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Remediation of Liquid Phase Banking in the Vicinity of Gas Condensate Producing Reservoirs Using Wettability Modification Method

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Abstract

To alter sandstone rock wettability towards approximately gas wetting state, this study utilized two new types of fluorocarbon-based chemicals. In order to obtain the intensity of wettability modification by spontaneous imbibition tests, static angle measurements, and core flooding which use hexadecane as well as brine, the current study employed a great deal of experiments representing the wettability condition of rock surface. The aim of applying surface characterization approaches, for instance, SEM, EDAX analysis and EDAX map was to consider and approve the adsorption of fluoro-chemical on the rock sample's surface. Respectively, contact angles for brine and hexadecane droplets on the treated surface by RTF solution, after treatment with fluorinated chemical were calculated 144 and 86. The contact angles made by brine and hexadecane droplets with the treated sandstone surface by 86-F solution were 152 and 100, respectively. Due to wettability alteration from highly liquid wet to approximately gas wet condition, spontaneous imbibition test of liquids into the first saturated sandstone core samples by dry air addressed that, before and after treatment, there has been a significant change in the amount of liquid imbibed into the cores.

***Keywords**: Wettability modification; Gas condensate; Gas wetting; Condensate Banking; Contact Angle; Spontaneous Imbibition.*

1. Introduction

In recent years' natural gas has become an important energy source. In the gas-condensate reservoirs, due to production with time the pressure of the reservoir fluid drops below its dew point in the vicinity of the producing wellbore, therefore, liquid drops (condensates) start to come out from the gas phase and two-phase flow is established. Liquid dropout results in condensate banking near-wellbore region that leads to a decrease in gas productivity. Several methods have been proposed to mitigate the gas condensate and liquid banking issue in the near-wellbore region including hydraulic fracturing, gas injection, and wettability alteration. Among the variety of techniques that have been proposed for reducing the effect of the condensate banking, wettability modification of gas reservoir rocks from water or oil-wet state to the gas wet condition is found to be a promising technique.

In the recent two decades, the wettability alteration technique has received tremendous attention in the mitigation of liquid banking. Related experimental studies started by Li and Firoozabadi in the range of room temperature [1-2] then extended to even higher temperatures up-to 93ºC by Tang and Firoozabadi [3]. Following the Firoozabadi's investigations and his group members, other researchers made improvement toward alleviating liquid banking by altering the wettability of different rock types to intermediate gas-wetting as well. Bang and Bang et al used two different solvents to carry a fluorinated surfactant, the mixture of ethanol and 2-butoxyethanol and the mixture of propylene-glycol and isopropyl-alcohol. These two treatment solutions showed successful application at reservoir conditions of higher temperature and surmounting pressure [4-5]. A new polymeric surfactant coating was introduced by Sharifzadeh et al and successfully applied for wettability alteration of the Sarkhun reservoir by utilizing a sol-gel process. Contact angle measurement, liquid imbibition tests, and surface characterization techniques, for instance, FTIR, SEM, and EDAX were applied to investigate the influence of wettability alteration [6]. Some of researchers studied Nano fluids as wettability alteration chemicals [7-12]. Aminnaji et al examined the application of Nano fluid for wettability modification of sandstone and carbonate rocks. They reported considerable change in wettability state of rocks being examined. In addition, they concluded that the initial oil saturation affects the ageing time and effectiveness of Nano fluid. Thus, a pre-treatment step was necessary before Nano fluid utilization [13]. Aguirre et al synthesized a Nanofluid to alter the sandstone rock sample wettability from liquid wet to gas wet state. The surfactant and nanoparticles in different combinations were examined and the optimum concentration for the best performance was found [14]. The new fluorocarbon-based chemical was proposed for wettability alteration by Hoseinpour et al. In their research, several dynamic and static experiments were applied on the treated and untreated sandstone rock surfaces to examine the influence of proposed fluorocarbon-based wettability modifier. As a result of their work, fluorocarbon agents were reported to be useful in order to reduce both water and condensate banking in gas condensate reservoirs [15]. The study manifested novel fluorocarbon chemicals for wettability modification of sandstone rock through gas wetting condition. Here, we used contact angle measurement to visually study the response of surface wettability alteration. Hence, surface analysis techniques such as FESEM, EDAX and EDAX map indicated the adsorption of fluorocarbon wettability modifier. Finally, to analyse the impact of fluoro-chemical adsorption on gas-liquid imbibition in rock samples, spontaneous imbibition tests were performed.

