Preventing Hydrate Adhesion with Magnetic Slippery Surfaces

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ABSTRACT: Hydrate formation is a common challenge in the oil and gas industry when natural gas is transported under cold conditions in the presence of water. Coatings are one of the solutions that have shown to be a promising approach to address this challenge. However, this strategy suffers from the intrinsic existence of a solid–liquid interface causing a high rate of hydrate nucleation and high hydrate adhesion strength. This proof-of-concept study highlights the performance of a magnetic slippery surface to prevent hydrate adhesion at atmospheric pressure using tetrahydrofuran hydrates. The coating consisted of a hydrocarbon-based magnetic fluid, which was applied to a metal surface to create an interface that lowered the hydrate adhesion strength on the surface. The performance of these new surfaces under static and dynamic (under fluid flow) conditions shows that the magnetic coating gel can be a potential inhibitor for hydrate adhesion as it reduced the torque value after the formation of hydrates.

1. INTRODUCTION

Gas hydrates are icelike solids that form when water is combined with a gas molecule such as ethane, methane, propane, or carbon dioxide at low temperatures and elevated pressure.¹⁻⁴ There are various deposits of hydrates below the permafrost and on the seafloor. Extensive research is being conducted to extract the gas that is trapped in the hydrates. The estimated reserve of hydrates is enormous, making hydrates a potential source of unconventional gas reserves.⁵ Although clathrate hydrates are a promising source of natural gas, the nucleation of hydrates in pipelines and adherence to the walls of subsea natural gas pipelines are major concerns.⁶,⁷ This causes blockages of pipelines and production tubing, making necessary the removal of the plug, which is a costly and complex process.⁸⁻¹⁰ In some extreme cases, the hydrate plugs may damage the gas transport facilities, which poses a safety hazard.

To prevent hydrate formation in subsea pipelines, chemical inhibitors are used, which fall into two categories, thermodynamic inhibitors and low-dosage hydrate inhibitors (LDHIs).¹¹ Examples of thermodynamic inhibitors include methanol as well as monoethylene glycol (MEG).¹² LDHIs are subdivided into kinetic inhibitors (KHIs) and antiagglomerants (AAs).¹³ When methanol or ethylene glycol is used at sufficiently high concentrations, hydrate formation can be prevented.¹² However, the required concentration of the thermodynamic inhibitors can be as high as 50% based on the water phase. Thermodynamic hydrate inhibitors are classified as inhibitors that prevent hydrate formation by elevating the pressure and lowering the temperature of formation for hydrates, which decreases the likelihood of hydrate formation.¹⁴ The advantage of using thermodynamic inhibitors is the reliability of the approach and the relatively low cost of the chemicals; however, this is offset by the volumes required and the need for recycling facilities to regenerate the MEG.¹⁴⁻¹⁶

Overall, the cost of methanol is lower than MEG per gallon; however, the amount used to inhibit hydrate mitigation is significantly high, making methanol injection costly, too.¹⁷⁻¹⁹ As stated above, the concentration of thermodynamic inhibitors is also extremely high (60% of the mass of water being produced).¹⁹ Furthermore, there are environmental and safety concerns surrounding thermodynamic inhibitors. For MEG, the cost is higher than that of methanol and the viscosity can cause issues with pumping the inhibitor, which can increase capital costs.²⁰ Insulating and heating pipelines is another approach, but this requires high operating costs and often thermodynamic inhibitors are required to inhibit hydrate formation but in a lower volume.¹,²

