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MODEL OF OIL AND GAS PIPELINE RINSING USING THE FLUID FLOW

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Pipes and channels, of devices for oil and gas transport are often exposed to impurities (sowdust, soot, grease, products of oil oxidation, crust of oil or scale, etc) that remain after poor quality filtration or are accumulated from the fluid that is being transported. The accumulated impurities reduce the flow cross section and increase pressure loos. The consequences are as following: low efficiency, frequent break downs, increased expenses etc.

By rinsing the sediment, a more reliable operation of the hydraulic devices is achieved.
The aim of this paper is to consider and present the rinsing procedure and to establish criteria for choosing the most suitable cleaning regime (optimal flow parameters and rinsing time).

Key words: Model, Gas, Pipeline, Rinsing, Flow.

INTRODUCTION

Rinsing of the pipes and channels of hydraulic devices, by fluid flow, is a procedure that has been used for a long time in technical practice. Pipelines of hydraulic installation on: mines, construction works, traffic machines, water supply, fluid supply in industries, gas lines, etc., are rinsed. Numerous procedures (mechanical, chemical, hydraulic, etc.) are used for these operations [2], [10], [11],[13]. Talking of the hydraulic rinsing, which is the topic of this paper, three procedures are used [14], [9]: stationary flow of clean fluid; unsteady flow of clean fluid; mixture flow-clean fluid - gas.

For these procedures, the following phases of the rinsing development process, are common [1], [10]:

- Removing the remaining particle from the wall of the pipe (channel);
- Levitation of the removed particle and drawing it into the flow;
- Transport of the removed particle

The question, which is of special importance for the technical practice, remains: how and based on what criteria do we decide on the choice of the rinsing procedure, ie. on the choice of the flow velocity and the time necessary for the rinsing procedure?

Unfortunately, there is no specifically defined answer to this question.

This paper will attempt to provide an answer, anaylising the rinsing of pipe, using the stationary fluid flow. The answer should be simple so as to enable quick decision that would further provide an efficient solution.

REMOVING THE PARTICLE FROM THE WALL OF THE PIPE

The condition for removing the solid particle from the wall of the pipe (channels) is defined by the following equation:

$$F_o \geq f_t \cdot F_a \tag{1}$$

Calculating the forces: Fo,and Fa is a complex process and the acquired results are inaccurate. Knowing that the resistance force Fo is proportional to the shear stress $F_o \approx B\tau$ (the coefficient B depends on the shape of the particle) as a criteria, for defining the force used to remove the

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particle from the wall pipe (channels), we can use the size of the shear stress τ, Pa.

$$\tau = \left.\frac{\partial c}{\partial r}\right|_r \quad (2)$$

Rinsing, using the turbulent flow of the clean fluid, is a procedure very often used in practice.

The fact that this procedure does not involve additional equipment makes it acceptable for most of the hydraulic devices. Practice has shown that shear stress, on the walls pipes (channels) is essential for the quality of particle removal. The value of the sheer stress depends on the stream velocity, and the stream velocity is one of the significant values.

The time of rinsing also significantly influences the quality, but the rinsing expenses as well. Since fluids of the same or weaker characteristics than of the working fluids are used for rinsing, the influence of viscosity should be considered as well.

Hydralically efficient and shorter process of rinsing is achieved by using the pulsing fluid flow. The accelerated impurity removal from the wall of the pipe (channel) is developed on behalf of the amplitude energy of the shear stress of the pulsing fluid flow [14]:

$$\tau_p = \eta \left.\frac{\partial c}{\partial r}\right|_{r=R} = \tau_o + |\partial \tau| \quad (3)$$

$\tau_0 = \eta \left.\frac{\partial c}{\partial r}\right|_{r=R}$ - stationary flow shear stress, Pa;

$|\partial \tau|$ - shear stress amplitude, Pa;

$Re = \frac{c \cdot d}{\nu}$ - Reynold's number.

These equations can be applied to $R\sqrt{\frac{f}{\nu}} > 50$ for laminar flow ie. $R\sqrt{\frac{f}{\nu}} > \frac{Re^{\frac{7}{8}}}{50}$ for turbulent flow.

The pulsations are produced artificially, by installing a special device in the installation rinsing device (pulsator: piston, valve or some other). The pulsator forms impact waves, in the fluid flow, which remove the particles quicker. In order to compare the rinsing efficiency of the pipe (channel) using the stationary and pulsing flow, it is best to establish a relationship of shear stresses during the fluid flow of the same characteristics (density, viscosity):

$$\frac{\tau_p}{\tau} + \frac{\tau_o + |\partial \tau|}{\tau} \quad (4)$$

Two phase fuild flow rinsing (liquid-gas) is more and more often applied due to its efficiency and lower expenses. This procedure typically requires specific equipment for forming and introducing mixtures into the device that is being rinsed. The rinsing efficiency is defined as following:

$$\frac{\tau_m}{\tau} = \frac{\left(1 - \frac{\varphi}{0,84}\right)^{1,75}}{(1-\varphi)^{2,3}} \quad (5)$$

DRAWING THE REMOVED PARTICLES INTO THE FLUID FLOW

The removal process of the solid particles from the pipe wall does not draw the particles into the fluid flow. This process depends on the values of vertical puslations of the turbulent flow.

