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Enhance the rheological properties of reservoir drilling fluid (RDF) using Fe_2O_3 as nanoparticle material

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Abstract

An effective drilling operation relies substantially on a reliable drilling fluid system, significantly impacting its success. Drilling fluids, particularly reservoir drill-in fluids (RDF), are crucial for minimizing formation damage and maximizing output. As soon as the reservoir is drilled, formation deterioration starts; thus, an optimized RDF with minimal harm is essential considering geology, reservoir fluids, and other factors. This study aims to improve reservoir drilling fluid to minimize skin damage by comparing nanoparticle-based RDFs with conventional drilling fluids used in the Mishrif formation, drilled horizontally 3000 meters. Employing nanoparticles in drilling fluids can improve performance and thermal resistance up to 300°F. Laboratory tests and field data were compared in this study. Nanoparticles in both freshwater and saltwater drilling fluids showed significant enhancements in filtration parameters and rheological qualities. Results indicated that the RDF with Fe_2O_3 nanoparticles enhanced filtration properties and stability. Optimal Fe_2O_3 concentrations were 1g at 300°F and 1.5g at 400°F. Adding Fe_2O_3 nanoparticles to reservoir drilling fluid resulted in a 40% reduction in fluid loss rate and decreased mud cake thickness. Additionally, nanoparticles improved the flow properties of the drilling fluid at high temperatures up to 200°F, ensuring a controlled and more consistent decrease in parameters such as plastic viscosity (PV), yield point (YP), and gel strength without any indication of thermal deterioration.

Keywords: Reservoir drill-in fluids; nanoparticles; fluid loss; filtration; Mishrif formation; thermal stability.

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1- Introduction

The main goal of a drilling fluid program is to choose an appropriate drilling fluid that minimizes formation damage. In addition to the delicate component, it is crucial to maintain the quality of the drilling fluid because drilling substantially affects the well's overall performance [1]. The mixture of solids and liquids that constitute drilling fluids is relatively stable. Incorporating a solids control program into the drilling fluid program is essential as it helps maintain the qualities of a suitable drilling fluid by ensuring that it remains simple and contains only a few additives. This approach focuses on managing particles' quantity, type, and chemical environment in the drilling fluid, thereby enhancing its effectiveness during transformation [1]. Drilling fluids used in the reservoir are called reservoir drill-in fluids (RDFs), and they are essential for protecting the formation and getting the most out of it. As soon as drilling begins in the reservoir, damage to the formation will commence. Reservoir fluids, geology, and other factors are studied to develop reservoir drill-in fluids (RDF) with the most negligible environmental impact. Following evaluation and approval of a reservoir drill-in fluids (RDF) system, distribution and use of the optimized fluid are required. The fundamental units of nanomaterial are called nanoparticles, which are tiny particles with sizes between one and one hundred nanometers [2]. Modern technology and petroleum industry advancements require drilling fluid to function well in challenging and complex environments. Drilling operations include high-temperature, high-pressure (HPHT) wells and ultra-deep-water drilling into shale formations. Therefore, significant research and development have been done on various emulsifiers, surfactants, and other additives to improve the quality of drilling fluid. While polymers are commonly used as additives in drilling fluid, nanotechnology has demonstrated its potential to enhance the properties of drilling fluid, especially in water-based muds.

The high reactivity of nanomaterials is attributed to their extraordinarily high surface area-to-volume ratio, which tends to increase as the forms become smaller. More chemical reactions occur because more reactive atom surfaces are exposed to one another [3-5]. To address current technological challenges, researchers are focusing on enhancing the rheological behavior of water-based muds (WBM). This involves exploring innovative materials such as biodegradable compounds and nanoparticles. By dedicating their attention to these advancements, researchers aim to develop solutions that