Alternatively, LDHIs can be used including KHIs, which delay the hydrate formation, or AAs, which prevent the hydrate adhesion. KHIs can be used as a substitute or in conjunction with thermodynamic hydrate inhibitors like methanol or monoethylene glycol (MEG).²¹,²² Typically, KHIs are water-soluble polymers that delay nucleation. There are various proposed mechanisms for KHIs with the water-soluble polymer forming hydrogen bonds with water molecules, therefore inhibiting hydrate formation.²³,²⁴ Examples of conventional water-soluble polymeric kinetic inhibitors are poly(vinyl caprolactam) and poly(vinyl pyrrolidone).²³ The
advantage of using KHI s is the lower volume required when compared to thermodynamic inhibitors (methanol or MEG). This significantly reduces the cost of regeneration as well as the purchase cost of hydrate inhibitors. However, the performance of KHI s can be limited because of the low inhibition properties of the KHI s during shut-ins, which is a major disadvantage. This necessitates the use of secondary hydrate control methods. Alternative LDHI s exist called antiagglomerants (AAs), which do not prevent hydrate formation but prevent hydrate adhesion, thereby preventing plugging. Therefore, AAs permit the formation of hydrates but keep the particles well dispersed. LDHI s are the most expensive hydrate inhibitors by per-gallon cost, even though the volume needed to be injected is far lower as compared to the other chemical inhibitors, but LDHI still makes up a huge amount as according to the previous work, the optimum amount of LDHI used 1 gal/bbl of water produced. Therefore, a cheaper and economical hydrate inhibitor is necessary to be developed. Furthermore, due to the extended period of shut-ins (2 weeks), an LDHI would not be able to inhibit hydrate plug formation. Overall, existing LDHI s do not meet all of the operational, performance, and cost demands, so new approaches are required.

The aim of this study was to explore an alternative approach to chemical inhibition using a ferrofluid as a coating to create a liquid—liquid interface that can prevent the adhesion of hydrates. This could be applied in high-risk areas such as low spots of the tubing and pipeline. The application of the ferrofluid in the pipeline can be done by pumping the fluid into the gas pipeline, and once the magnetic fluid reaches the designated low spot, magnets that are placed on the outer part of the pipeline will attract the fluid onto the inner wall of the pipeline, creating a liquid—liquid interface, preventing the adhesion of hydrates. The concept is further illustrated in Figure 1. In the event of pigging operations, the magnetic fluid can be easily removed from the inner pipeline surface without unsettling the magnets on the outer wall of the pipeline.

The magnetic slippery surface used in this study was created using a ferrofluid, which consists of finely dispersed magnetic particles in a carrier fluid, a conventional liquid with magnetic properties. The particles in the ferrofluid are dispersed uniformly through the carrier liquid, even when a magnetic field or any other force field is introduced. This permits the application of ferrofluids in many fields such as ferrofluid sealing, heat transfer enhancement, magnetic separation, biomedicine, and inertia damping. There are a variety of ferrofluids that have been prepared, which include hydrocarbon-based, water-based, organic-liquid-based, and silicon-based ferrofluids. This study focuses on hydrocarbon-based ferrofluids. In addition, ferrofluids have been investigated to prevent ice adhesion by forming an icephobic coating, where the ferrofluid was extremely effective. The magnetic field does not only form an icephobic surface with the ferrofluid but also locks the ferrofluid in place. By locking the ferrofluid in place, the magnetic fluid is able to withstand high shear stresses from the production flow. Furthermore, production costs can be lowered using hydrocarbon-based magnetic fluid due to the low evaporation rate, which increases the longevity of the magnetic fluid. With the use of ferrofluids, a significant investment must be provided to coat the low spot of the pipeline with the magnetic fluid, but when compared in the long term, the cost of hydrate inhibition will be lower. In a further study, a hydrocarbon-based ferrofluid was employed as an antiscaling magnetic slippery surface. Using a hydraulic circuit to test the magnetic fluid portrayed prominent results where the formed scale did not adhere to the pipe wall. The results from the above work also support the conclusion made by Irajizad et al. as well as convey the excellent antiscaling property of ferrofluids.

For this study, a hydrocarbon-based ferrofluid was used as a magnetic slippery surface for inhibiting the adhesion of hydrates onto steel substrates due to the interface between the hydrate and the ferrofluid. The self-healing properties and the ability of the magnetic field to latch the magnetic fluid in place enable the longevity of the ferrofluid and the fluid to overcome high shear stress, respectively. More importantly, the magnetic fluid can be applied under conditions of shear. However, the fluid can deplete over time; therefore, a ferrofluid gel was also used to prevent the loss of the coating. The ferrofluid coating was studied with a model hydrate using tetrahydrofuran (THF), which is commonly used for testing KHI s. Ideally, the ferrofluid would be tested under pressure, but that is nontrivial, and a specially designed system would be required, which is why THF hydrates were used. THF hydrates have been used in numerous studies as a model for hydrate formation. The use of THF hydrates is due to the simplicity of producing and handling the hydrates formed as this is only a preliminary test to determine the adhesion inhibition of ferrofluids.