2. Materials and experimental methods

2.1. Thin sections and treated samples' preparation

In the current study, rectangular sliced sandstone rocks were made, and then their surfaces were smoothened. Each sample had dimensions of about 2×2 cm and 2 mm thickness. To clean the slices from any contaminant, samples were washed in the Soxhlet containing toluene and methanol. After that, sandstone slices were placed in an oven for 1 day under 100ºC until residual solvents vaporized. These clean samples were immersed in the RTF 10 wt. % and 86-F 6 wt. % solutions for 1 day at 50ºC. The beakers containing treatment solutions should be sealed to prevent the solution from vaporization. In the end, nitrogen gas was used to dry the treated samples. To prepare the samples for SEM and EDAX analyses, all of the steps mentioned before were repeated on the powders of sandstone rock. For spontaneous imbibition test, sandstone core samples from outcrops with porosity and permeability of 19% and 10 md were utilized.

2.2. Contact angle

Contact angles of brine and hexadecane droplets were obtained on the sandstone slices before and after treatment. Measurements were performed at 25ºC temperature in the defined system (rock/air/brine-hexadecane). To determine the contact angles, 5µl drops of brine and hexadecane were placed on the treated and untreated sandstone slices. Photographs of droplets were captured employing a Dino-Lite microscopic digital camera.

2.3. Surface characterization

Scanning electron microscopy (SEM) and energy dispersive X-ray analysis (EDAX) techniques were applied to obtain high-quality images of surface topography and detect the elements present on the sandstone powder surface, respectively. In addition, the distribution of existing elements was determined in the map analysis.

2.4. Spontaneous imbibition test

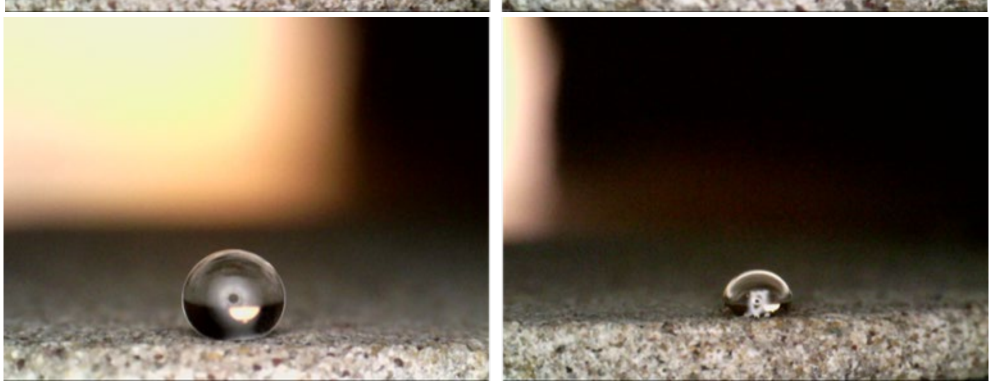
In this step, treated and untreated core samples were selected to be examined in spontaneous imbibition tests under ambient conditions to demonstrate how alteration of wettability affects the liquid imbibition at the core scale [16-19]. The intensity of wettability alteration could be determined by the amount of liquid imbibed into a rock sample. The difference between the weight of core before and after imbibition shows the ultimate volume of liquid imbibed into a rock sample. To avoid swelling of clay that maybe exist in the sandstone, 2 wt. % NaCl brine was applied in water imbibition. In this stage, the spontaneous imbibition experiments were performed for core samples before and after treatment then corresponding results were presented as liquid imbibition amount versus time curves. The chemical treatment of sandstone core samples was conducted by injecting 20 PVs of RTF solution and 86-F solution at a temperature of 50°C. The changes in capillary pressure (force) which were established by wettability alteration into intermediate gas-wet condition, could control spontaneous imbibition in gas condensate reservoirs.

