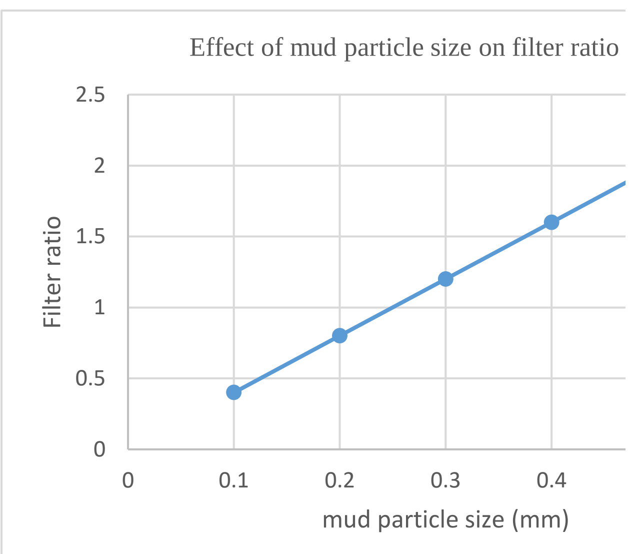

Figure 2: Graph of mud size particle against filter ratio.

From the graph in the Figure 2 it can be inferred that as the mud particles size increases, the filter ratio also increases. The higher extrusion ratio is significant not for non-passage of the coarser materials in the mud and this enhances its excitation and flow along the vibrating bed as it gets separated from the mud fluid.

ii. Effect of frequency, amplitude and throw index

Keeping all other parameters constant from the Equation 6, it can be observed that as the vibration frequency increases there is a corresponding increase in the throw index which is an indication of the move activity of particles. From the equation 6, consider values for amplitude, frequency of vibration as shown in Tables 3 and 4 and the corresponding graphs in Figures 3 and 4, it can be observed that there is a direct relationship of proportionality between the throw index, the vibration frequency, and amplitude of the mud particles.

Table 3: Effect of throw index, vibration frequency on mud shaker performance.

F(Hz)	10	15	23	30	35
D_i	221	497	1169	1990	2708

Table 4: Effect of throw index and amplitude on mud shaker performance

λ (mm)	0.1	0.5	0.7	1	1.5
D_i	221	497	1169	1990	2708

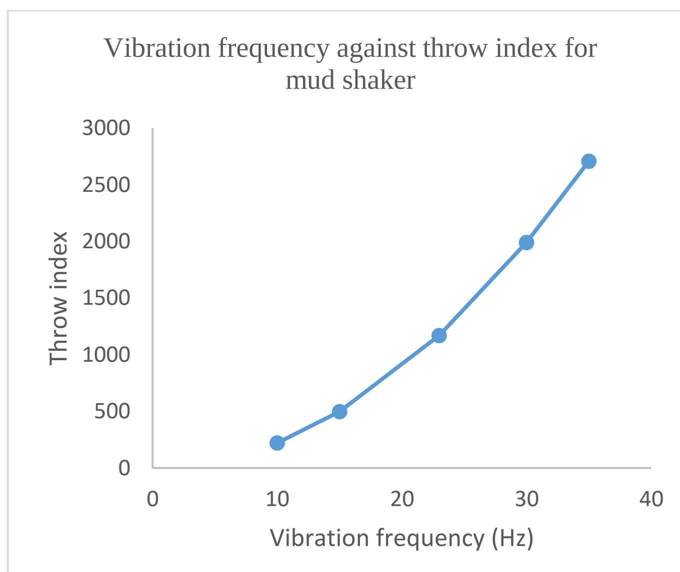

Figure 3: Graph of frequency against mud particle throw index

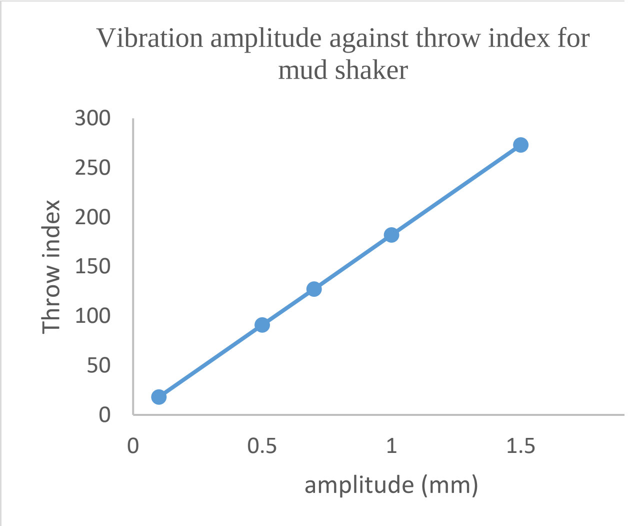

Figure 4: Graph of amplitude against mud particle throw index

As the mud particles oscillate reaching high and low amplitudes of vibration in a fast sequence within a given period of time, there is frequency of contact between the mud coarse particles and the vibrating filter bed causing a continuous energy gain for vertical oscillation and consequential flow of the particles in the direction for collection why the fluid passage through the filter pores is enhanced for efficient fluid/particle separation. The variation in range of vibration frequency f during the working of conventional shale shaker is 16-26 Hz. [16].

iii. Scree pore size and screen slope

In order to keep the performance of the mud liquid effective, the shaker should ensure most particles cannot pass through the screen or filter pores. It is expected that when $\eta > 1$, much of the particles will be excited by the vibrating bed and flow in the direction of coarse material collection while the fluid will pass through the pores into the fluid collector. This may be negated when the tilting of the vibrating bed with respect to the horizontal plane is increased forcing the mud fluid angle of repose to be effective and the mud flows more rapidly towards the coarse particle collector. From the Equation 3 it can be observed that the throw index is inversely proportional to the cosine of the screen slope which implies a decrease in the throw index as screen angle increases.