According to the statistical theory of turbulence, the local speed c of the fluid flow can be presented as following:

$$c = \bar{c} + \tilde{c} \quad (6)$$

The vertical component of this speed is:

$$\tilde{c} = (0,1 - 0,2)\bar{c} \quad (7)$$

The frequency f of pulsation in the turbulent flow, in a pipeline of diameter d is defined by formula:

$$f = \frac{c}{d} \quad (8)$$

Experiments show that the speed of floating particles co [3] is a variable value dependent of the particle size and that it has a probability characteristic. The probability of floating particles is defined as following:

$$P_o = \frac{c_y \cdot \Delta t_y}{c_s \cdot \Delta t_s} \quad (9)$$

$c_s = \sqrt{\frac{\rho_s - \rho}{\rho} g \cdot d_s}$ - the velocity of particle (diameter, ds) sedimentations, m/s;

$\Delta t_s = \frac{\rho_s d_s}{18\nu}$ - sedimentation time (the particle is increased for the value of its diameter ds).

Therefore, the active force, that brings the particle into a floating state, is the result of the pulsing fluid volume having an impact on the particle of the same volume. The particle movement equation is as following:

$$\frac{\pi}{6} d_s^3 \frac{dc_{sy}}{dt} = \frac{\pi}{6} d_s^3 \rho \frac{d\tilde{c}_y}{dt} - 3\eta\pi d_s c_{sy} - \frac{\pi}{6} d_s^3 g(\rho_s - \rho) \quad (10)$$

$3 \cdot \eta \cdot \pi \cdot d_s \cdot c_{sy}$ - particle's resistance to movement (Stock's law);

$\frac{\pi}{6} d_s^3 g(\rho_s - \rho)$ - the gravity force.

In the moment t=0 csy=0. Having in mind the sedimentation velocity cs the particle velocity, vertically, is:

$$c_{sy} = \frac{\rho_s d_s}{18\eta}\left(\tilde{c}_y^2 - c_s^2\right)\left[1 - exp\left(-\frac{18\eta}{\rho_s d_s^2} t\right)\right] \quad (11)$$

The vertical component of the pulsing velocity csy from formula (11) must provide the following condition: csy>cs. The maximum speed t→∞ is defined by the following equation:

$$c_{y,max.} = \frac{\rho_s d_s}{18\eta}\left(\tilde{c}_{sy}^2 - c_s^2\right) \quad (12)$$

The boarder values, of probability changes, of bringing into floating state assuming that the component of the pulsing velocity acts according to the Gauss distribution, can be defined by the following equation

$$P_1 = P\left[1 \geq \frac{\rho_s d_s}{18\eta}\left(\tilde{c}_{sy}^2 - c_s^2\right) \geq 0\right] \quad (13)$$

Or, considering formula 7:

$$P_1 = \Phi\left(\sqrt{\frac{(0{,}1 - 0{,}2)\tilde{c}^2 d_s \rho}{c_s^2 d \rho_s}}\right) \quad (14)$$

Where Φ is the tablular value of the Gauss distribution.

For: ρ s= 7850kg/m3 (sowdust); oil density ρ =850kg/m3; particle diameter ds=100μm; pipeline diameter d=25mm; pipeline length L=2m; resistance coefficient λ=0,02, the values of probabilities, of bringing the particle into floating state, is in Table 1.

TRANSPORT OF FLOATING PARTICLE

Particles separated from the pipe's wall and brought to the fluid flow, need to be transported to the filtration point. Maximum horizontal velocity is [3]:

$$c_{x,max.} = c\left[1 - exp\left(-\frac{18\eta}{\rho_s d_s^2} t\right)\right] \quad (15)$$

The particle trajectory is defined by horizontal cx,max. and vertical sedimentation velocity cs.

