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RESEARCH PAPER

Removal of asphaltene deposition from well columns: Impact of casing composition

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ABSTRACT

Asphaltene precipitation and deposition in oil reservoirs, wells, transportation, and refineries pose severe problems. Thus, it is important to evaluate its influence by using cutting-edge techniques such as surface treatment. The purpose of the current investigation is to demonstrate how the alteration of casings composition can influence the threshold at which asphaltene can be dislodged from the well column. This can be accomplished by changing surface energy properties. To evaluate the kinetic changes in the removal velocities of asphaltene particles, the intermolecular asphaltene-oil-casing adhesive forces were calculated using the surface energy characteristics of the casings. A study on the experimental size distribution of asphaltene particles was also conducted as a supplement to the theory of surface energy. The mean size of asphaltene particles decreased from 0.6 to 0.4 microns in live oil while the pressure decreased from 5500-4500 psia at 80°C for 260 minutes, before reaching an asymptote. The results showed that particle rebound has a significant impact on the critical velocity of asphaltene removal from the well column which are profoundly influenced by the casing substrate. This can be considered as a viable physical-based surface treatment method to mitigate the deposition of asphaltene in well columns.

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1. INTRODUCTION

The deposition of heavy organic solids, such as asphaltene, in upstream oil reservoirs and wells as well as downstream oil transmission lines and refineries is one of the difficult problems that would compromise the process performance during the extraction, production, transportation, and processing [1]. Due to its unique extent, the creation of asphaltene deposits will cause a reduction in oil output and significant environmental penalties. Aside from the operational problems, the economic effects of asphaltene formation also include high deposition control costs, the potential for producing wells to remain in severe deposition, and environmental problems including the greenhouse gas impact and pollutant disposal [2], [3].

A number of wells in some of Iranian oilfields (10-15%, according to comprehensive field data

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from 2006), have organic deposition issues, with asphaltene accounting for a large portion of the problem. It may be necessary to close the well and spend high cleaning expenditure to solve this problem. To retain the production rate from these reservoirs, an appropriate strategy to mitigate and remove asphaltene deposition during the production and even after the well is closed seems necessary [4]. As a result, Table 1 presents a brief review of the widely-used techniques for controlling the deposition of asphaltene, including the use of chemicals such as asphaltene inhibitors or solvents and surface treatment. However, the physical approach of surface treatment would change the affinity of the surface itself to be less prone to the asphaltene deposition. Needless to say, the use of chemicals would result in the pollution of different forms in the reservoir and facilities. Therefore, the current study focuses on the surface treatment strategy and look into the composition of casings to intensify the removal of asphaltene deposition.

Before developing any kinetics and thermodynamics models to predict the evolution of asphaltene deposition in well columns and conducting experiments, it is important to have a thorough understanding of the principles of asphaltene precipitation, aggregation, transportation, deposition, and removal. The asphaltene particles move from the bulk media to the casing-crude oil interfaces after being precipitated from crude oil through inertia, eddy diffusion, turbulence impaction, gravity deposition, and thermophoretic processes. Thereafter, the forces of the asphaltene-media-casing adhesion and the asphaltene-media-asphaltene cohesion cause the asphaltene to deposit on the surface of the casing. In addition, various possible removal mechanisms can function, causing the accumulated asphaltene particles to dislodge the surface of the casing. The purpose of the current study, as stated earlier, was to demonstrate how the type of casing might affect the removal of asphaltene deposits. This might be explained as a positive outcome for a surface treatment strategy to successfully address the issue of asphaltene deposition in the upstream oil sector without using hazardeous chemicals. However, few research studies have focused on the deposition of asphaltene on the solid surfaces of production equipment and string surfaces, particularly when considering the influence of the molecular structure of the asphaltene particles [11], [12]. Thus, it can be inferred that these studies ignored the removal process and simply considered the thermodynamics of asphaltene deposition [13]–[17].

It should be noted that the current study considered how the composition of the casing affected the removal mechanisms by analyzing the surface energy characteristics of the casing surfaces and then calculating the surface energy-based interaction energies to determine the asphaltene removal threshold (see Table 2). To do this, the surface energy attributes and interaction forces for the interactional system of asphaltene-casing (two different grades of carbon steel) brought into contact in a crude oil media were utilized. The measurements of surface and interfacial tension as well as contact angle at solid-air and solid-liquid interfaces were used to determine the surface energy attributes for the interactional system [18].

