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Mitigation of Gas Condensate Banking Using an Integrated Chemical Approach

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Abstract

In gas reservoirs, the well production can be reduced due to the development and accumulation of condensate in the near-wellbore zone. Various techniques are used to minimize the condensate damage and maintain hydrocarbon production. Hydraulic fracturing and wettability alteration techniques are the most effective methods. However, these techniques are expensive, especially in deep gas reservoirs. This paper introduces a new approach for mitigating condensate accumulation by integrating the hydraulic fracturing and wettability alteration treatments. The efficiency of two chemicals that can generate multiple fractures and alter the fracture surfaces to less condensate status is investigated in this work. Thermochemical fluids and chelating agent solutions are used to mitigate the condensate damage and improve gas production for the long term. Several laboratory measurements were carried out to study the performance of the proposed approach; coreflooding, zeta potential, and nuclear magnetic resonance (NMR) experiments were conducted. The chemicals were injected into the tight rocks to recover the condensate and improve the flow conductivity. Zeta potential was performed to assess the rock wettability before and after the chemical injection. Moreover, the changes in pores network due to the chemical treatments as analyzed using the NMR technique. Thermochemical treatment removed around 66% of the condensate liquid, while the chelating agent reduced the condensate saturation by around 80%. The main mechanism for condensate removal during thermochemical flooding is the generation of micro-fractures that increase the rock permeability and improve the condensate flow. On the other hand, chelating agents can alter the rock wettability toward less oil-state, leading to considerable recovery of the condensate liquid utilizing a wettability alteration mechanism. Finally, an integrated approach is suggested to injecting thermochemical fluids followed by chelating agent solutions. The proposed technique can lead to generating micro-fractures of less oil-wet surfaces, consequently, the condensate bank can be removed by more than 90%.

Keywords: Condensate bank, tight gas reservoirs, thermochemical fluids, chelating agents, integrated approach

Introduction

In tight reservoirs, the development of condensate liquid in the near-wellbore region can cause several types of formation damage, leading to a considerable reduction in the hydrocarbon productivity (Sayed and Al-Muntasheri, 2016; Ahmed, 2018; Ayub and Ramadan, 2019; Hassan *et al.*, 2019). Usually, in tight reservoirs, the condensate will be immobile which results in generating a liquid bank that blocks the gas flow (Muskat, 1951; Fevang and Whitson, 1996; Asgari *et al.*, 2014). In some cases, the gas production can be reduced by more than 85% due to the development of a condensate bank around the wellbore. Therefore, various methods are used to mitigate the condensate banking problems and improve gas production (Sayed and Al-Muntasheri, 2016; Sayed *et al.*, 2018; Hassan *et al.*, 2019).

Gas recycling, hydraulic fracturing, and chemical injection are the common methods used for condensate mitigation (Linderman *et al.*, 2008; Maleki *et al.*, 2012; Mahdiyar and Jamiolahmady, 2014). Injection of hydrocarbon or nonhydrocarbon gases can maintain the reservoir pressure above the dew point pressure, leading to condensate re-vaporization (Fevang and Whitson, 1996; Odi, 2012; Meng and Sheng, 2016). However, the gas injection should be applied every 5 to 9 months to maintain effective performance, based on the condensate composition and reservoir properties (Sayed and Al-Muntasheri, 2016; Hassan *et al.*, 2019; Ayub and Ramadan, 2019; Jia *et al.*, 2019). Furthermore, hydraulic fracturing is applied to create creating conductive paths around the wellbore, resulting in reducing the required pressure to flow the condensate liquid to the wellbore (Khan *et al.*, 2010; Mahdiyar and Jamiolahmady, 2014; Jiang *et al.*, 2020). However, the condensate liquid can accumulate around or inside the fractures leading to a significant reduction in the fracturing conductivity (Mahdiyar and Jamiolahmady, 2014; Hou *et al.*, 2016).