3. Results and discussion

3.1. Contact angle

Contact angle evaluation was applied to determine the efficiency of chemical treatment with RTF and 86-F on the treated samples. In this step, wettability modification of the rock surface was confirmed by measuring contact angles of brine and hexadecane droplets. Droplets of brine and hexadecane on the treated samples are depicted in Figures 1a and 1b. Contact angles of 144 and 86 were obtained for brine and hexadecane droplets on the treated surface by RTF solution, respectively. In addition, brine and hexadecane droplets made contact angels of 152 and 100 with the treated sandstone surface by 86-F solution, respectively. Contact angles obtained for treated surfaces demonstrated wettability modification from liquid wet condition to intermediate gas wetting state.

(a)

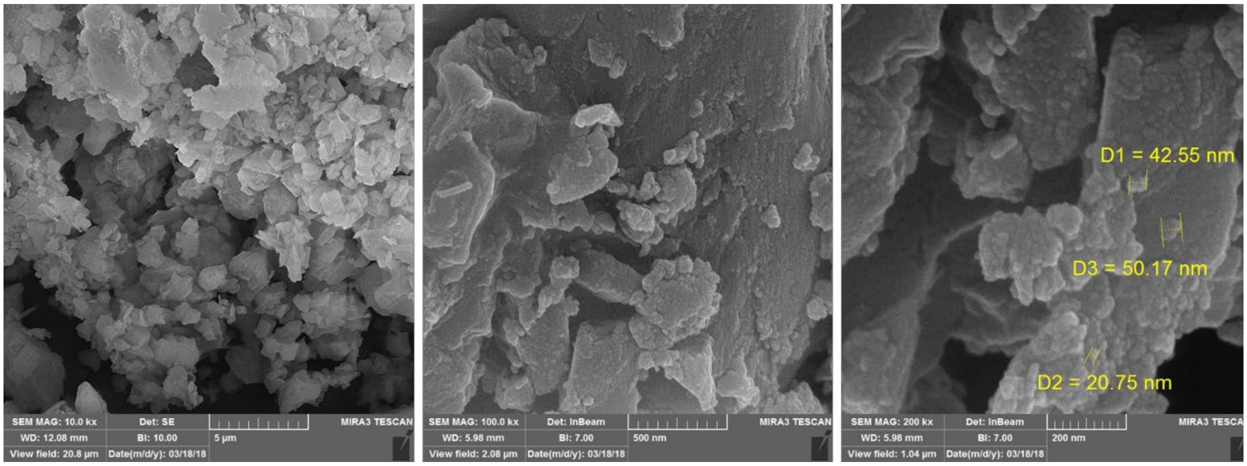


(b)

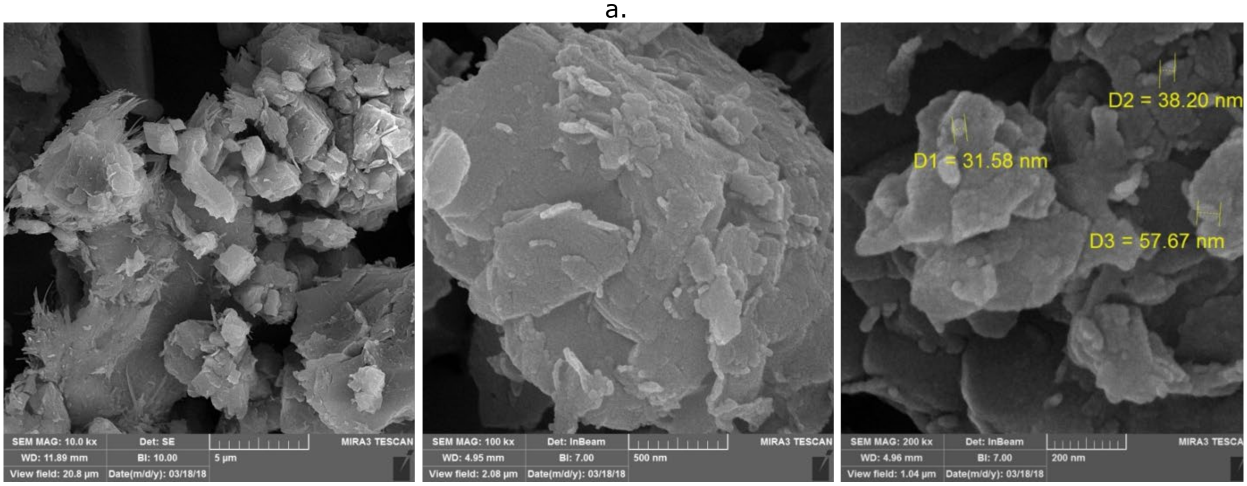
Figure 1. (a) Droplets of brine and hexadecane on the treated sample by RTF solution. (b) Droplets of brine and hexadecane on the treated sample by the 86-F solution