2. EXPERIMENTAL SECTION

2.1. Materials. Tetrahydrofuran (99% inhibitor free) and polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene were purchased from Sigma-Aldrich and used as received. An oil-based ferrofluid with a density of 1.21 g/cm³ was used, which consisted of iron oxide, oil-soluble dispersants, and...
hydrotreated light was purchased from Ferrotec Inc. The magnetic fluid used has flash and boiling points of 95 and 223 °C, respectively. The precise composition of the ferrofluid mixture is proprietary information, but the general composition is as shown in Table 1.

### Table 1. Composition of the Ferrofluid

| composition                        | proportion % (by volume) |
|------------------------------------|--------------------------|
| iron oxide (magnetite)             | 8                        |
| oil-soluble dispersant             | 14                       |
| light hydrocarbon oil              | 78                       |

2.2. Preliminary Test Procedure to Determine the Antiadhesion Properties. First, an experiment was conducted to prove that the ferrofluid has a good icephobic surface. Hence, a droplet of distilled water (30 μL) was placed on a 7 × 0.5 cm² NS2 neodymium magnet coated with the ferrofluid and placed in a freezer at −5 °C for 30 min. The magnet was then removed and tilted at various angles to see whether there was any solid—liquid interface formed due to the adhesion of the formed ice to the surface of the magnet.

Tetrahydrofuran (THF) hydrate was then used. THF is miscible with water and forms hydrates at temperatures below 4.4 °C and atmospheric pressure when a solution of 19.1% THF (by weight) in water is used. Therefore, a droplet of 19.1% THF solution was placed on a 7 × 0.5 cm² NS2 neodymium magnet. The magnet along with the droplet was then placed in the freezer at −5 °C for 30 min. The magnet was then removed and tilted at various angles. The experiment was then repeated by coating the surface of the neodymium magnet with the ferrofluid and diesel oil separately.

2.3. Mechanical Test of THF Hydrates. This test was performed to determine how much force was required to overcome the adhesion between the hydrate and the ferrofluid. A mold was created by pouring 50 mL of distilled water in a steel cylinder along with steel wires and placed into the freezer −15 °C for 3 h. A total of 25 mL of 19.1 wt % THF solution was then added with a cuboid neodymium magnet (7 × 0.5 × 0.5 cm³) immersed at a depth of 0.5 cm and placed in the freezer for another 2 h. The mold was then inverted, and the open side of the magnet was placed into 50 mL of distilled water with steel wires and placed in the freezer for 3 h. The experimental configuration is shown in Figure 2. Water was then added at 200 mL intervals into the pail until the magnet broke off from the mold.

The volume of water was recorded and converted to the force required to overcome the hydrate adhesion force using Formula 1.

\[
F = \left( \rho V_i + m_p + m_{\text{gel}} \right) g
\]  

where \( F \) denotes the force, \( \rho \) is the density of water used, \( V_i \) is the volume of water needed to overcome the adhesion force, \( m_p \) is the mass applied to the coating, \( m_{\text{gel}} \) is the mass of the bottom mold, and \( g \) is the gravitational constant. The experiment was then repeated by varying the immersion depth of the neodymium magnet bar and later coating the neodymium magnet with the ferrofluid.

2.4. Torque Measurement of THF Hydrates on a Ferrofluid Coating. This study was performed to examine the adhesion inhibition properties of the ferrofluid under dynamic conditions (shear flow). The experiment was carried out with the ferrofluid in both liquid and gel forms. The gel ferrofluid was prepared by adding polystyrene-block-poly(ethylene-ran-butylene)-block-polystyrene (co-polymer) to the oil-based ferrofluid at a ratio of 1:24 and preswollen for 20 h and then heated up at 120 °C for 2 h in an oven. The gel was prepared by stirring on a hot plate at 110 °C for 1 h. The mixture was then cooled to room temperature and later placed in an oven at 50 °C for 20 h. The gel was then allowed to cool to room temperature. For the shear flow experiment, 30 mL of 19.1 wt % THF solution was poured into a steel cylinder coated with 10 mL of the ferrofluid liquid and placed in an insulated Styrofoam box filled with ice. An overhead stirrer was then used to simulate a dynamic flow as the temperature of the fluid decreased below the THF nucleating temperature. The torque value was calculated by analyzing the change in revolutions per minute (RPM) using Formula 2.

\[
T = \frac{9.549 \times P}{\Delta \text{RPM}}
\]  

where \( T \) represents the torque, \( P \) is the power supplied to the overhead stirrer, and \( \Delta \text{RPM} \) is the change in RPM from the initial value where 19.1 wt % THF was stirred to the final value when hydrates had formed. The experiment was then repeated by switching off the stirrer until the hydrate was formed, which is approximately 1 h and then the stirrer was switched on. This was done to test the adhesion inhibition properties of the ferrofluid under shut-in conditions. The experiment was then repeated by varying the amount of the liquid magnetic fluid coating and followed by the magnetic fluid gel. The apparatus setup is as shown in Figure 3.

