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Dedicated to the 80th anniversary of the Silesian University of Technology

Silesian University of Technology
Faculty of Transport and Aviation Engineering

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Gulzada MASHATAYEVA*, Beibit MYRZAKHMETOV
Satbayev University, Department of Technological Machinery and Equipment,
22 Satbaev str., 050013, Almaty, Kazakhstan
Aleksander SŁADKOWSKI
Silesian University of Technology
Krasińskiego 8, 40-019 Katowice, Poland
* *Corresponding author*. E-mail: gulzadamashatayeva@gmail.com

EFFECT OF SAND SEDIMENTATION ON WELL PRODUCT TRANSPORTATION

Summary. The article addresses the issues of predicting and analytically evaluating sand sedimentation, which has a critical impact on the efficiency of product transportation during oil well operation. Sand production is accompanied by the deposition of mechanical impurities in tubing strings (TBS), especially under unstable or intermittent operation of downhole pumping equipment (DPE). A decrease in the upward flow velocity contributes to the formation of sand plugs, leading to frequent equipment failures and a reduction in production rates. A comprehensive analysis was conducted of the factors influencing sand settling, including the density and viscosity of oil, particle diameter, and flow parameters. A methodology is proposed for calculating the sedimentation time and the critical flow velocity required to maintain stable sand suspension and prevent accumulation above the pump. The results show that maintaining an upward fluid velocity above the sand settling velocity ensures reliable transportation of produced fluids and extends the service life of well equipment. The developed methodology can be applied to optimize operating regimes and activate protective systems in challenging geological and technical conditions.

ВЛИЯНИЕ ОСЕДАНИЯ ПЕСКА НА ТРАНСПОРТИРОВКУ ПРОДУКЦИИ В УСЛОВИЯХ ЭКСПЛУАТАЦИИ СКВАЖИН

Резюме. В статье рассматриваются вопросы прогнозирования и расчетного анализа седиментации песка, оказывающей критическое влияние на эффективность транспортировки продукции в процессе эксплуатации нефтяных скважин. Пескопроявление сопровождается выпадением механических примесей в насосно-компрессорных трубах (НКТ), особенно в условиях нестабильной или периодической работы глубиннонасосного оборудования (ГНО). Снижение скорости восходящего потока способствует образованию песчаных пробок, что приводит к частым отказам оборудования и снижению дебита. Проведен комплексный анализ факторов, влияющих на оседание песка — плотность и вязкость нефти, диаметр частиц, параметры потока. Представлена методика расчета времени седиментации и критической скорости потока, необходимой для устойчивого выноса песка и предотвращения его накопления над насосом. Результаты показывают, что соблюдение условий, при которых скорость восходящего потока превышает скорость оседания песка, обеспечивает стабильную транспортировку добываемой жидкости и продлевает срок службы скважинного оборудования.

1. INTRODUCTION

A significant portion of the world’s hydrocarbon reserves is located in productive formations composed of weakly cemented rocks. During the development of such reservoirs, the destruction of the reservoir framework occurs, leading to intensified release of mechanical impurities—commonly referred to as sand production. Under these conditions, the oil ascending through the tubing string (TBS) contains abrasive particles that cause wear on pumps, valves, and connections [1-2]. Depending on the granulometric composition of the sand, fluid viscosity, and flow velocity, there is a considerable risk of particle settling and the formation of sand plugs above the downhole pumping equipment (DPE) (Fig. 1).

The most intensive release of mechanical impurities is typically observed during the following operational phases:

- well start-up after maintenance;
- following short-term shutdowns;
- under unstable equipment operation conditions.

Fig. 1. Characteristics of sand plugs in the tubing string (TBS) and downhole pumping equipment (DPE) during oil production under high sand production conditions

Sand discharges during these periods exhibit a peak nature, which is difficult to predict. To mitigate sand production, both technical and technological measures are employed, including optimization of production regimes, the use of sand traps, filters, anchors, and maintaining sufficient upward flow velocity. However, the most commonly used slotted filters are prone to clogging by clay and fine particles, while sand control systems are economically justified only for high-flow-rate wells [3].

Reducing the production rate is often recommended to limit sand carryover; however, this approach is generally ineffective and can exacerbate the settling of coarse sand fractions during well shutdowns, contributing to the formation of dense sand plugs within the tubing string (TBS). One proposed solution is to reduce the TBS diameter to increase flow velocity, thereby exceeding the critical sedimentation threshold [4]. However, this also leads to increased hydraulic resistance and energy consumption.