3.2. Surface characterization experiments

In the current study, several methods were used for surface characterization and verification of chemical adsorption onto the rock sample. SEM images were acquired for surface morphology after treatment. Furthermore, EDAX analysis and EDAX maps were performed to obtain surface characterization. SEM images of treated sandstone powders by RTF and 86-F solutions are presented in Figures 2a and 2b, respectively.



a.



b.

Figure 2. (a) SEM images of treated sandstone powders by RTF solution. (b) SEM images of treated sandstone powders by the 86-F solution

EDAX analysis was applied for surface characterization and verification of the chemical adsorption on the sandstone rock samples surfaces. The results of the EDAX analysis of treated powder samples are presented in Figure 3. Detection of fluorine and carbon elements leads to verify chemical layer deposition and development on the sample's surface. This is a reason of decrement in liquid repellency and surface free energy. EDAX maps of various elements on the treated samples are presented in Figures 4a and 4b. Yellow and pink dots illustrate carbon and fluorine atoms that were constituting elements of RTF and 86-F.

3.3. Imbibition experiment

Figures 5a and 5b show liquid imbibition curves of treated cores with RTF and 86-F solutions as a function of time. Brine and hexadecane imbibition into the treated core with RTF solution decreased from 9.1 and 7.2 g to 0.65 and 4 g, respectively. In addition, imbibition of brine and hexadecane liquids decreased from 9 and 7.1 g to 0.6 and 2.6 g, respectively, for the core treated with 86-F solution. As it clears from these figures, the liquid imbibition was decreased after core treatment. This conveys the message that the pore surface of cores prefers to be wetted by the air (gas) phase.

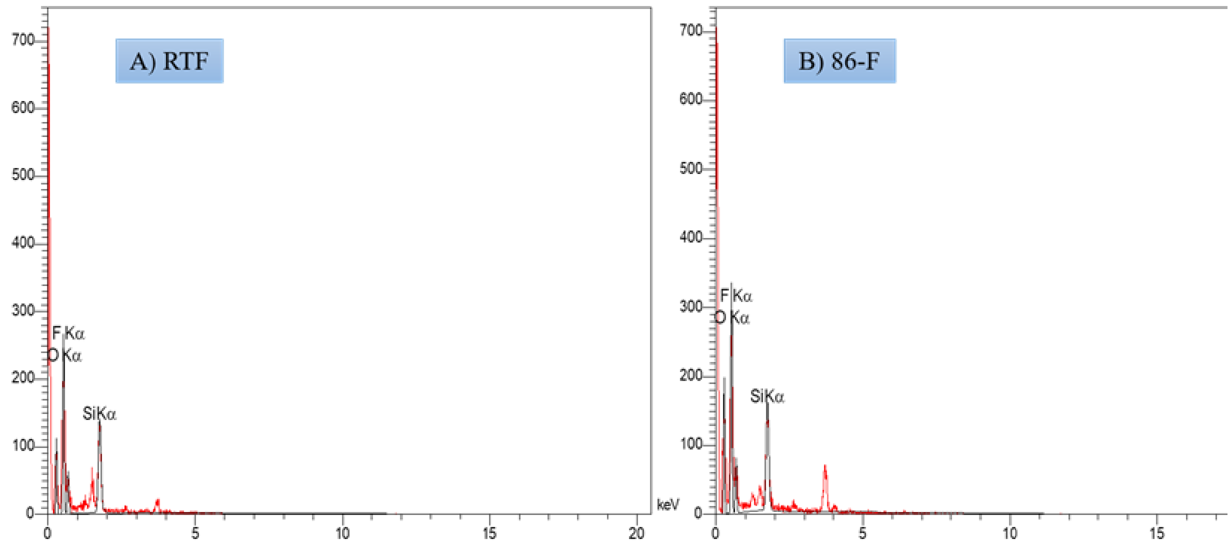
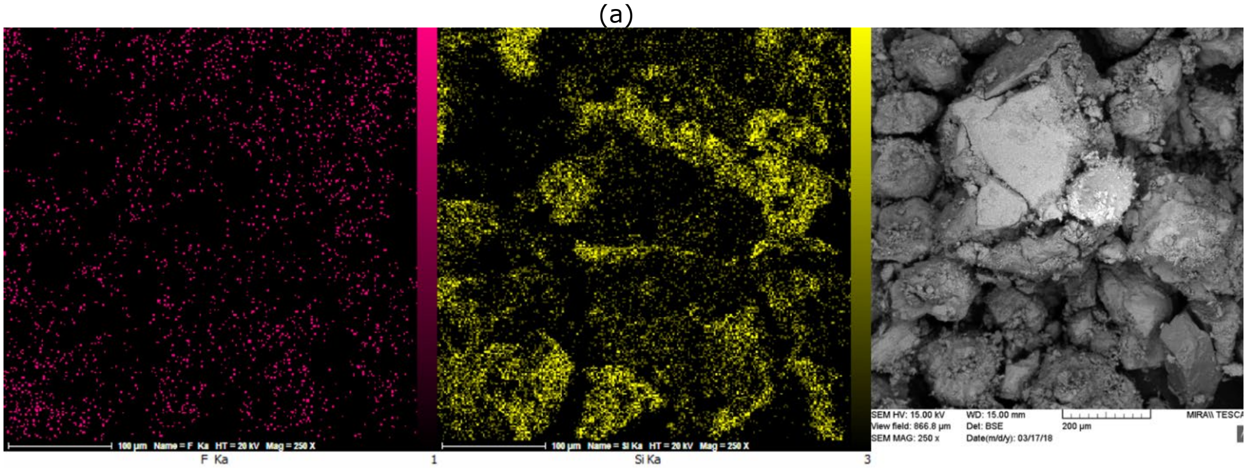