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effectively tackle the issues at hand [6]. Krishnan et al. investigated the impact of boron nanoparticles on WBM at temperatures up to 302 °F and pressure of 500 psi. They reported enhanced fluid characteristics under HPHT settings. Nanoparticles protect against polymer breakdown, improving drilling fluid stability under downhole temperature conditions [7]. Davoodi, studied the impact of pistachio shell powder on drilling fluid characteristics and found a 44% reduction in fluid loss [8]. Dejtaradon et al. investigated the thermal stability of rheological parameters in water-based mud (WBM) with ZnO and CuO nanoparticles (NPs) at temperatures of 25°C, 50°C, and 80°C. The results indicated that ZnO NPs exhibited superior overall efficacy compared to CuO, with enhanced rheological characteristics at elevated temperatures. Furthermore, a substantial decrease in fluid loss at elevated temperatures was observed with a mere 0.8 wt% of nanoparticles, and a thinner mud coating was also achieved [9]. Nwabueze et al. examined the impact of rice husk and sweet potato on drilling fluids characteristics by using 0–8 grams in the drilling fluid. Their study reported an 8% decrease in fluid loss and a filter cake thickness of roughly 3 mm [10].

In a 2022 study, Jaguar et al. successfully developed a nano-biodegradable drilling mud by combining SiO_2 and TiO_2 with pomegranate peel (PP) and Prosopis fractal plant (PFP). Incorporating PP and TiO2 in the drilling mud enhanced rheological and filtration properties, as revealed by the research findings. This innovative approach showed promising results in improving the performance of the drilling fluid [11, 12]. The main goal of this study is to optimize the selection and quantities of chemicals and additives used in formulating drilling fluids. These drilling fluids aim to possess reservoir-friendly characteristics and demonstrate high-temperature tolerance, specifically for horizontal drilling operations in the Mishrif formations located in Basra. Several RDFs' laboratory measurements and field data were employed in the horizontal interval for this aim. Numerous drilling characteristics were considered, such as the buildup volume, lost circulation, drilling cost, penetration rate, and rheological and filtration qualities of the drilling fluid. Recent research on nanoparticles in drilling fluids is shown in Table 1.

Table 1. Recent studies on nanoparticles in drilling fluids

Nanoparticles	Functions	References
SiO_2	Circulation friction resistance	[13]
	Shale stabilization.	[14]
	Reduction in filtration.	[11, 15]
TiO_2	. Enhances the rheological and thermal stability.	[16]
α-MnO_2	Reducing the loss from filtration.	[17]
ZnO	HPHT, shale stabilization and improved filtration control.	[18]
Al_2O_3	Improve the rheological properties.	[19]
Fe_2O_3	Enhances filter cake and fluid loss.	[20]

2- Experimental work

2.1. Materials of reservoir drilling fluid

The reservoir drilling fluid Used in the west Qurna oil field south of Iraq in the horizontal section is about 3000m in Mishrif formation. The chemicals described were supplied by the Schlumberger firm (Basra, Iraq) with a purity level of 99.8%.

a. Caustic soda (NaOH)

In water-based drilling fluids, caustic soda is utilized as a source of hydroxyl ions to raise or regulate pH levels, preventing bacteria growth and drilling damage. The typical range of NaOH concentration in drilling fluids is 0.2 to 4.0 lb/bbl.

b. Soda ash (Na_2CO_3)

The primary use of soda ash is to eliminate soluble calcium salts from drilling fluids and make waters that contain gypsum and anhydrite. Some soda ash is also utilized in the clay beneficiation process. The typical range of Na_2CO_3 concentration is 0.2 to 4.0 lb/bbl.

c. Duo-Vis/Flo-vis

As the main viscosities, Duo-vis provides mud with its viscosity and creates a viscous structure that facilitates cutting conveyance to the surface. It also has outstanding suspending qualities, which keep weighting agents and drilled cuttings from settling.

d. XLS lube

Lube chemicals assist the mud cake quality lift out of the hole more effectively, increase penetration rate, and prolong bit life (Tripping).

e. M-I cide

M-I Cide effectively manages the issues of microbial-induced slime and corrosion in drilling, completion, workover, and packer fluids, all while maintaining a user-friendly application. Effective Against anaerobic and aerobic microorganisms. Protect polymers from bacterial breakdown.

2.2. Fe_2O_3 nanomaterial

Fe_2O_3 is the most commonly utilized NP due to its heat transfer characteristics and low cost.

Fig. 1 shows the procedure of this work, where the Fe_2O_3 nanomaterial is added to reservoir drilling fluid (RDF) with different concentrations, and rheological properties are measured.