In addition, chemical techniques provide an encouraging approach for removing the condensate banking damage and restoring gas productivity (Al-Anazi *et al.*, 2007; Bang *et al.*, 2009; Al-Yami *et al.*, 2013; Ajagbe and Fahes, 2020). Different types of chemicals are injected to remove the condensate liquid including; solvent and surfactants. Solvents are used to dissolve the condensate liquid and decrease the total viscosity, resulting in condensate removal. Surfactants are used to reduce the interfacial tension at the condensate/ gas interface, leading to enhancing the condensate flow (Karandish *et al.*, 2015; Sharifzadeh *et al.*, 2015). However, the injection of solvent or surfactant will solve the condensate problem for the short term, and the condensate will be generated and accumulated again around the wellbore (Schultz *et al.*, 2003; Hassan *et al.*, 2019). Therefore, wettability alteration chemicals are proposed as an effective solution for condensate banking damage, by reducing the liquid-wetness of the rocks (Al-Anazi *et al.*, 2007; Karandish *et al.*, 2015; Liu *et al.*, 2015). The common chemicals used in wettability alteration treatments are anionic surfactants, fluorochemical, fluorocarbon, and fluorinated silica (Li *et al.*, 2011; Zheng and Rao, 2011; Aminnaji *et al.*, 2015; Safaei *et al.*, 2020).

Different techniques are used for mitigating condensate banking and improve reservoir productivity. However, most of the available methods are either expensive or temporary treatments. Also, chemical treatments are usually targeting one or two removal mechanisms, and limited studies present the integration of different chemicals. Among different techniques, hydraulic fracturing and wettability alteration treatments have shown effective performance for solving the condensate damage problems. The limitations of these treatments can be minimized by modifying the treatment application. For example, hydraulic fracturing treatments are mainly applied by generating pressure pulses from the surface that leads to frack the reservoir formation and generate conductivity paths. In situ pressure generation will be a good modification of the conventional hydraulic fracturing operations, which results in higher performance and less operation cost, since the pressure pulses will be generated only with the target formations. Moreover, injecting wettability alteration chemicals after applying hydraulic fracturing can solve the issue of condensate accumulation within the fractures.

Therefore, this work aims to study the performance of two effective fluids that can combat the condensate damage challenges. In this work, thermochemical fluids and chelating agent solutions were used to remove the condensate bank and increase the formation productivity. Thermochemical fluids can react at the reservoir condition and generate pressure pulses that lead to creating multiple fractures. The chelating agent can alter the rock surface to less liquid-wet status leading to mitigate the condensate accumulation. Different approaches are used to assess the performance of thermochemical fluids and chelating agent treatments. Coreflooding, zeta potential, and nuclear magnetic resonance (NMR) experiments were conducted. The condensate removal and the recovery mechanism during thermochemical and chelating agent flooding are analyzed.

Materials and Measurements

Materials

Tight rock samples were used in this work, the rock samples were prepared for the condensate removal treatment by drying the samples and measuring their petrophysical properties. The samples have an average permeability of 0.6 mD and total porosity of 13%. The core length and diameter are 4 and 1.5 inches, respectively. Furthermore, the used chemicals are thermochemical solutions that are sodium nitrite and ammonium chloride. Also, ethylenediaminetetraacetic acid (EDTA) chelating agent was used in this work. Thermochemical fluids can generate pressure up to 5000 psi and temperature up to 700 °F, based on the chemical concentration and volumes. EDTA can successfully adjust the rock surface charge leading to alter the rock wettability to less oil-wet conditions. Moreover, 3wt% KCl solution was used to measure the rock permeability as well as saturating the rock samples for NMR measurements.

Measurements

In this work, the performance of thermochemical and chelating agent solutions in removing the condensate damage and improve productivity is studied. Various laboratory measurements were used including; coreflooding, NMR, and zeta potential analysis. The chemical solutions were injected into the tight cores at high pressure and high-temperature conditions. Thermochemical fluids were injected to react only inside the rock samples to generate the pressure pulses. The rock porosity system was analyzed before and after thermochemical flooding using the NMR technique. The T2 profiles were used to understand the changes induced in the tight pores network due to the chemical treatment. Moreover, chelating agents were injected to change the rock wettability and improve condensate mobility. Zeta potential measurements were used to assess the rock surface charges before and after chelating agent flooding. In all lab analyses, the same experimental conditions were applied before and after the treatment to minimize the experimental errors and to obtain representative results.