Figure 3. EDAX analysis of treated powder samples

(a)



(b)

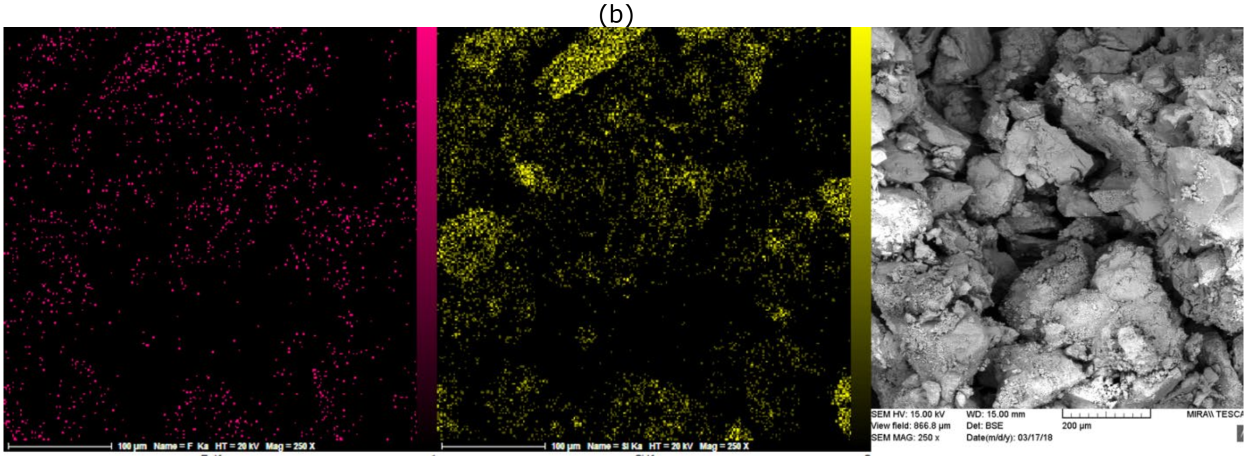
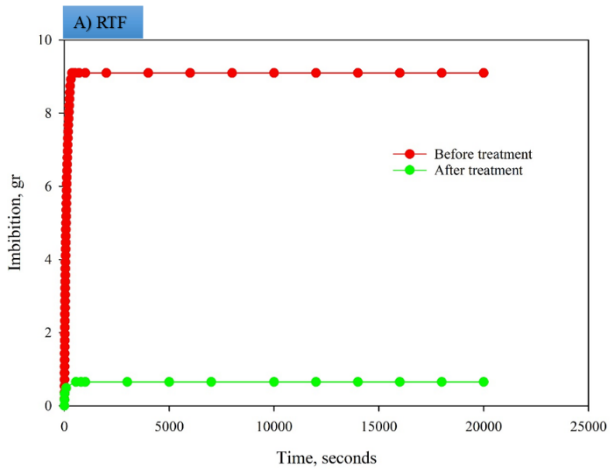