The probability of particle transport is defined by the equation:

$$P_{tr} = \frac{c\Delta t_x}{c_s \Delta t_y} \quad (16)$$

Table 1. The separation, transport probability and rinsing time of the 25mm pipeline

Particle diameter d_s, m	Sedimentation velocity, c_s m/s $c_s = \sqrt{\frac{(\rho_s - \rho)}{\rho} g d_s}$,	Flow velocity, c m/s	Floating probability $P_1 = \Phi\left(\sqrt{\frac{0{,}15\bar{c}^2 d_s \rho}{c_s^2 d \rho_s}}\right)$	Probability P_1,	Transport probability $P_2 = \Phi\left(\frac{\bar{c}\sqrt{d_s}}{c_s\sqrt{d} - 0{,}15\bar{c}\sqrt{d_s}}\right)$	Probability P_2.	Total probability $P=P_1P_2$	Rinsing time $t = \frac{7}{20}\frac{1-P}{P}\frac{d}{d_s}\frac{L}{c}$, s
		1	0,089	0,535	0,787	0,782	0,413	4974
		5	0,448	0,670	7,46	1	0,670	344
$1x10^{-4}$	0,0898	10	0,897	0,813	-	1	0,813	80
		15	1,346	0,909	-	1	0,909	26
		20	1,795	0,963	-	1	0,963	7

The transportation and the sedimentation time are defined by the equations:

$$\Delta t_x = \frac{2 \cdot St \cdot d_s}{(3 \cdot St + 2)c}; \Delta t_y = \frac{\rho_s d_s^2}{18\eta} \quad (17)$$

$St = \frac{\rho_s d_s c}{18\eta}$ - Stok's number

By the analogy with the previous procedure we derive the following function:

$$P_2 = \Phi\left(\frac{\bar{c}\sqrt{d_s}}{c_s\sqrt{d} - 0{,}15\bar{c}\sqrt{d_s}}\right) \quad (18)$$

For the above mentioned conditions, the probability values for transportation are given in Table 1.

For successful rinsing, it is necessary to fulfill both of the conditions, ie. it is necessary to separate and transport the impurity particle. Therefore, the probability of simultaneous separation and transport is:

$$P = P_1 \cdot P_2 \quad (19)$$

The particle transport is most commonly done in leap of particles, lengths of leap is ls., For the period of time dt, the number of particles included in the separation and transportation process is defined by equation:

$$N_i = l_{sk} \cdot P \cdot f \cdot dt \quad (20)$$

The number of particles that remain: Nio-Ni., at a length L of the pipline is:

$$N_{io} - N_i \approx L(1-P)dN_i \quad (21)$$

From the eqation:

$$L(1-P)dN_i = l_{sk} \cdot P \cdot f \cdot dt \quad (22)$$

We derive:

$$\frac{N_i}{N_{io}} = exp\left(-\frac{l_{sk}}{L}\frac{P}{1-P}f \cdot t\right) \quad (23)$$

The optimal rinsing time is calculated based on the assumption that only 5% of registered particles is contained in the pipline. This is achieved when the exponent in the equation (23) is equal to 7. If it is adopted that ls=20ds,than from the equation (23) we derive the following:

$$t_{opt.} = \frac{7}{20}\frac{1-P}{P}\frac{d}{d_s}\frac{L}{c} \quad (24)$$

The rinsing efficiency, the most favourable regime is best seen in the equation for specific energy consumption, Table 2.

Table 2. Specific energy consumption

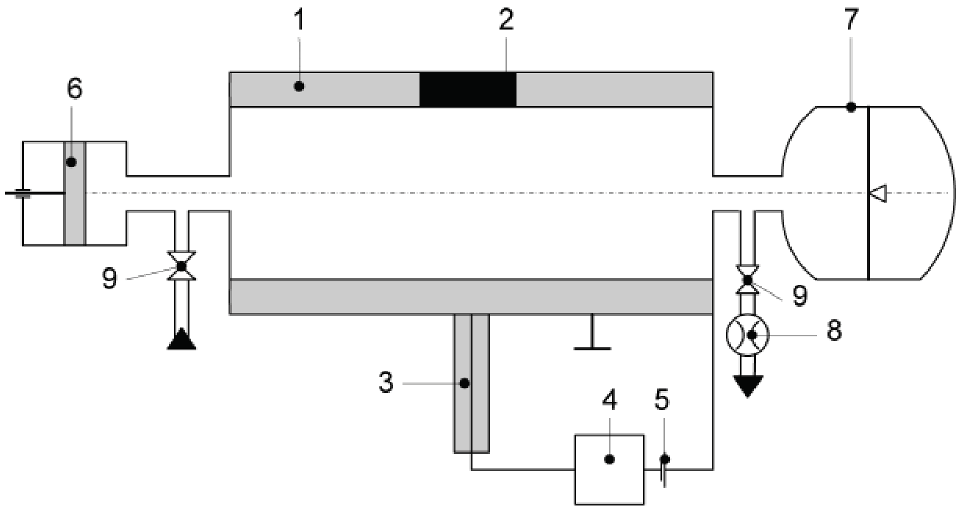
d, m	A, m^2	c, m/s	q, m^3/s	$\Delta p, Pa$	P,W	t, h	e=P/q,Wh/l
0,025	0,00049	1	0,49	680	0,333	1,38	0,937
		5	2.45	17000	41,65	0,095	1,615
		10	4,90	68000	333,2	0,022	1,496
		15	7,35	153000	1124,5	0,0072	1,101
		20	9,80	272000	2665,6	0,0019	0,516