3- Methodology

3.1. Data collection

Data from drilling horizontal sections south of Iraq was gathered in the field. The limestone white, chalky Mishrif Formation comprised the drilled reservoir parts. A horizontal drilling technique is employed to create a 90°

angle, drilling into the rocks with an approximate open-hole section length of 3000 meters.

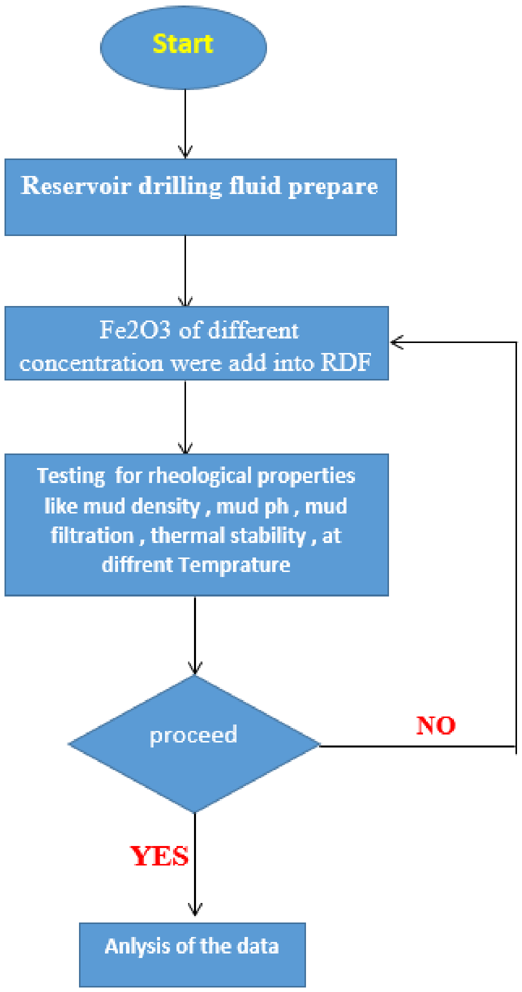

Fig. 1. Experimental procedure flowchart

3.2. Drilling fluid preparation

Five samples of reservoir drilling fluid were prepared, along with five samples of reservoir drilling fluid containing Fe_2O_3. The preparation process involved utilizing a hot plate stirrer and a Hamilton Beach mixer for 30 minutes.

3.3. Rheological measurements of the drilling fluids

The rheological parameters of the prepared drilling fluid samples, including plastic viscosity, yield point, and gel strength, were assessed using an API standard viscometer (FANN 35). These measurements were conducted at different temperature conditions within a range from 220°F to 500°F. Calculate the values for plastic viscosity and yield point based on the readings obtained at 300 and 600 RPM of the viscometer rotor. Gel strength for both (10sec and 10min) was measured.

- The plastic viscosity (PV) in centipoise (cP) was determined by PV= $R_{600} - R_{300}$
- The yield point (YP) in pounds per 100 square feet (Ib/100 ft²) was calculated by YP=$R_{300} - PV$

4- Results and discussions

Ten samples were prepared to enhance the rheological properties. Five samples were formulated without Fe_2O_3, while the other five samples included Fe_2O_3 nanoparticles. These samples were tested at different temperature ranges from 200 to 400 F, along with varying concentrations of Fe_2O_3 nanoparticles. The results of plastic viscosity, yield point, and gel strength (10sec and 10min) for the two reservoir drilling fluids are presented in Table 2.

Table 2. Results of rheological properties at elevated temperatures for two distinct types of fluids

Drilling Fluid	Sample	Temperature °F	YP (Ib/100 ft²)	PV (cP)	Gel Strength (lb/100 ft²) 10-sec Gel	10-min Gel
RDF	1	200	25	15	10	8
	2	250	25	13	8	8
	3	300	23	12	8	7
	4	350	20	11	6	6
	5	400	19	9	4	5
RDF+ Fe_2O_3	1	200	25	15	10	8
	2	250	26	14	10	10
	3	300	23	14	9	10
	4	350	24	13	8	9
	5	400	25	12	10	8