Table 1. Various strategies to combat asphaltene deposition

Approach	Author(s)	Year	Significant outcomes	[Ref.]
Chemical use	Jennings et al.	2018	The impact of pressure on asphlatene inhibition was investigated experimentally. It was found that the inhibitor performance in asphaltene stability was more significant at lower pressure.	[5]
	Campen et al.	2020	Inhibition mechanism of polyol asphaltene inhibitor was studied in different stability conditions of asphaltene particles in the presence of n-heptane. Although the inhibitor mitigated the asphaltene aggregation, the deposition rate increased.	[6]
	Mansouri et al.	2022	Nanocomposites of zirconia-zinc-copper were studied to remove the asphaltene depositions which led to the porosity/permeability improvement.	[7]
Surface treatment	Moradi et al.	2019	A hydrophilic phosphate coating was employed on a carbon steel surface. It desirably led to less asphaltene deposition.	[8]
	Haji-Savameri et al.	2021	Nanosilica and polytetrafluoroethylene (PTFE) were investigated as the inner coating materials on metal surfaces in the presence of asphaltene particles. The findings showed that PTFE performed efficiently to combat the asphaltene deposition.	[9]
	Abbas & Peres	2023	The operational field data of the fluoropolymer-coated tubes showed that the coating could control the asphaltene deposition.	[10]

In addition, the size distribution of asphaltene particles was obtained using a high-pressure microscope (HPM) in a flow assurance system (FLASS) apparatus.

2. Research Method

2.1. Materials and methodology

2.1.1. Materials and experimental measurements

Two different grades of carbon steel casings and a sample of crude oil with asphaltene extracted from it were utilized in this investigation. It should be mentioned that the crude oil and casing coupons were taken from one of the oil fields located in the south of Iran. Moreover, the asphaltene sample was provided by the extraction from the oil sample according to the IP-143 standard. By applying the total surface tension, interfacial tension, and contact angle measurements using a drop shape analyzer (Krüss DSA-100, Germany) at ambient temperature and atmospheric pressure, the materials were characterized with respect to the theory of surface energy (see section 3).

2.1.2. Size distribution of asphaltene particles

HPM facilitates tracking the growth of the precipitated asphaltene particles in terms of their mean size and the mean area within the FLASS apparatus. The working parameters of temperature, pressure, mixer power, and sample flow rate may all be changed using this apparatus.

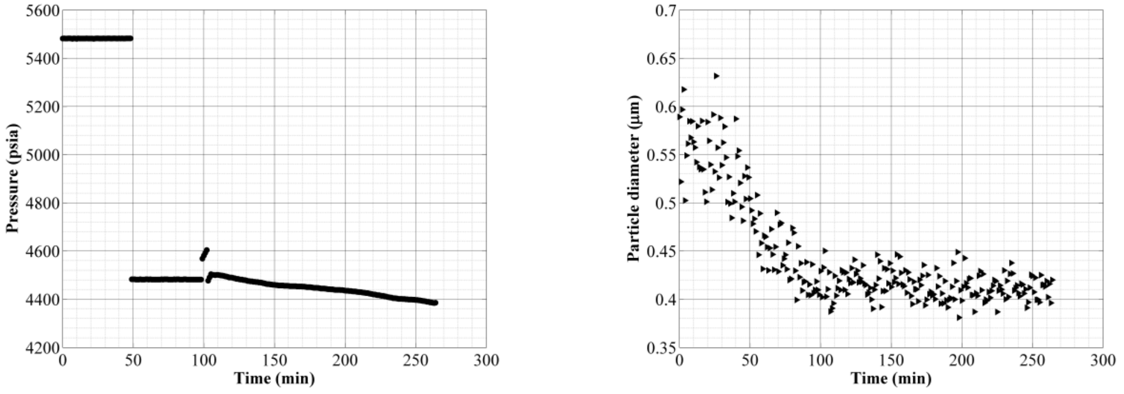
The size distribution of the asphaltene particles was investigated over the course of around 260 minutes. This was accomplished by pumping 60 cc of the live oil from the main cell to the HPM and leaving it there for around 50 minutes, at 5500 psia and 80 $^{\circ}\mathrm{C}$ (see Figure 1a) to ensure that an equilibrium condition was reached. The live oil pressure was then reduced from 5500 psia to 4500 psia at a constant temperature of 80 $^{\circ}\mathrm{C}$ and over a period of 50 to 100 minutes to determine the effect of pressure reduction on the kinetics of particle formation (see Figure 1a). The sample was then left for a further 160 minutes with the flow rate lowered from 0.2 to 0.05 cc/min to see how much the size of the asphaltene particles would change with the flow rate (see Figure 1a).