Figure 4. (a) EDAX maps of F and Si elements on the treated sample by RTF. (b) EDAX maps of F and Si elements on the treated sample by 86-F

(a)



(b)

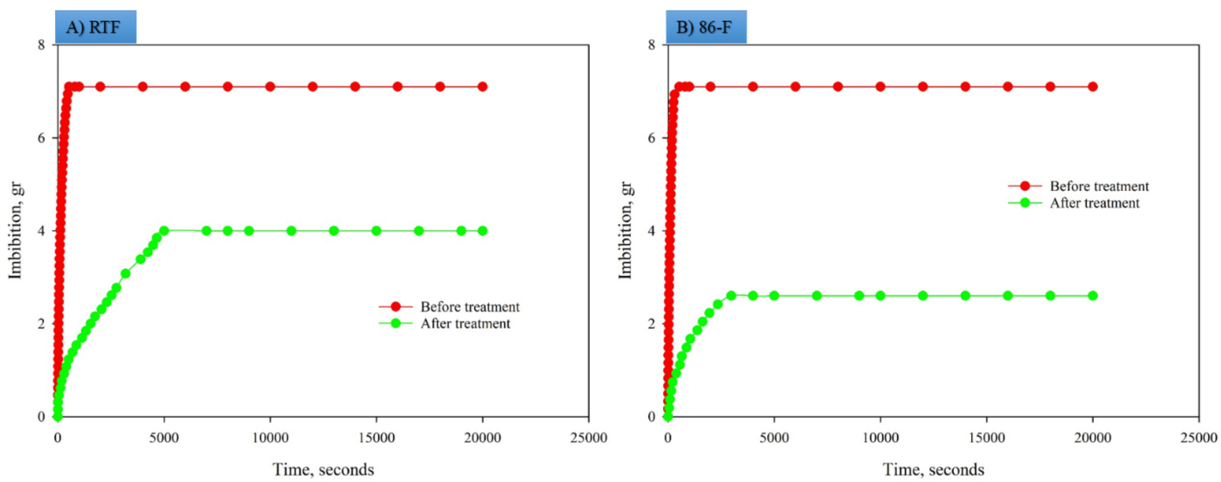


Figure 5. (a) Imbibition of brine into sandstone cores over time. (b) Imbibition of hexadecane into sandstone cores over time

4. Conclusions

In the near future, it is expected that reservoir fluid pressure in most of gas-condensate reservoirs drops below dew point pressure and may undergo condensate blockage. Previous studies related to chemical treatment have proven that adsorption of fluorinated chemicals on different surfaces could lead to the innovative application of these chemicals as hydrophobic and oleophobic agents. Since fluoro-chains of fluorinated surfactants have shown both hydrophobic and oleophobic behaviors, these surfactants can serve as water and condensate repellent agents in the petroleum industry for gas and oil reservoirs. According to the obtained results in this study conclusions can be drawn as follows:

- Static angle measurement of liquid droplets on the sandstone samples demonstrated wettability modification of rock surface from liquid-wet towards gas-wet in all systems.
- The slight alteration in contact angle can remarkably affect the imbibition amount on a core scale.
- To characterize the heterogeneity of treated surfaces, SEM images were obtained. Hence, for dispersal of adsorbed elements on the coated surface and elemental analysis, EDAX analysis and EDAX map were implemented, respectively. SEM images with EDAX analysis

that taken together clearly demonstrated the formation of the chemical film on the surface of the samples coated with RTF and 86-F.

- Ultimate volume of spontaneous imbibition of liquid phases into the treated sandstone cores decreased remarkably.

Conflict of interest statement

On behalf of all the co-authors, the corresponding author states that there is no conflict of interest.

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