CONCLUSION

The fabricated mud shaker was tested in a farm settlement where swampy soil was excavated for recycling and used for animal feeding and farm house after further purification. The detail design indicates the significance of the throw index, frequency of vibration, amplitude and filter ratio in evaluating the performance of the mud shaker. The analysis of the results clearly underlines the need for the mud shaker to be rigidly affixed allowing for the proper vibration of the screen/vibration bed to force the mud mixture materials in the respective direction. External forces could impair the vibration of the shaker could inhibit the smooth flow and separation of the mud particles and fluid. The spring compression index should be high beyond that which may cause it to reach its elastic limit as result of the designed load capacity of the shaker. The fabricated mud shaker is a promising design that can be commercially produced locally to enhance the Nigerian local content initiative.

REFERENCES

1. MANOHAR, L. & HOBEROCK, L.L. (1988). Solids-conveyance dynamics and shaker performance. *SPE Drill. Eng.*, **3**(4): 385-394. [http://dx.doi.org/10.2118/14389-PA]
2. DONG, K.J. & YU, A.B. (2012). Numerical simulation of the particle flow and sieving behavior on sieve bend/low head screen combination. *Minerals Engineering*, **31**: 2-9. [http://dx.doi.org/10.1016/j.mineng.2011.10.020]
3. CLEARY, P.W & SAWLEY, M. (2002). DEM modeling of industrial granular flows: 3D case studies and the effect of particle shape on hopper discharge. *Applied Mathematical Modelling,* **26**(2): 89-111. [http://dx.doi.org/10.1016/S0307-904X(01)00050-6]
4. GUIFENG, W. & XIN, T. (2011). Screening efficiency and screen length of a linear vibrating screen using DEM 3D simulation. *Mining Science and Technology* (China), **21**(3): 451-455. [http://dx.doi.org/10.1016/j.mstc.2011.05.026]
5. JIANZHANG, X & XIN, T. (2012). Particle stratification and penetration of a linear vibrating screen by the discrete element method. *International Journal of Mining Science and Technology*, **22**(3): 357-362. [http://dx.doi.org/10.1016/j.ijmst.2012.04.013]
6. LALA, Z., YUEMIN, Z. & CHUSHENG, L. (2011). Simulation of the screening process on a circularly vibrating screen using 3D-DEM. *Mining Science and Technology*. (China), **21**(5): 677-680. [http://dx.doi.org/10.1016/j.mstc.2011.03.010]
7. YANHUA, C. & XIN, T. (2010). Modeling screening efficiency with vibrational parameters based on DEM 3D simulation. *Mining Science and Technology*. (China), **20**(4): 615-620.

8. ZHANG, S., ZHOU, S., LV, Z. & HUA, J. (2016). Dynamical Model and Simulation on Variable Linear Shale Shaker. *Journal of Software Engineering*, **10**(3): 241-252. [10.3923/jse.2016.241.252]
9. GOLENKO, A.V. & YAMALIYEV, V.U. (2016). Main Directions for Shale Shakers Improvement. Electronic scientific journal; Oil and Gas Business, **6**: 23-40.
10. KOROSTELKIN, A.A., FILINTSEV, A.A., NOVOKSHONOV, V.V. & NIKITIN, A.V. (2020). On shale shaker's structural optimization and performance improvement. IOP Conference Series: Materials Science and Engineering, **986**. III Quality Management and Reliability of Technical Systems 27-29 August, St Petersburg, Russian Federation.
11. ATROSHCHENKO, V.A., D'YACHENKO, R.A., KICHKAR' I.Y. & KICHKAR Y.E. (2019). Control of a Shale-Shaker Electrical Drive System. *Chemical and Petroleum Engineering*, **55**(5/6): 508-513. [https://doi.org/10.1007/s10556-019-00653-2]
12. NASCENTES, C., MURATA, V.V., LOPES, L.C.O. (2022). Mathematical modeling of solids-drilling fluid separation in shale shakers in oil fields: A state of art review. *Journal of Petroleum Science and Engineering*, **208**(A), 109270, DOI:10.1016/j.petrol. 2021.109270
13. HAMROCK, B.J., SCHMID, S.R. & JACOBSON, B.O. (1999). Fundamentals of machine elements. McGraw-Hill companies Columbia. Ohio, USA.
14. ZHOU, S.Z., ZHANG, S., LV, Z.P. & QIN, L. (2016). Research and Simulation on Solids-Conveyance Law of the Shale Shaker. *The Open Petroleum Engineering Journal*, **9**: 33-43.
15. ZHANG, M. & DENG, R. (2013). Working Theory and Testing Technique of Shale Shaker, **3**. Petroleum Industry Press: Beijing, China.
16. DU, C.W. & ZHU, W.B. (2006). Basic parameter selection of drilling fluid shale shaker. *Oil Field Equipment*, **35**(5): 12-14.