

The Role of Drilled Formation in Filter Cake Properties Utilizing Different Weighting Materials

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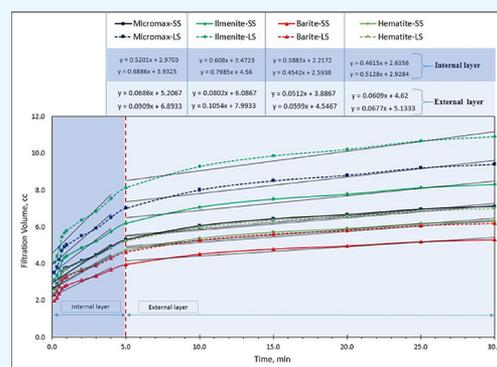
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ABSTRACT: The filter cake formed during a filtration process plays a vital role in the success of a drilling operation. There are several factors affecting the filter cake build-up such as drilled formation, drilling fluid properties, and well pressure and temperature. The collective impact of these two factors (i.e., formation and the drilling fluid) on the filter cake build-up needs to be fully investigated. In this study, two types of formations represented as limestone and sandstone were used with different weighting materials to assess and compare their impact on the filter cake properties, filtration behavior, and solid invasion. The used weighting materials are manganese tetroxide, ilmenite, barite, and hematite. The filter cake was formed under a temperature of 200 °F and differential pressure of 300 psi. Nuclear magnetic resonance spectroscopy was employed to explore the pore structure of the used core samples. The results showed that the properties (i.e., shape and dimensions) of the different weighting materials are the dominant factors compared to the formation characteristics in most of the investigated filter cake properties. Nevertheless, the formation properties, namely, the permeability and pore structure, have a somehow higher contribution when it comes to the filter cake porosity and thickness. For solid invasion, there were no clear results about the main factor contributing to this issue.



INTRODUCTION

The energy demand around the globe is increasing exponentially, which leads to hydrocarbon resources, with difficulties in development, to be considered. Deep reservoirs, which usually have high pressure and high temperature (HPHT), can be considered among these resources.¹ Such a reservoir needs special attention in its different processes such as the drilling process.² Designing a drilling fluid is one of the important sub-processes of drilling activities since it is considered as the blood of the drilling operations. Drilling fluids consist of many additives to achieve their functions, which include lubricating and cooling the bit, carrying the cutting to the surface, forming the filter cake, and controlling the formation pressure.^{3,4} In deep reservoirs, a weighting material has a more significant role due to the high formation pressure that needs to be controlled.

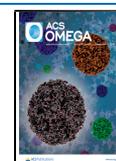
Many materials were used as weighting agents over the years, and researchers are still looking for new materials and ways to improve the existing ones. Examples of common weighting materials include barite, calcium carbonate, ilmenite, hematite, manganese tetroxide (Micromax), galena, stibnite, and potash.^{5–11} One potential method to improve the weighting material performance is by reducing its particle size; this introduced more options such as micronized barite, micronized ilmenite, and micronized manganese tetroxide as weighting materials.^{12–17} Furthermore, other researchers used a mixture of several weighting materials with the aim of mitigating drilling

instability issues such as barite sagging and of improving the drilling mud properties.^{8,18} Also, nanoparticles were investigated as weighting agents by several studies that showed a general improvement in the drilling fluid properties.^{2,19–22} Accordingly, selecting the right weighting material is not a trivial task and it depends on many factors including the cost, the required properties (i.e., density), and its solubility in conventional filter cake removal treatments since it affects approximately 70–80% of the filter cake structure.²³

The filter cake should be removed at the completion stage to start the hydrocarbon production.^{24–26} The filter cake should be impermeable and thin to protect the formation and avoid any problems such as pipe sticking.²⁷ The filter cake consists usually of two layers depending on the drilling fluid components, and these layers are the polymeric layer and weighting material layer.²⁸ The polymeric layer coats the weighting material layer, and it needs to be removed to allow the reaction between the filter cake and the solvent.²⁹ The weighting material layer is in