4.1 Rheological properties

a. Plastic viscosity

Fig. 2 shows the effect of temperature on plastic viscosity for two types of RDF, with and without (Fe_2O_3). The RDF sample's plastic viscosity (PV) was initially measured at 15 cP and decreased to 9 cP. On the other hand, in the RDF sample with the addition of Fe_2O_3, the plastic viscosity (PV) was recorded at 15 Cp and subsequently decreased to 12 cP. Fe_2O_3 NPS was introduced to improve the stability of the polymer and prevent degradation. The results indicated that the RDF with Fe_2O_3 was significantly 20% more stable than the RDF sample without Fe_2O_3.

b. Yield point

Fig. 3 Represents the results of RDF With/Without Fe_2O_3 on yield point value, which is affected by different concentrations of RDF with numerous temperatures applied. In the RDF sample, the yield point decreased from 25 to 19 lb/100 ft², resulting in a loss of approximately 24%. However, in the RDF sample with the inclusion of Fe_2O_3, the yield point exhibited improved performance and demonstrated more excellent temperature resistance, specifically up to 400° F.

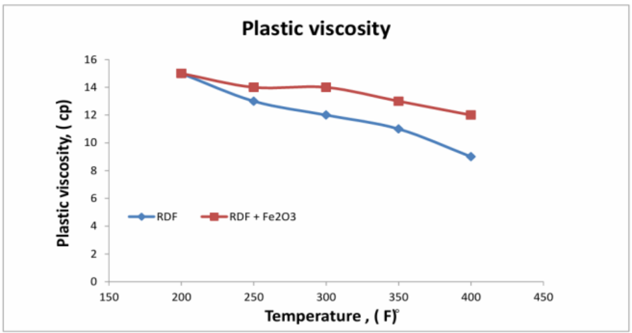

Fig. 2. Temperature effect on PV of RDF and RDF with Fe_2O_3

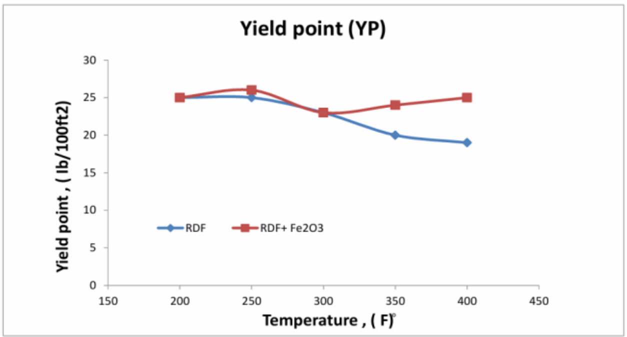

Fig. 3. Temperature effect on YP of RDF and RDF with Fe_2O_3

c. Gel strength

Fig. 4 and Fig. 5 present the analysis of gel strength qualities for 10 seconds and 10 minutes at elevated temperatures. In general, the gel strength of the Reservoir drilling fluid without Fe_2O_3 decreased as the temperature increased. For instance, at 200F, the gel strength was only 10 lb/100ft² for 10 seconds and 8 lb/100ft² for 10 minutes. At 400F, the gel strength was further reduced to 4 lb/100ft² for 10 seconds and 5 lb/100ft² for 10 minutes. This indicates a loss of 60% at 10 seconds and 37.5% at 10 minutes. On the other hand, the gel strength of the 10-second and 10-minute RDF samples with Fe_2O_3 exhibited greater stability than the RDF without Fe_2O_3.