LABORATORY RESEARCH OF THE PIPELINE RINSING PROCESS

By monitoring the state of the pipeline installation, it is the technologist's task to predict such a regime of cleaning the pipeline which would provide maintenance of the desired purity class. Based on the shear stress of the rinsing surface, the technologist needs to define the optimal rinsing fluid speed and the time necessary for rinsing, all with an aim to acquire the desired quality of the pipeline purity. In order to achieve this connection, apart from theoretical considerations, it is also necessary to conduct a great number of experiments. For that purpose, a laboratory test facility has been set up, Fig. 1. In the middle part of the rinsing pipeline (1) an implant (2) has been installed with artificially imposed impurities. The shear strees gauge (3) measures stress on the pipe's walls according to the procedure that is similar to the procedure presented in the article [4].

Fluid flow is provided by the gear pump, and the flow is measured by the flow gauge (8). In this phase of research the stationary fluid flow has been used, although the laboratory facility has been set up to operate with unsteady flow as well.

The impurities (sowdust) have been imposed on the implant by the process of gluing and drying (acetone). Using acetone for gluing, gives the most realistic connection force (athesia) between the particles and the pipe's walls.



1. *Rinsing pipeline*
2. *Implant with artificially imposed impurities*
3. *Measuring the shear stress*
4. *Oscilograph*
5. *Charging source*
6. *Pulsator*
7. *Gas battery*
8. *Flow gauge*
9. Valve

Figure 1. Test device scheme

The roughness of the point where impurities have been imposed is similar to the size of the roughness of new iron seamless pipes (λ=0,02). Rinsing of the pipeline is done by the oil flow of SAE 10 gradation. The number of particles is calculated by the use of microscope. Upon processing the measurment data, the output values are given in Table 3.

Table 3. Shear stress dependency for the oil purity class

d, m	A, m^2	c, m/s	q, m^3/s	$\Delta p, Pa$	P,W	t, h	e=P/q,Wh/l
		1	0,49	680	0,333	1,38	0,937
		5	2.45	17000	41,65	0,095	1,615
0,025	0,00049	10	4,90	68000	333,2	0,022	1,496
		15	7,35	153000	1124,5	0,0072	1,101
		20	9,80	272000	2665,6	0,0019	0,516

DISCUSSION AND CONCLUSIONS

The problem of rinsing the pipeline of the hydraulic pipes and channels is constantly present in the process of servicing and maintaining in: mining, oil and gas production, construction works, traffic, hydraulic transportation of solids, etc. Using theoretical analysis and experiments we have tried to find valid criteria for the choice of the rinsing parameters (the flow velocity c and rinsing time t) which would provide optimal cleaning regime. The laboratory facility that we had avaliable during this research could not enable a greater speed range, and we therefore had to limit ourselves to operate with speeds up to 20m/s. Still, we feel, that for industrial conditions, this range can be accepted as realistic. Any speed increase, for real facilities would most often exceed the posibilities of power devices (pumps), and rinsing would therefore entail the introduction of additional equipment, which would further lead to the increase of expenses.

Upon realizing the set tasks, one can conclude:

- By monitoring the removal and transport process of the solid particles, as the probable value, enables us to choose the most favourable flow velocity, based on the desired quality of solid particle removal.
- That the specific energy consumption grows with the speed increase up to a certain limit (10m/s), after which it would soon start to subside, Table 2. This points to the fact that the optimal flow speed should be in the range of 10-20m/s.
- By comparing the data acquired on the laboratory facility with the data recommended for the desired cleaning quality values, Table 3, one can conclude that rinsing done using the fluid flow can achieve the class 3 quality, Table 3, which is for a great majority of technical devices acceptable.

For finer rinsing, much greater speeds should be used and longer operation time, which significantly raised the expenses.

In the end, we can say that by applying the procedure, that has been presented in this paper, we can easily and quickly acquire technological rinsing parameters that provide us with a desirable rinsing quality, involving minimal expenses.

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Nomenklature:

c-speed, m/s; $\bar{c}$ -middle pulsed speed, m/s; $\tilde{c}$ =80.1-0.2) $\bar{c}$ -vertical component of pulsed speed, m/s; c_s-settling velocity, m/s; d_s-particle diameter, m; f-frequency; f_t-friction coefficient; F_o-drag koeficient, N; F_a-drag, N;	r-radius, m; N_{io}, N_i-number of particles; P, P_o, P_1, P_2-probablities; t-time, s; uparticle velocity, m/s; Δt_o, Δt_s-settling time, s; Φ-Gaiss distribution; φ=0.84 μ-viskozity, Pas; ρ-dencity of solid, kg/m^3;

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