The operation of aging reservoirs, many of which have been switched to intermittent production due to low productivity, presents particular challenges. During downtime, sand settling in the TBS becomes unavoidable. The height of such plugs can reach several tens of meters and, upon well restart, may cause pump jamming or tubing failures. These complications result in frequent interventions, reduced production, and increased operational costs [5].

While sedimentation in a quiescent fluid can be described using classical physics, predicting particle settling in a moving medium—especially under turbulent conditions—is significantly more complex. Therefore, developing practical methods for calculating sedimentation time under real operating conditions of downhole pumping equipment (DPE) remains a relevant task. Such methods would enable optimized planning of equipment shutdown intervals and help prevent the formation of stable sand plugs.

2. METHODOLOGY

During the operation of downhole pumping equipment (DPE), a stable fluid flow is established in the tubing string (TBS), which is generally capable of transporting mechanical impurities. However, under real operating conditions, the flow velocity may be insufficient to carry larger sand particles, leading to their accumulation above the pump [6]. This issue is particularly relevant for mature reservoirs, where wells are frequently switched to intermittent production modes. Under such conditions, sand settling occurs both in stationary and flowing fluids.

The settling velocity of particles in a quiescent fluid is determined based on factors such as oil viscosity, sand particle size distribution, and concentration [7]. At low impurity concentrations (<0.1%), the particles are considered non-interacting and sediment independently. As sand particles move upward with the flow, they are subject to gravitational force, drag from the fluid, and friction against the pipe walls—all of which influence their settling behavior (Fig. 2).

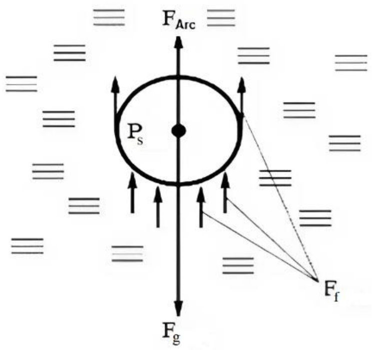

Fig. 2. Forces acting on sand as it moves through the tubing

The resistance force (friction) during particle deposition in a viscous liquid is expressed by:

$$F_f = 6\,\pi \times \upsilon_d \times r \times \vartheta_{d.s} \quad (1)$$

where υ_d -dynamic viscosity of oil, Pa·s; $\vartheta_{d.s}$ - sand deposition rate, m/s; r - radius of sand, m.

The process of sand sedimentation in a liquid depends primarily on its viscosity and flow rate. Inside pump and compressor pipes (PCP), the fluid flow regime can vary with height: in the lower zones, it is turbulent, but as it rises, it can stabilize and become laminar due to the limited diameter of the pipes [9].

In generalized form, the resistance force to particle movement in a flow is defined as:

$$F_f = \zeta\, S\, \frac{\rho_{\text{н}} \times \vartheta_{d.s}}{2} \quad (2)$$

where ζ coefficient of resistance of the medium to particle motion; S - particle cross-sectional area, m^2; $\vartheta_{d.s}$ - sand particle settling velocity, m/s.

The value of ζ depends on the Reynolds number:

- when Re ≤ 2, the flow is laminar, and the relationship between ζ and Re is as follows: $\zeta = 24Re^{-1}$.
- for intermediate values (2<Re ≤ 500), Allen's formula can be used in calculations: $\zeta = 18{,}5Re^{-0{,}6}$.
- in turbulent flow conditions, when Re >500, the drag coefficient has a constant value: ζ = 0,44.

For irregularly shaped particles, a correction is introduced: ζ ' = k ζ ,

In this study, sand is modeled as a spherical particle with a volume of $\frac{\pi d^3}{6}$ and a density of ρ_p. A stable system is considered in which particles move in a laminar upward flow at a constant speed.

The chart (Fig. 3) visually complements the generalized formulation of drag force acting on settling sand particles, as described by Equation (3), where resistance depends on particle cross-section, fluid density, and settling velocity. The diagram clearly demonstrates how the drag coefficient ζ varies with particle diameter and the corresponding Reynolds number, delineating zones of laminar, transitional, and turbulent flow.