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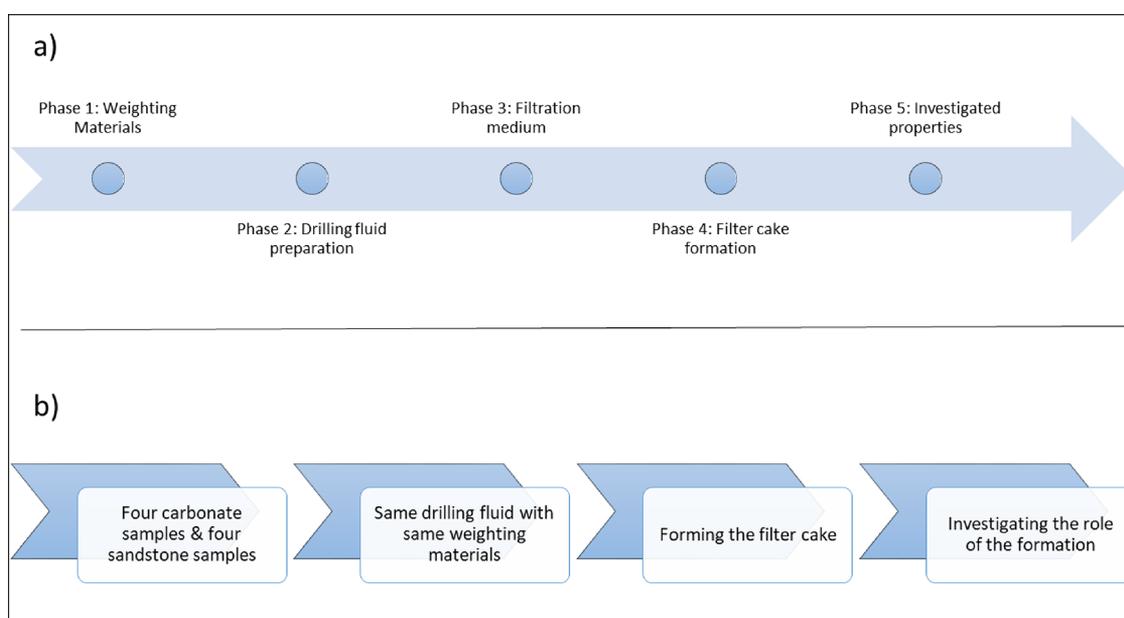


Figure 1. Methodology workflow: (a) for objective 1 and (b) for objective 2.

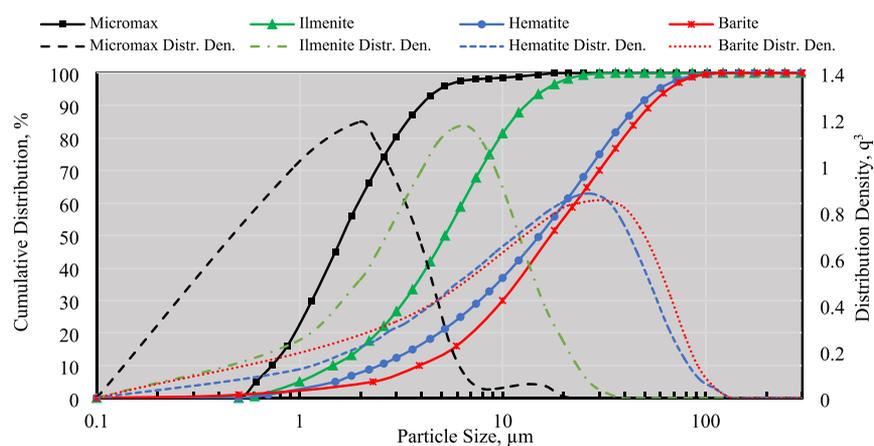


Figure 2. Particle size distributions for Micromax, ilmenite, hematite, and barite.

direct contact with the drilled formation; hence, some solid particles might invade the formation pores, causing formation damage.^{30,31}

The formation damage can occur for three main reasons, namely, incompatibility of drilling fluids with the formation rock or fluid, filter cake, and solid invasion caused by the solid particles in the drilling fluid.³² All the previous works that have been discussed depend mainly on the drilling fluid recipe and somehow on the formation properties. There is a possibility for another source of damage during the removal of the filter cake.^{33,34} The solid invasion can alter the formation properties and induce damage to the near-wellbore area. Hence, there will be a negative impact on the well productivity. Different studies were conducted to assess the impact of the different weighting materials on the formation characteristics. Gamal et al. studied the change in the pore system and the rock characterizations for sandstone and carbonate formation.^{35,36} They used barite (BaSO_4), Micromax (Mn_3O_4), ilmenite (FeTiO_3), and hematite (Fe_2O_3) as weighting materials. Moreover, Bageri et al. investigated deeply the effect of the same weighting materials on mud rheology and the filtration properties for the sandstone.³⁷ Similarly, Fattah and Lashin investigated the

impact of mud density and weighting materials (i.e., barite and calcium carbonate) on the formation damage and filter cake properties.³⁸ They used a ceramic disk as the filtration medium. However, the effect of the weighting materials on the filtration process for carbonate formation and the role of the formation on how the weighting material can impact the filter cake and the formation properties were not investigated intensively to the knowledge of the authors.