### 3. RESULTS AND DISCUSSION

3.1. Preliminary Test on the Antiadhesion Property of the Ferrofluid. This preliminary experiment was conducted to prove the antiadhesion properties of ferrofluids under static conditions. Figure 4 shows the images obtained from the experiments using water on neodymium magnets.

Figure 4A,B shows the formation of ice from the water droplet on the surface of the magnetic fluid. Clearly, the ferrofluid does not prevent the formation of ice, so the magnets were tilted to a maximum angle of 90°. As can be seen from the images in Figure 5, at the angle of 90°, the ice formed on the surface of the magnet does not drop, concluding that the adhesion force of the ice onto the surface of the magnet is strong enough to prevent the ice from falling. This is not surprising since ice adheres strongly to surfaces. However,
when the surface is coated with a ferrofluid, the ice slides along the surface and falls onto the steel plate with the slightest of movement, which is in line with previous research, where a magnetic slippery surface (ferrofluid) is an excellent icephobic surface.

The experiment was repeated using 19.1 wt % tetrahydrofuran solution, which showed that the ferrofluid does not prevent the nucleation of hydrates, but when the magnet was tilted up to an angle of 90° (Figure 6), the results obtained were similar to the outcome of the water-only case where the adhesion force is strong enough to prevent the hydrate from

Figure 3. Schematic of the experiment configuration used to investigate the adhesion inhibition properties of the ferrofluid and ferrofluid gel.

Figure 4. (A) Water droplet on the ferrofluid-coated neodymium magnet; (B) formed ice droplet on the ferrofluid-coated neodymium magnet.

Figure 5. 90° tilted ice droplet on a neodymium magnet.

Figure 6. 90° inclined THF hydrate on a neodymium magnet.
falling off the magnet. When the test was repeated in the presence of a ferrofluid coating, the hydrate did not stick to the surface of the magnet and falls of as soon as the magnet is moved slightly. This demonstrated that the ferrofluids do not prevent the formation of hydrates but lower the adhesion of hydrates.

The experiment was then repeated by coating the neodymium magnet with diesel oil as a control to eliminate the possibility of antiadhesion due to hydrocarbons in the ferrofluid. The diesel-coated neodymium magnet did not inhibit the formation of both hydrate and ice and the experiment was continued with the tilting of the magnet to an angle of 90° as shown in Figures 7 and 8.

When the neodymium magnet was tilted at an angle of 90° as shown in Figures 9 and 10, both the hydrate and ice formed can be seen to adhere strongly to the surface of the neodymium magnet. Hence, diesel oil as a representative hydrocarbon is a poor adhesion inhibitor and supports the initial claim of this research that the magnetic properties (iron particles) contribute to the antiadhesion properties of the fluid.

### 3.2. Mechanical Test of THF Hydrates

To quantify the strength of the adhesion between the hydrate and the coating, a test was performed using the experimental configuration shown in Figure 2. Figure 9 illustrates the results obtained from testing the adhesion of hydrates. When the magnet was immersed at depths of 0.5 and 1 cm, averages of 4 and 15 kg were required to overcome the adhesion force the hydrate had on the magnet.

Meanwhile, when the magnet was immersed to 2 and 2.5 cm, 21 kg of weight was insufficient to overcome the adhesion force between the hydrate and the magnet. The maximum weight that could be used was 21 kg, which was the volume limit experimental configuration; in particular, the cable that connected the weight to the hydrate failed. The main observation for these experiments without a ferrofluid coating
is the substantial force that is required to separate the magnet from the hydrate mold. On the contrary, in the presence of a ferrofluid coating on the neodymium magnet, the magnet did not adhere to the hydrate as when removing the sample from the freezer, the magnetic-fluid-coated magnet comes out with a minimal force. This indicates that a minimal force was required to overcome the adhesion forces between the magnet and the hydrate mold in the presence of the ferrofluid coating. Again, this proves that the magnetic fluid is an excellent hydrate adhesion inhibitor.