Results and Discussion

Condensate liquid can accumulate around the wellbore and block the gas flow, leading to a significant reduction in hydrocarbon production. Chemical treatment can reduce the condensate saturation in the near-wellbore region, resulting in minimizing the impact of condensate banking. Wettability alteration is the most effective mechanism that can help in mitigating the condensate accumulation, mainly by reducing the liquid wetness on the rock surface around the wellbore. Also, hydraulic fracturing presents an effective solution for alleviating the condensate bank damage, by creating conductive paths around the wellbore. Thermochemical fluids can be used to generate pressure pulses at the wellbore conditions, the generated pulses can induce multiple fractures in the tight formations. Wettability alteration and hydraulic fracturing mechanisms can be integrated to provide conductive paths with less liquid wet surfaces, as will be discussed in this paper. First, the performance of thermochemical fluids in removing the condensate bank and improve the rock conductivity is presented. Then, the performance of the chelating agent solution in mitigating the condensate accumulation by altering the rock surface charge is analyzed. Finally, an integrated approach that combines the benefits of thermochemical fluids and chelating agents is presented.

Thermochemical Fluids

Thermochemical fluids were injected into tight rock samples to mitigate the condensate banking. Figure 1 shows the profiles of remaining condensate saturation and pore pressure during the injection of thermochemical fluids, where four injection cycles were applied. Around 66% of the condensate liquid was removed using thermochemical treatment. After four injection cycles, the remaining condensate saturation is around 34%. The highest reduction in condensate saturation was achieved during the first injection cycle; around 57% of the condensate liquid was recovered at the first cycle, this could be due to the high liquid saturation. Applying more treatment cycles led to a further reduction in the condensate saturation. It should be noted that two injection approaches can be used during thermochemical treatment; continuous or cyclic injection techniques. Our lab investigations indicated that the cyclic injection approach would provide better performance compared to the continuous injection. Because more time (soaking periods) will be provided during the cyclic injection, which improves the thermochemical reaction and more pressure pulses will be generated. Moreover, during injection cycles, the pore pressure increased significantly due to the thermochemical reaction inside the tight pore space, a maximum pore pressure of 1940 was achieved. The sudden rise of pore pressure can induce multiple fractures in the rock matrix. NMR technique was used to analyze the rock samples before and after the chemical injection. Figure 2 shows the incremental porosity profiles before and after thermochemical treatment, multiple fractures were generated after the treatment. The fracture generation was indicated by the second peak between relaxation time of 100 and 1000 ms, confirming that a new pore space of larger pore throat was generated after the treatment. Basically, this new pore space represents multiple fractures. Overall, thermochemical treatment can successfully mitigate the condensate accumulation by inducing multiple fractures that help in recovering the condensate liquid.