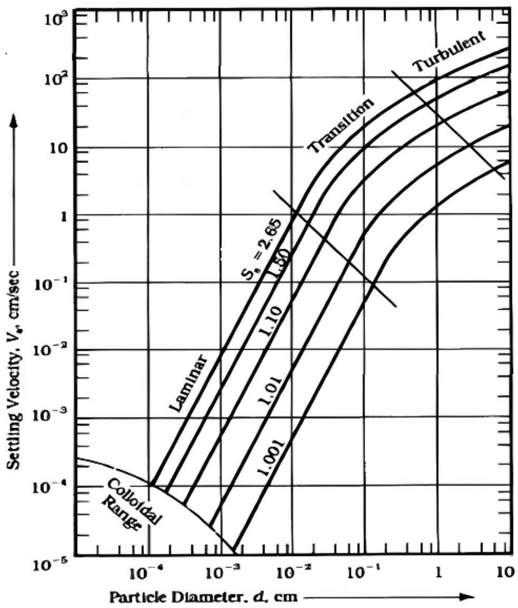

Fig. 3. The logarithmic diagram “sedimentation velocity and particle diameter” obtained from PIS experimental data shows three zones [10]

For particles that do not move according to Stokes' law, the sedimentation velocity of a sand particle can also be determined using Cheng's formula:

$$\vartheta_{d.s.} = \frac{\nu}{d} \times \left(\sqrt{25 + 1.2 \times d_d^2} - 5\right)^{1.5} \quad (3)$$

where ν - kinematic viscosity; d - particle diameter, m; d_d - dimensionless diameter.

Formula (4), based on extensive experimental data, allows calculating the settling velocity of sand under various flow conditions and Reynolds number values (Fig. 4).

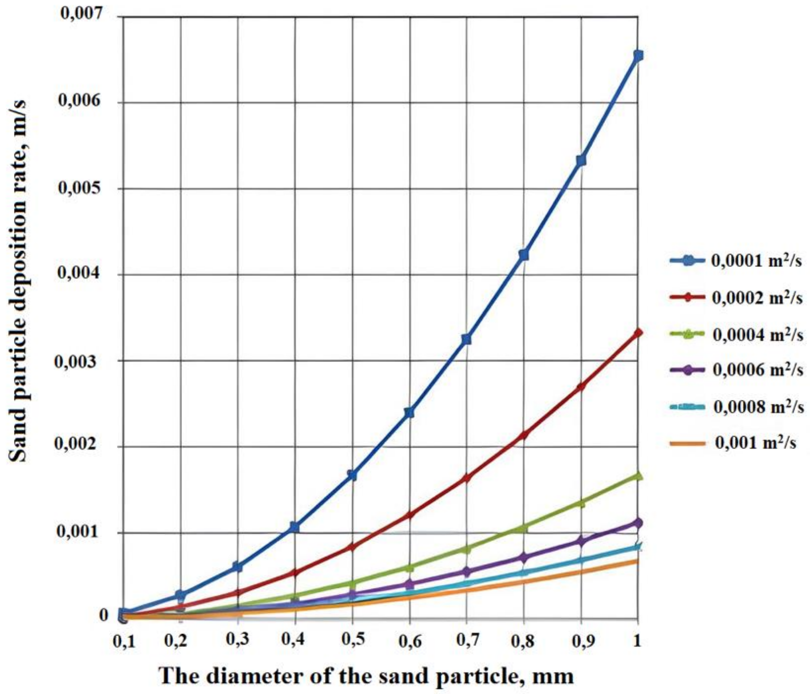

Fig. 4. Dependence of the sedimentation velocity of sand particles of various sizes in a liquid at values of the kinematic viscosity of the liquid from $10 \cdot 10^{-6}$ to $100 \cdot 10^{-6}$ m^2/s

As shown in the graph, the settling velocity of sand particles is significantly influenced by their size (volume scales with the cube of the diameter) and the fluid's viscosity [11]. Increased viscosity substantially reduces sedimentation rates, which must be considered when selecting well operating regimes and planning sand control measures.

Predicting the settling time of particles with different grain sizes in crude oil of varying viscosity and density enables better control over the duration of operational shutdowns and helps prevent the formation of stable sand plugs above the downhole pumping equipment (DPE).

Under real conditions, coarse particles settle first, forming the bottom layer, followed by medium-sized particles, while finer fractions may remain suspended for a longer time [12]. As a result, each fraction has a distinct sedimentation time.

In practice, sand composition is often assessed based on fluid samples taken at the wellhead, which can be misleading. The upward fluid velocity is not always sufficient to transport coarser particles, which tend to settle above the pump. This leads to inaccuracies in theoretical sedimentation models.

The temperature gradient along the tubing string (TBS) affects the oil's viscosity, complicating calculations. For simplified analysis, the viscosity is often assumed to be constant along the entire length of the tubing.