To have a better understanding of the effect of hydrate adhesion, the surface area that was adhered by the hydrate for each immersion was calculated using the following procedure:

1. The total surface area of the hydrate adhered to the magnet was calculated using the below formula

   \[
   \sum S, \text{ cm}^2 = 4W\Delta h, \text{ cm}^2 + WL, \text{ cm}^2
   \]

   where \( \sum S \) is the total adhered surface area, \( W \) is the width of the magnet, cm (\( \sim 0.5 \text{ cm} \)); \( \Delta h \) is the depth of immersion, cm; and \( L \) is the length of the magnet, cm (\( \sim 0.5 \text{ cm} \)).

2. The average force required to separate the magnet from three repeat tests is shown in Table 1, where the force required to separate the hydrate per surface area was calculated using the following formula

   \[
   \text{force per surface area, N/cm}^2 = \frac{F}{\sum S}
   \]

   where \( \sum S \) is the total adhered surface area, \( W \) is the force required to separate the neodymium magnet from the hydrate mold, N.

The results obtained are tabulated in Table 2.

As seen in Table 2, the force per surface area or pressure increases as the immersion depth of the magnet increases in the absence of the ferrofluid. The reason for the lower pressure value for the depth of immersion of 2 cm is justified due to the constraint mentioned previously. This experiment demonstrates the amount of pressure required to detach the hydrate from the walls of the pipeline.

When the magnet was coated with the ferrofluid, a small amount of force was required to detach the magnet, and this means that there is minimal adhesion between the ferrofluid and the hydrates. This offers a possible strategy to prevent hydrates from sticking to pipelines. However, these experiments are under static conditions, so subsequent experiments were performed under dynamic conditions.

### 3.3. Torque Measurement of THF Hydrates

The experiment was conducted under shear flow (flowing), and a shut-in condition was simulated by stopping the stirring. The amount of the ferrofluid required to prevent hydrate adhesion was determined under these conditions. The torque value obtained is the direct representation of the level of the adhesion of hydrates; the higher the torque value, the higher the force required for the stirrer to rotate. This is due to the formation of THF hydrates in the steel cylinder and adherence to the wall forming a solid and hence preventing the stirrer to rotate. The results are tabulated for flowing and shut-in conditions in Tables 3 and 4 and the results are plotted in Figures 10 and 11, respectively.

#### Table 2. Force per Surface Area and Volume for the Mechanical Test of THF Hydrates

| depth of immersion \( \Delta h \), cm | surface area, cm\(^2\) | average force, N | force/surface area, N/cm\(^2\) |
|---|---|---|---|
| 0.5 | 1.25 | 35.399 | 28.320 |
| 1 | 2.25 | 143.427 | 63.745 |
| 2 | 4.25 | >206.010 | >48.473 |
| 2.5 | 5.25 | >206.010 | >48.473 |

#### Table 3. Flowing Condition Using the Ferrofluid Liquid to Inhibit Hydrate Adhesion

| amount of ferrofluid, mL | torque, N m | note |
|---|---|---|
| 10 | 1.08 | high adhesion of hydrates |
| 15 | 0.63 | high adhesion of hydrates |
| 20 | 0.44 | high adhesion of hydrates |
| 25 | 0.35 | low adhesion of hydrates |
| 30 | 0.35 | low adhesion of hydrates |

#### Table 4. Shut-in Condition Using the Ferrofluid Liquid to Inhibit Hydrate Adhesion

| amount of ferrofluid, mL | torque, N m | torque, N cm | note |
|---|---|---|---|
| 10 | 0.65 | 64.86 | high adhesion of hydrates |
| 15 | 0.48 | 47.74 | high adhesion of hydrates |
| 20 | 0.40 | 39.51 | traces of adhesion of hydrates |
| 25 | 0.34 | 34.38 | no adhesion of hydrates |
| 30 | 0.34 | 34.38 | no adhesion of hydrates |

![Figure 11. Shut-in condition using the ferrofluid liquid.](image-url)
with the hydrate adhering to the uncoated surface. When the amount of the ferrofluid was increased, the surface area for hydrate adhesion decreased, but some of the liquid ferrofluid was found detached and mixed with the THF solution and forming dispersed hydrates. This is because the shear force acting on the ferrofluid from the stirring process is higher than the magnetic force acting on the ferrofluid liquid. This causes an inaccurate reading of the RPM measurements. At the end of the experiment, there were hydrates adhering to the wall of the steel cylinder, indicating that most of the magnetic fluid had mixed with the 19.1 wt % THF solution. Hence, a more viscous ferrofluid gel was used, and the readings are as shown in Tables 5 and 6. The data is also illustrated in Figures 12 and 13.