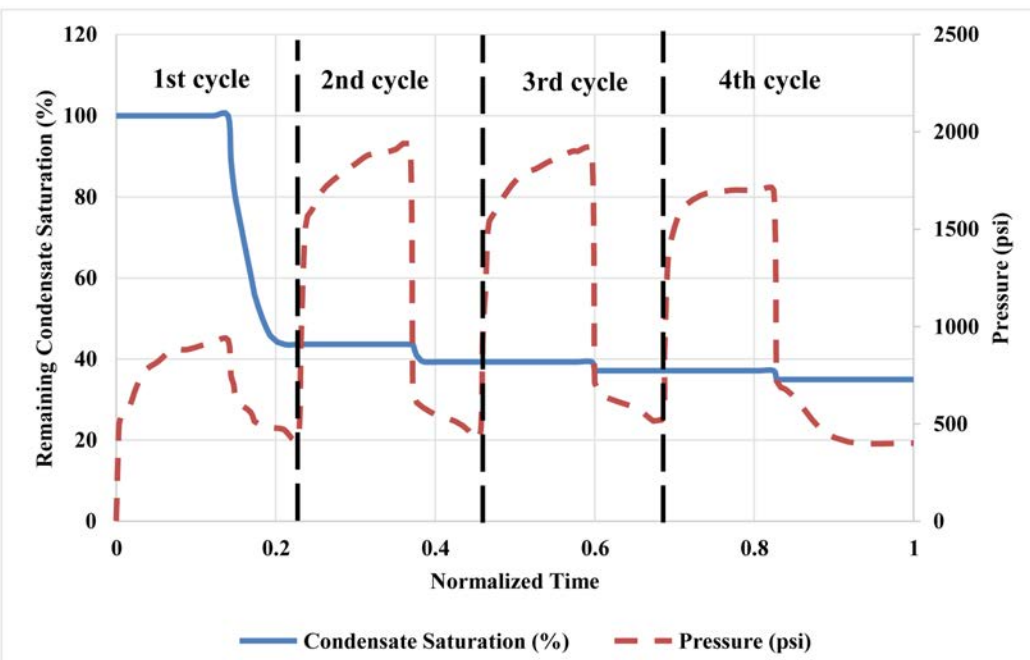

Figure 1—Profiles of remaining condensate saturation and pore pressure during the injection of thermochemical fluids, four injection cycles were applied.

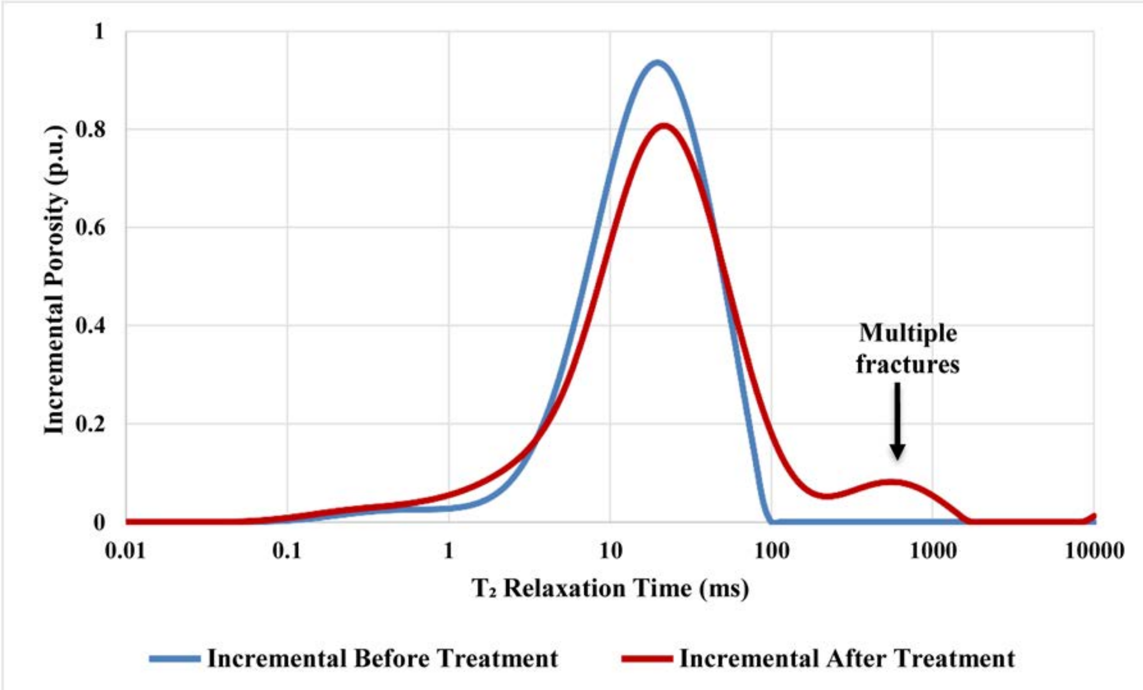

Figure 2—The incremental porosity profiles pre-and post- thermochemical injection, multiple fractures were generated due to the chemical treatment.