According to Figure 1a, the change of asphaltene particle diameter against time has been plotted in Figure 1b. According to this figure, for the first 50 minutes the system is in equilibrium, the mean diameter of the particles linearly drops with time nearly 25% from 0.6 µm to 0.45 µm. The mean diameter again reduces by around 11%, from 0.45 m to 0.4 m, during 50 to 100 minutes with a 1000 psi pressure reduction. On the other hand, after another 160 minutes of decreasing the flow rate from 0.2 to 0.05 cc/min, the mean particle size remains essentially constant. Figure 1 shows the pressure as the operational parameter that has the greatest influence on the kinetics of particle size distribution.

2.2. Theory

2.2.1. Surface energy and interaction forces

From a molecular standpoint, a substantial body of attention [19], [20] has been given to the surface and interaction forces, particularly for those of interfacial phenomena taking place at the interfaces of solid-liquid, in this case, the crude oil-casing.



(a) (b)

Figure1. The outcome of FLASS experiment: a) live oil pressure and b) mean particle diameter over time

The Lewis acid-based approach (Eq. 1 in Table 2) yields the surface energy and its Lifshitz-van der Waals (LW), electron donor and electron acceptor components for the extracted asphaltene and the two casings. Moreover, the surface tension and its components for the crude oil sample were determined using the correlation of the water-oil interfacial tensions as given in Eqs. (2-3).

In this study, the extended Derjaguin-Landau-Verwey-Overbeek (XDLVO) theory [21], [22] was employed to calculate the LW (Eq. 4) and Lewis acid-based (Eq. 5) interaction forces as the components of the adhesion force for an asphaltene particle were brought into contact with the casing surface in an oil media.

2.2.2. Removal mechanisms

Based on a force balance for a resting spherical asphaltene particle on the flat surface of the casing with the lift, stored elastic, adhesion, and drag forces imparted on it, the critical velocities of the asphaltene removal (Eqs. 6-8) from well column are achieved. Table 2 lists the correlations of critical velocities.

The physical characteristics of the crude oil, such as density and dynamic viscosity, as well as the geometry and composition of the well column, have an impact on the critical removal velocities, as shown in Table 2. This study solely considered one of these factors—the effect of casing composition on the removal of asphaltene particles from well columns. This analysis took into account the parameters of the casing surface and interaction forces, which are shown in Table 2.

Based on Table 2, first, using Eq. (1), the surface energy and three LW, electron donor, and electron acceptor components of the asphaltene particles and casing surfaces were calculated. The surface tension and its components for the crude oil sample were then calculated using Eqs. (2–3). The interaction forces in Eqs. (4-5) were calculated using the surface energy properties of the interacting substances asphaltene, casing, and crude oil. Finally, using Eqs. (6–8), the threshold for asphaltene removal by various processes was determined.

Table 2. Correlations of critical removal velocities as well as surface energy and interaction forces