In this work, two different formation types were used as a medium with different weighting materials to assess their combined impact on the filter cake and the formation properties. The utilized core samples are sandstone and carbonate with different properties for each type, and the weighting materials used include barite, hematite, ilmenite, and Micromax. This work is an extension of the work of Gamal et al.^{35,36} focusing on the filter cake properties in carbonate and comparing the role of the formation properties in filter cake properties with different weighting materials. The investigated filter cake properties include filter cake thickness, porosity, permeability, and filtration volume. The impact of weighting materials on each formation was evaluated by the change in porosity.

MATERIALS AND EXPERIMENTS

The general methodology that was followed in this work to achieve the first objective is shown in Figure 1a. The weighting material's properties and the drilling fluid formulation are presented in Phase 1 and Phase 2. Phase 3 presents a description of the porous media (i.e., the core samples) that were used to form the filter cake as shown in the next phase (i.e., Phase 4). The investigated properties of the filter cake are shown in Phase 5. Figure 1b shows the second objective that involves the comparison and the role of the formation in the filter cake properties. A similar sequence was followed for sandstone formation in ref 37, which was used for comparison. A detailed description of the tests and equipment used are available in refs 35 and 36.

Phase 1: Weighting Materials. Four different weighting materials were used, namely, Micromax, ilmenite, barite, and hematite. The particle size distribution is shown in Figure 2 for the different weighting materials. The cumulative distribution for hematite and barite is relatively close to each other, compared to that for the Micromax and ilmenite. Moreover, the distribution density for each weighting material is shown with the peaks for Micromax, ilmenite, barite, and hematite at particle sizes of 2.2, 6.77, 27.37, and 32.86 μm , respectively. The values for D_{10} , D_{50} , and D_{90} for each weighting material are shown in Figure 3. The D_{10} , D_{50} , and D_{90} represent the

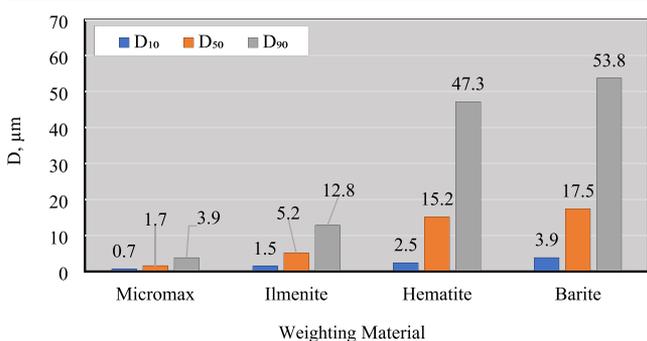


Figure 3. Weighting material particle sizes.

percentage of the particles below the 10, 50, and 90% of the sample particle sizes, respectively. Clearly, the Micromax has the smallest particle size followed by ilmenite, then hematite, and finally barite. There is a great difference between the smallest particle (D_{10}) and the largest particles (D_{90}) for hematite and barite compared to the Micromax and ilmenite. The chemical composition in terms of the elemental analysis by X-ray fluorescence spectroscopy for the weighting materials is shown in Table 1. The main elements from the mineralogy perspective for Micromax are manganese (Mn), iron (Fe) and titanium (Tn) for ilmenite, and barium (Ba) and sulfur (S) for barite, while hematite consists mainly of iron.^{35,36} The shape of the weighting agent's particles was determined using a high-resolution SEM image. The results are shown in Figure 4. The figure also shows the dimensions of the particles for each weighting material. As can be seen, the Micromax has a spherical shape while the other weighting materials have an irregular shape.