Chelating Agent

The performance of the EDTA chelating agent in recovering the condensate liquid from rock samples was studied. Seawater brine and deionized water were used as references fluids; the same experimental conditions were applying during seawater brine, deionized water, and 5wt%EDTA floodings. Figure 3 shows the profiles of remaining condensate saturation during the injections of seawater, 5wt%EDTA, and deionized water. Using 5wt% EDTA solution led to a recovery of around 80% of the original condensate in place, and remaining condensate saturation of 20% was achieved at the end of EDTA treatment. However, injection of seawater and deionized water showed a recovery of 20% and 50%, respectively. Given that the same experimental conditions were applied; therefore, it can be concluded that chelating agents can remove more condensate liquid compared to seawater and deionized water. The primary removal mechanism is considered to be wettability alteration. Injection of chelating agents can lead to altering the rock surface charges, resulting in less oil-wet conditions (Jackson et al., 2016; Mahmoud and Al-Hashim 2018). Therefore, in this work, the changes in rock surface charges were examined using different concentrations of EDTA chelating agent. Figure 4 shows the zeta potential results during the injections of 5, 7.5, and 10 wt.% of EDTA chelating agent, more negative charges were obtained at higher EDTA concentrations. In the presence of oil, more negative charges were observed indicating that EDTA successfully alters the rock wettability to less oil-wet conditions. Initially, the liquid oil has negative surface charges due to the presence of the carboxylic group, hence inducing negative charges at rock surface leads to repulsive forces due to the same electrical charges. Consequently, the oil droplets will move away from the rock surface, resulting in a less oil-wet condition. Increasing the EDTA concentrations led to an increase in the magnitude of the surface charges, thereby more repulsive forces will be induced. Overall, injection of EDTA chelating agent into condensate region can change the rock surface charges to more negative values, leading to a less oil-wet condition due to the repulsive forces between the rock surface and the condensate droplets.

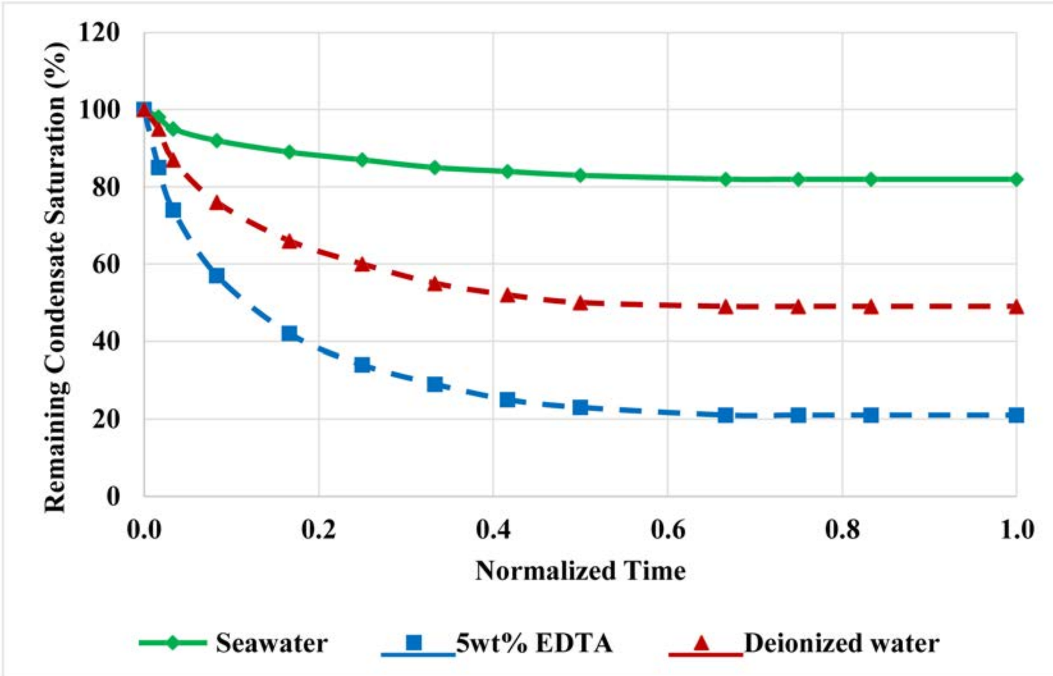

Figure 3—Profiles of remaining condensate saturation during the injections of seawater, 5wt%EDTA, and deionized water.