To determine the sand settling time, the total height of the tubing string (H_{TBS}) is divided by the sand settling velocity:

$$\tau = \frac{\mathrm{H}_{TBS}}{\vartheta_{\mathrm{d.s.}}} \tag{4}$$

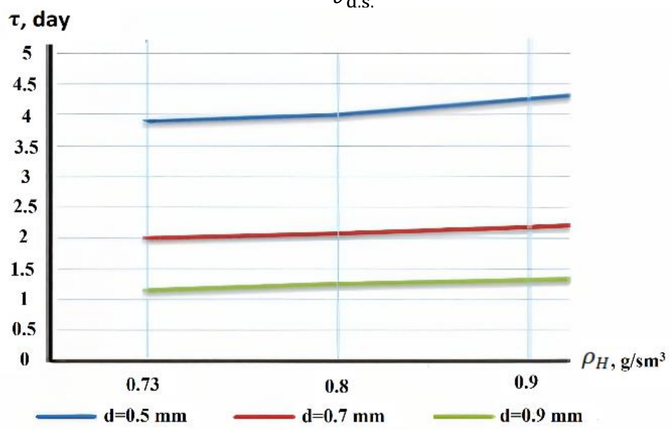

Fig. 5. Dependence of sand sedimentation time on oil density

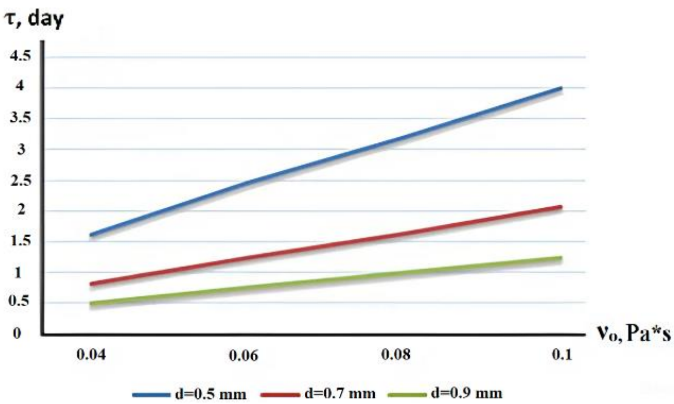

Fig. 6. Graphs showing the dependence of sand sedimentation time on oil viscosity

By varying the parameters influencing sedimentation (particle diameter, oil viscosity, and density), the approximate sand settling time was calculated for a fluid column height of 1000 m in the tubing string (TBS). Figs. 5 and 6 present graphs showing the dependence of settling time for sand particles with a density of 2.9 g/cm³ on oil density and viscosity [13]. The results indicate that as oil viscosity and density increase, the settling time also increases. A 20% increase in particle diameter reduces settling time by 30.5%, while a 20% decrease in oil viscosity shortens the settling time by 18.5%.

3. RESULTS

As a result of the conducted analysis, a methodology was developed for calculating the sand settling time in tubing strings (TBS), taking into account the dynamic and physicochemical parameters of the medium-namely, oil viscosity, sand density and grain size distribution, as well as the flow regime of the fluid. It was established that the most critical factor contributing to the formation of sand plugs during intermittent well operation is when the sand settling time exceeds the duration of downhole pump shutdown [14].

Analytical expressions are proposed to determine the critical upward flow velocity required to ensure sand transport and to predict the allowable duration of technological shutdowns. It was found that an increase in oil viscosity and density significantly extends the settling time of sand, particularly for fine fractions. The derived dependencies can be used to optimize the operating conditions of downhole pumping equipment and to design effective sand control strategies.

4. CONCLUSIONS

As a result of the study, an analytical method was developed to calculate the sand settling time in tubing strings (TBS), taking into account oil viscosity, sand density and grain size distribution, as well as the fluid flow regime. It was established that a key factor in the formation of sand plugs during intermittent operation of downhole pumping equipment (DPE) is when the sand settling time exceeds the pump downtime. Critical upward flow velocities were identified that ensure stable sand transport, enabling a rational approach to selecting operational parameters. It was shown that increasing oil viscosity and density significantly prolongs settling time, especially for fine fractions, whereas coarse particles settle faster and form stratified layers [15-16].

Furthermore, it was revealed that conventional sampling at the wellhead may not accurately represent the full particle size distribution, as larger sand grains tend to settle in the tubing and do not reach the surface. This reduces the accuracy of assessing actual downhole conditions [17]. The proposed method allows for predicting the risk of sand plug formation, optimizing pump operation schedules, and developing effective sand control strategies—particularly important for mature and low-yield fields. The findings may be used to improve the operational reliability of DPE and reduce failure rates in sand-producing environments.

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