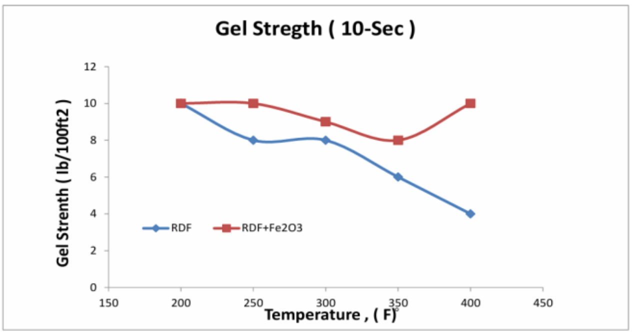

Fig. 4. Temperature effect on 10-sec gel strength of RDF and RDF with Fe_2O_3

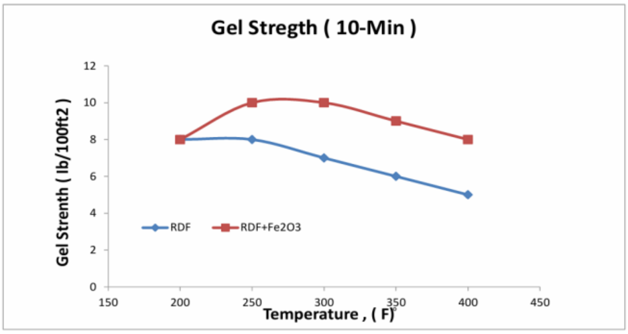

Fig. 5. Temperature effect on 10-min gel strength of RDF and RDF with Fe_2O_3

4.2 Filtration properties

To enhance filtration control and assess the filtration properties, ten samples were prepared, as indicated in Table 3. Five samples were formulated without Fe2O3, while the other five samples included Fe_2O_3 nanoparticles. These samples were tested at different temperature ranges from 200 to 400 F, along with varying concentrations of Fe_2O_3 nanoparticles.

Table 3. Results of fluid losses and filter cake thickness for the tested samples at various applied temperatures of the (RDF), (RDF + Fe_2O_3)

Drilling Fluid	Sample	Temperature	Fluid Loss	Filter Cake Thickness
		◦F	cm^3 /30 min	1/32''
RDF	1	200	10	0.001
	2	250	10.5	0.0015
	3	300	12	0.002
	4	350	13.3	0.0041
	5	400	15	0.005
RDF+ Fe_2O_3	1	200	10	0.001
	2	250	10.3	0.0015
	3	300	10.7	0.0018
	4	350	10.9	0.002
	5	400	11	0.0023

Fig. 6 Showed that the increase in concentrations of RDF led to an increase in fluid losses from 10 cc/30 min to 15 cc/30 min, which means a 50% increase; the result will be out of range. Fe_2O_3NPS, after being added to RDF, Fe_2O_3 demonstrated the best performance in reducing filtration and protecting the polymer from breaking. The fluid loss behavior of RDF with different concentrations of Fe_2O_3 is depicted in Fig. 6. The fluid loss increased from 10 cc/30 min to 11 cc/30 min at 400 F, which means a 10% increase.

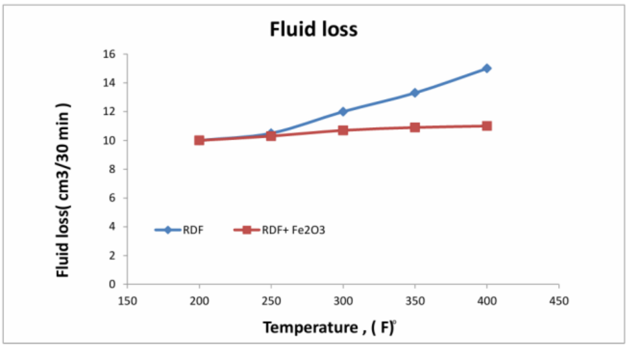

Fig. 6. Temperature effect on fluid loss of RDF and RDF with Fe_2O_3

Fig. 7 Shows that the result of RDF increased the Filter cake thickness from 0.001 (1/32 inch) to 0.005 (1/32 inch); the result was out of range. When the Fe_2O_3 NPS was added to RDF, Fe_2O_3 exhibited the best performance in protecting the polymer from breaking down and showed superior results. The behavior of filter cake thickness was examined for RDF with different concentrations of Fe_2O_3, as illustrated in the provided data; concentrations were recorded as increasing from 0.001 (1/32 inch) to 0.0023 (1/32 inch).