Table 5. Flowing Condition Using the Ferrofluid Gel to Inhibit Hydrate Adhesion

| amount of ferrofluid, mL | torque, N m | torque, N cm | note                  |
|-------------------------|-------------|--------------|-----------------------|
| 10                      | 1.04        | 103.60       | high adhesion of hydrates |
| 15                      | 0.50        | 50.42        | low adhesion of hydrates |
| 20                      | 0.39        | 38.78        | traces of adhesion of hydrates |
| 25                      | 0.35        | 35.18        | no adhesion of hydrates |
| 30                      | 0.35        | 35.18        | no adhesion of hydrates |

Table 6. Shut-in Condition Using the Ferrofluid Gel to Inhibit Hydrate Adhesion

| amount of ferrofluid, mL | torque, N m | torque, N cm | note                  |
|-------------------------|-------------|--------------|-----------------------|
| 10                      | 0.61        | 60.84        | high adhesion of hydrates |
| 15                      | 0.45        | 45.23        | low adhesion of hydrates |
| 20                      | 0.39        | 38.62        | traces of adhesion of hydrates |
| 25                      | 0.34        | 34.38        | no adhesion of hydrates |
| 30                      | 0.34        | 34.38        | no adhesion of hydrates |

4. CONCLUSIONS AND RECOMMENDATION

This proof-of-concept study demonstrates that a ferrofluid can be used to prevent hydrate adhesion to a metal surface. The studies were conducted at atmospheric pressure, and under these conditions, the ferrofluid shows promising performance as an alternative to prevent the adhesion of hydrates in pipelines. The liquid form of the magnetic slippery surface shows exceptional antiadhesion characteristics under static and dynamic conditions, but the long-term stability is an issue. Therefore, when the system is gelled, the coating is more durable. Further tests will focus on high-pressure conditions that simulate conventional field operations more closely where the presence of produced hydrocarbons may dilute the gel or the liquid. Hence, sensitivity analysis of the optimum carrier fluid to be used with the iron particles could be carried out. In addition, the effect of the shear stress and strain that the hydrocarbon flow may impose on the ferrofluid can be further investigated by utilizing the flow loop apparatus.

As shown in Figures 12 and 13, the torque required in the presence of the ferrofluid gel is much lower than the torque required in the presence of the ferrofluid liquid. This is due to the fact that the co-polymer used to thicken the magnetic fluid prevents the ferrofluid from mixing with the THF solution, ensuring that the surface area of the steel cylinder is completely coated with the antiadhesive coating for longer periods. The previous research with ice also confirmed these observations where a more viscous magnetic fluid reduced the loss of fluid.33 In Figures 12 and 13, the minimum torque required is 34 N cm when 25 mL and 30 mL of the ferrofluid gel are used during shut-in conditions, and the minimum torque required is 35 N cm during flowing conditions due to the mass of the hydrate block formed adhering to the overhead stirrer.

Furthermore, from the experiment conducted, the amount of the ferrofluid required per cubic centimeter was also obtained. Using the ferrofluid liquid alone, the required volume cannot be determined as the more the magnetic fluid used, the more the magnetic fluid was lost to the shear force. In Figures 11 and 12, the appropriate amount of the magnetic gel required is approximately 25 mL for a surface area of 86 cm². This means that a ratio of 1:3 of the surface area of steel to magnetic liquid is required to completely coat the surface, ensuring optimum adhesion prevention from the deposition of hydrates.

Note
The authors declare no competing financial interest.
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NOMENCLATURE

THF tetrahydrofuran
LDHI low-dosage hydrate inhibitors
MEG monoethyleneglycol
KHIs kinetic Inhibitors
AAs antiagglomerants
RPM revolutions per minute

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