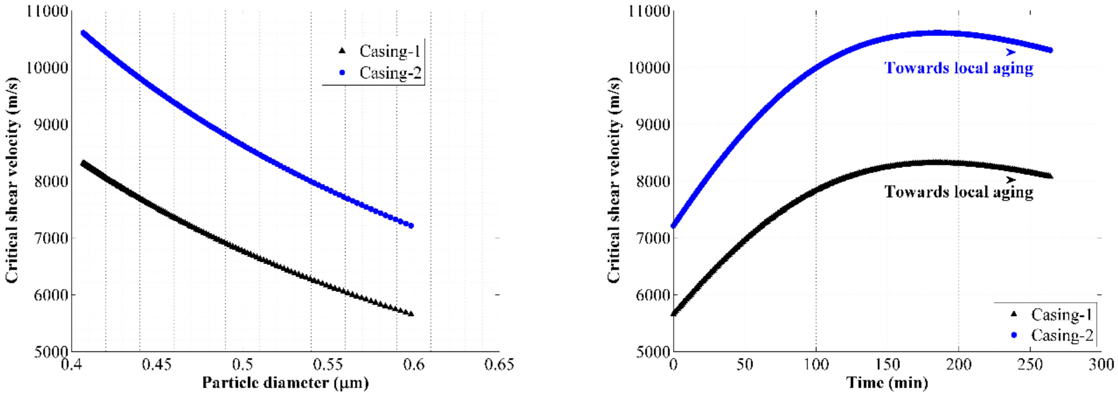
No.	Equation	Ref.
1	$\gamma_L\left(1+\cos\theta\right)=2\left(\sqrt{\gamma_C^{LW}\gamma_L^{LW}}+\sqrt{\gamma_C^{+}\gamma_L^{-}}+\sqrt{\gamma_C^{-}\gamma_L^{+}}\right)$	[23], [24]
2	$\gamma_{WO}=\gamma_W+\gamma_O-2\left(\sqrt{\gamma_W^{d}\gamma_O^{d}}+\sqrt{\gamma_W^{p}\gamma_O^{p}}\right)$	[25]
3	$\gamma_{WO}=\gamma_W+\gamma_O-2\left(\sqrt{\gamma_W^{LW}\gamma_O^{LW}}+\sqrt{\gamma_W^{+}\gamma_O^{-}}+\sqrt{\gamma_W^{-}\gamma_O^{+}}\right)$	[23], [24]
4	$F_{AOC}^{LW}=\frac{d\Delta G_{AOC}^{LW}}{dL}=2\pi d_A(\sqrt{\gamma_A^{LW}}-\sqrt{\gamma_O^{LW}})(\sqrt{\gamma_S^{LW}}-\sqrt{\gamma_O^{LW}})$	[26]
5	$F_{AOC}^{AB}=\frac{d\Delta G_{AOC}^{AB}}{dL}=-2\pi d_A(\sqrt{\gamma_A^{+}\gamma_O^{-}}+\sqrt{\gamma_A^{-}\gamma_O^{+}}+\sqrt{\gamma_C^{+}\gamma_O^{-}}+\sqrt{\gamma_C^{-}\gamma_O^{+}}$ $-\sqrt{\gamma_O^{+}\gamma_O^{-}}-\sqrt{\gamma_O^{+}\gamma_O^{-}}-\sqrt{\gamma_A^{+}\gamma_C^{-}}-\sqrt{\gamma_A^{-}\gamma_C^{+}})$	[26]
6	$u_{Critical}^{Shear}=\left[\left\|F_{AOC}^{LW}+F_{AOC}^{AB}\right\|\Big/(0.3164)\rho_O d_A^{2}(\frac{\rho_O D}{\mu_O})^{-0.25}\right]^{1/1.75}$	-
7	$u_{Critical}^{Rolling}=\left[4.52\left\|F_{AOC}^{LW}+F_{AOC}^{AB}\right\|a\Big/\rho_O d_A^{3}(\frac{\rho_O D}{\mu_O})^{-0.25}\right]^{1/1.75}$	-
8	$u_{Critical}^{\mathrm{Rebound}}=\sqrt{Q_e-Q_{adh}/0.5m^{*}}$	-