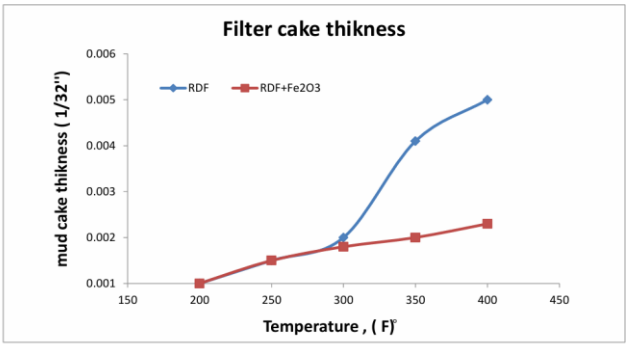

Fig. 7. Temperature effect on filter cake thickness of RDF and RDF with Fe_2O_3

5- Conclusion

The primary objective of this study was to develop drilling fluid with the optimal concentration of Fe_2O_3 nanoparticles to prevent polymer degradation at temperatures exceeding 200ºF while enhancing rheological and filtration properties. The results are summarized as follows:

1. Thermal stability: The addition of Fe_2O_3 nanoparticles significantly improved the thermal stability of the reservoir drilling fluid at different concentrations and temperatures, up to 200ºF.
2. Reaction in Fluid loss: Adding Fe_2O_3 nanoparticles into reservoir drilling fluid resulted in a 40% reduction in fluid loss rate and a decrease in mud cake thickness. The increased rate of fluid loss and thin mud coating are beneficial for more efficient drilling operations, as they reduce the likelihood of differential sticking issues and minimize formation damage caused by filtrate invasion.
3. Enhanced Flow Properties: The addition of nanoparticles improved the flow properties of the drilling fluid at high temperatures, up to 200ºF, by causing a controlled and more consistent decrease in parameters such as PV, YP, and gel strength without any indication of thermal deterioration.
4. Optimal Concentration: At 300ºF, the optimal concentration of Fe_2O_3 was found to be 1g and at 400ºF, it was 1.5g.

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تحسين الخصائص الريولوجية لسائل حفر المكمن (RFD) باستخدام (Fe_2O_3) كجسيمات نانوية

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الخلاصة

عملية الحفر الفعالة تتطلب سائل حفر ذو خصائص جيدة . إن خصائص سائل الحفر لها أثر كبير في عملية الحفر . تعد سوائل الحفر ضرورية لتقليل أضرار الطبقة المنتجة وزيادة الإنتاج إلى الحد الأقصى، وخاصة سوائل الحفر في المكمن (RDF). حيث يتم انشاء سوائل حفر خاصة في المكامن وتستخدم في الطبقات المنتجة للنفط.و تهدف هذه الدراسة إلى تحسين سائل الحفر في المكمن لتقليل تضرر الطبقة من خلال مقارنة سوائل الحفر في المكامن ذات الجسيمات النانوية مع سوائل الحفر التقليدية في المكمن المستخدمة في طبقة المشرف الذي تم حفره أفقيا على عمق ٣٠٠٠ متر داخل المكمن. يمكن أن يؤدي استخدام الجسيمات النانوية في سوائل الحفر إلى تحسين الأداء والمقاومة الحرارية حتى ٣٠٠ درجة فهرنهايت. في هذه الدراسة يتم مقارنة سائل الحفر (RDF) بدون جسيمات نانوية مع سائل الحفر بوجود الجسيمات النانوية ($RDF+Fe_2O_3$). أدى استخدام الجسيمات النانوية في كل من سوائل الحفر في المياه العذبة والمياه المالحة إلى تحسين كبير في خواص الترشيح والصفات الريولوجية. أظهرت النتائج أن RDF مع Fe_2O_3 يعزز خصائص الترشيح والاستقرار. لذلك، عند ٣٠٠ فهرنهايت كان التركيز الأمثل لـ Fe_2O_3 هو واحد غرام وعند ٤٠٠ فهرنهايت كان ١,٥ غرام. أدت إضافة جسيمات Fe_2O_3 النانوية إلى سائل الحفر في المكمن إلى انخفاض بنسبة ٤٠% في معدل فقدان السوائل وانخفاض في سمك كعكة الطين.وكذلك أدت إضافة الجسيمات النانوية إلى تحسين خصائص سائل الحفر عند درجات حرارة عالية تصل إلى ٢٠٠ درجة فهرنهايت، عن طريق التحكم في معدل انخفاض الخصائص الريولوجية مثل PV وYP وهذا يدل على التحكم الفعال للمواد النانوية (Fe_2O_3) في طين حفر المكمن.

الكلمات الدالة: سوائل الحفر في المكمن، الجسيمات النانوية، فقدان السوائل، الترشيح، طبقة المشرف، الاستقرار الحراري.