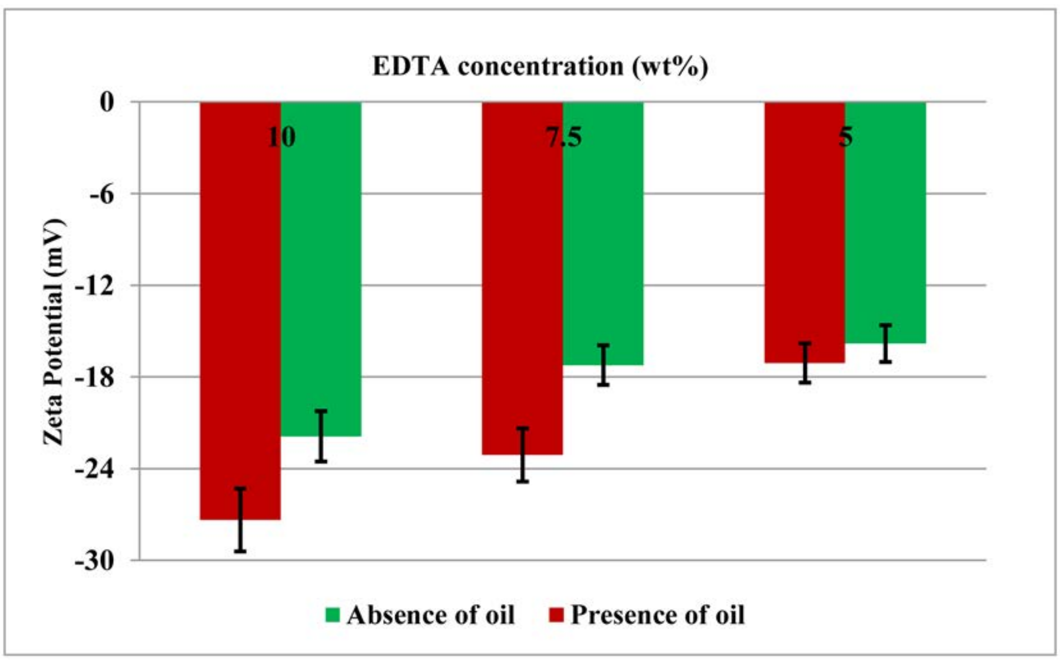

Figure 4—Zeta potential results during the injections of 5, 7.5, and 10 wt.% of EDTA chelating agent, more negative charges were obtained at higher EDTA concentrations.

An Integrated Chemical Approach

Chelating agents and thermochemical fluids can be injected sequentially to remove and mitigate the condensate accumulation. First, thermochemical fluids can be injected to react downhole and induce multiple fractures around the wellbore, leading to an increase in the formation conductivity. Thereafter, chelating agents such as EDTA can be injected to change the wettability of the fracture surface to less oil-wet status. This technique can integrate the benefits of both thermochemical fluids and chelating agents. A very efficient treatment can be provided by applying this approach, a condensate removal of more than 90%

can be achieved. A remaining condensate saturation of less than 10% can be obtained, which significantly improves gas production and minimize any liquid blockage. Applying the integrated approach can provide higher condensate removal compared to the conventional treatments because more removal mechanisms will be involved. Thermochemical fluids will reduce the required pressure to flow the condensate liquid, by inducing conductive paths that increase the total formation permeability. While chelating agents change the rock surface charges to more negative values that induce repulsive forces and alter the rock wettability to less oil-wet conditions. Overall, thermochemical fluids and chelating agents' solutions showed very attractive performance in mitigating the condensate bank. Several removal mechanisms can contribute to removing the condensate liquid and preventing condensate accumulation. However, integrating chelating agents and thermochemical fluids showed better performance, resulting in a condensate removal efficiency of more than 90%, and remaining condensate saturation of less than 10% can be achieved. Nevertheless, more investigations are required to optimize the performance of the integrated chemical treatment. Finding the optimum chemical volumes and treatment time can be an attractive research topic. Also, examining the condensate removal efficiency on large scale is highly recommended.

Conclusions

This paper presents an integrating chemical approach for removing the condensate banking, using thermochemical fluids and chelating agents. The individual performance of these chemicals was studied, then an integrated approach that combines the efficiency of both fluids is discussed. The following conclusions can be drawn based on this work;

- Injections of thermochemical fluids and chelating agents can remove around 66% and 80% of the condensate liquid, respectively.
- The thermochemical treatment induces multiple fractures in the treated rocks due to the in situ generation of pressure pulses.
- Chelating agent treatment can alter the rock surface wettability by increasing the negative surface charges of the rock surface.
- An integrated approach is presented that mitigates the condensate damage by more than 90%, utilizing the effective mechanisms of thermochemical and chelating agent fluids.

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Nomenclature

EDTA: Ethylenediaminetetraacetic acid
KCl: Potassium chloride
mD: Millidarcy
ms: Milliseconds
NMR: Nuclear magnetic resonance

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