3. Results and Analysis

3.1. Critical shear velocity as a function of particle size: casing material effect

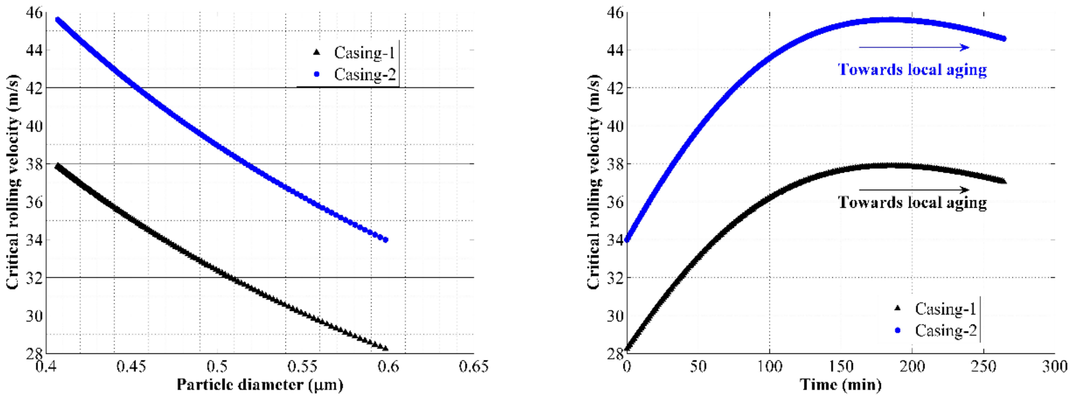
The variations of the critical shear velocity with the mean asphaltene diameter and time for the two investigated casings are depicted in Figure 2. The removal of smaller asphaltene particles would be more difficult as seen in Figure 2a. In other words, the bigger asphaltene particles need a lower shear velocity to bounce off the casing surface. Figure 2b shows the evolution of the critical shear velocity over time. As time goes on, the removal of particles becomes harder because the velocity rises. This keeps happening until critical velocity-time behavior starts to follow a nearly asymptotic pattern. In this area, the critical velocity no longer varies over time. At constant pressure and temperature, it may be inferred that the deposited layer has started to locally age.

Most significantly, Figure 2a suggests that the casing material has a significant influence on the removal of asphaltene particles from the casing surface. It should be mentioned that while having different chemical compositions, the two investigated casings are of a similar kind. This would, in turn, demonstrate the significance of surface properties in terms of the casing surface energy features.



(a) (b)

Figure 2. Critical shear velocity against a) mean particle diameter and b) time



(a) (b)

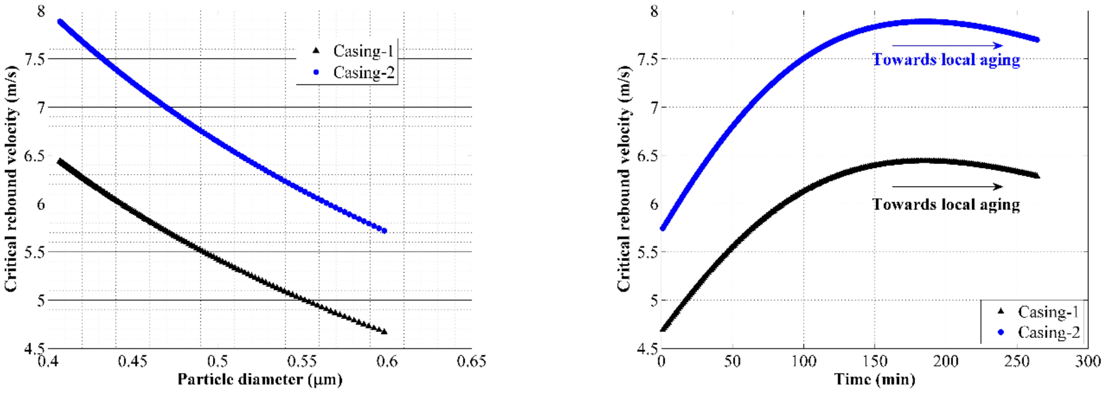
Figure 3. Critical rolling velocity against a) mean particle diameter and b) time

3.2. Critical rolling velocity as a function of particle size: casing material effect

As shown in Figure 3, the same descriptions that apply to the critical shear velocity also apply to the critical rolling velocity. It is discovered by comparing their orders of magnitude that the asphaltene particles are more likely to roll against one another and detach off the surface of the casing than to be removed due to the shear force.

3.3. Critical rebound velocity as a function of particle size: casing material effect

When the critical rebound velocity is plotted versus mean particle diameter and time as shown in Figure 4, similar outcomes to those of the preceding sections are obtained. The rebound has the lowest critical velocity across Figures 2-4. Thus, it can be claimed that the predominant mechanism for removing asphaltene particles from the casing surfaces is the rebound of asphaltene particles.



(a)

(b)

Figure 4. Critical rolling velocity against a) mean particle diameter and b) time

4. Conclusions

The goal of the current research was to examine how the composition of the casing would influence the threshold for the removal of asphaltene by shear force, rolling, and rebound processes from the well column. This is why surface energy and FLASS-based theoretical and experiments were used. The results revealed that:

- Among the operating conditions of pressure and flow rate, pressure has the greatest kinetic impact on the mean asphaltene particle size over time.
- The influence of casing type is considerable for all the essential removal velocities of shear force, rolling, and rebound, according to the theoretical conclusions.
- Under the conditions of experiments in this study, the asphaltene particles would first leave the surface of the casing via rebound, then by rolling, and finally by shear force.
- As time elapses, the deposit layer would start to age gradually, making it harder to remove the asphaltene particles from the surface of the casings.
- The critical removal velocities of shear force, rolling, and rebound rise by about 31%, 22%, and 24%, respectively due to the compositional shift from casing-1 to casing-2, at the end of the experiment after 260 minutes when the mean diameter of asphaltene particles is about 0.4 micron.

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Nomenclature

	Notation	
a	Contact radius	(m)
d	Particle diameter	(m)
D	Casing diameter	(m)
F	Interaction force	(N)
ΔG	Interaction energy	(J)
L	Separation distance	(m)
m^*	Effective mass	(kg)
Q_{adh}	Adhesion energy	(J)
u	Critical velocity	(m/s)
	Greek symbols	
γ^+	Electron acceptor sub-component of surface energy/tension	(N/m)
γ^-	Electron donor sub-component of surface energy/tension	(N/m)
γ^{AB}	Lewis acid-base (AB) component of surface energy/tension	(N/m)
γ^d	Dispersive component of surface energy/tension	(N/m)
γ_L	Liquid surface tension	(N/m)
γ^{LW}	Lifshitz-van der Waals (LW) component of surface energy/tension	(N/m)
γ^p	Polar component of surface energy/tension	(N/m)
θ	Contact angle	(Degree)
ρ	Density	(kg/m^3)
μ	Dynamic viscosity	(kg/m.s)
	Subscripts	
adh	Adhesion	
A	Asphaltene	
AOC	Asphaltene-oil medium-casing surface	
C	Casing	
e	Elastic	
L	Liquid	
O	Oil medium	
W	Water	

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چکیده

ترسیب و ته‌نشست آسفالتین در مخازن نفت، چاه‌ها، خطوط انتقال و پالایشگاه‌ها منجر به ایجاد مشکلات جدی می‌شود. بنابراین، بررسی اثرات ناشی از آن با استفاده از تکنیک‌های به روز همچون اصلاح سطح رویکردی مناسب می‌نماید. هدف مطالعه حاضر نشان دادن چگونگی تاثیر تغییر ترکیب شیمیایی لوله جداری بر آستانه زدوده شدن ذرات آسفالتین از ستون چاه است. این مسئله با تغییر خواص انرژی سطحی انجام پذیر است. به منظور ارزیابی تغییرات سینتیکی سرعت زدوده شدن ذرات آسفالتین با استفاده از خواص انرژی سطح لوله‌های جداری، نیروهای چسبندگی بین مولکولی در سیستم آسفالتین-نفت-لوله جداری محاسبه شدند. به عنوان مکمل تئوری انرژی سطح، مطالعه آزمایشگاهی توزیع اندازه ذرات آسفالتین نیز انجام شد. با کاهش فشار نمونه نفت زنده از ۵۵۰۰ به ۴۵۰۰ پام در دمای ثابت ۸۰ درجه سانتی‌گراد و به مدت ۰۶۲ دقیقه، متوسط اندازه ذرات آسفالتین از ۰/۶ به ۰/۴ میکرون کاهش و در نهایت به سمت یک رفتار مجانبی تمایل یافت. نتایج نشان داد که مکانیسم ضربه ناگهانی ذره که به شدت از جنس لوله جداری تاثیر می‌پذیرد، اثر قابل توجهی بر سرعت دفع آسفالتین از ستون چاه دارد. در نتیجه، می‌توان روش فیزیکی اصلاح سطح بر مبنای تغییر جنس لوله جداری را به عنوان یک رویکرد موفق برای کاهش تشکیل رسوب آسفالتین در ستون در نظر گرفت.

نحوه استناد به این مقاله:

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