Phase 2: Drilling Fluid Preparation. The weighted materials were added separately to different samples from a batch of prepared water-based drilling fluids. To formulate one barrel of the drilling fluid, the standard mud recipe consisting of

several components (i.e., see Table 2) was used.³⁵ The drilling fluid viscosity is controlled by xanthan gum (XC polymer) and bentonite. Moreover, starch serves as a fluid loss agent while the filtration properties can be improved by adding a bridging agent like calcium carbonate. Potassium hydroxide was added to adjust the pH, and potassium chloride was used as a clay swelling inhibitor. All the mud samples had almost the same density (i.e., ~ 14 ppg); this is an important point to reduce the variables in the comparison between the different weighting materials. In addition, the rheological properties in terms of plastic viscosity (PV), yield point (YP), and gel strength after 10 s and after 10 min were measured at 80 °F for the different formulations, and the results are listed in Table 3.³⁷

Phase 3: Porous Media (Filtration Media). Two different types of core samples were used in this work as filtration media: Berea Buff sandstone and carbonate. All core samples have similar dimensions of 1.5" diameter and 2" length. The carbonate sample consists mainly of calcium carbonate (i.e., 99.29 wt %), and the sandstone samples mostly contain quartz (95 wt %) and the remaining 5 wt % represent the clay minerals. The samples were saturated with brine (3 wt % of KCl) to minimize clay swelling. Nuclear magnetic resonance spectroscopy (NMR spectroscopy) was employed to explore the pore structure of the cores. The transverse relaxation time (T_2) was measured using the CPMG pulse sequence. The optimization parameters for the scanned parameters are as follows: a signal to noise ratio of 200, recycle delay of 11,250 ms, and Tau value of 0.1 ms. The pore structures and permeability values are shown in Figure 5 and Figure 6 for sandstone and limestone samples, respectively. The range for sandstone permeability is 168–185 mD with a porosity range of 20.8–21.3%,³⁷ while the carbonate has a permeability range equal to 53.6–62.2 mD and a porosity range equal to 18.5–19.2%.

Phase 4: Forming the Filter Cake. Forming the filter cake was performed using a fluid loss test apparatus under a differential pressure of 300 psi and temperature of 200 °F for each drilling mud with a specific weighted material. The filtration test was conducted under the designed condition of pressure and temperature for 30 min as per the American Petroleum Institute (API) standards for filtration property evaluation.³⁹ After forming the filter cake, it was placed in an oven at a temperature of 212 °F for 3 h to vaporize the water. The weights and dimensions of the filter cake were recorded before and after placing the filter cake in the oven, which are represented by wet filter cake weight (FC_{nw}) and the dry filter cake weight (FC_{ndw}), respectively. Each weighting material filter cake was formed on both core types to assess the impact of the weighting materials on the filter cake properties, the transport properties, and the invasion for a different type of formation. Table 4 shows the transport properties for each core with corresponding drilling mud (i.e., for each weighting material) used to form the filter cake.

RESULTS AND DISCUSSION

As is shown in the methodology workflow figure (i.e., Figure 1), different properties were investigated in this work including the filtration behavior, filter cake permeability, filter cake porosity, filter cake thickness, and core properties.

Filtration Behavior. Mud filtration is the initial stage in the filter cake formation, and its behavior can provide a different indication regarding the filter cake characteristics such as the layers. The filtration behavior (i.e., filtration volume versus time) for the investigated weighting materials in both formation types

Table 1. X-ray Fluorescence Spectroscopy Analysis for the Weighting Materials

barite (barium sulfate)		hematite (iron oxide)		Micromax (manganese tetraoxide)		ilmenite (titanium-iron oxide)	
element	%	element	%	element	%	element	%
Mg	0.00	Na	0.20	Mn	97.60	Mg	1.98
Al	1.96	Al	0.75	Si	0.50	Al	0.74
Si	5.18	Si	0.50	Al	0.45	Si	1.44
S	15.84	P	0.03	K	0.18	S	0.04
K	1.34	Cl	0.32	Ca	0.03	K	0.24
Fe	0.97	K	0.21			Ti	37.04
Cu	0.02	Ca	0.03			V	0.40
Sr	0.59	Sc	0.01			Fe	55.86
Ru	0.18	Ti	0.01			Zr	0.04
Rh	6.14	V	0.02			Nb	0.02
Ba	69.36	Cr	0.02			Ru	0.23
Pb	0.05	Fe	95.84			Rh	2.43
		Rb	0.01			Pd	0.18
		Ru	0.23			Sb	0.12
		Rh	2.91			Bi	0.07
		Sn	0.20				
		Sb	0.03				
		Te	0.16				
		Bi	0.00				
		U	0.03				

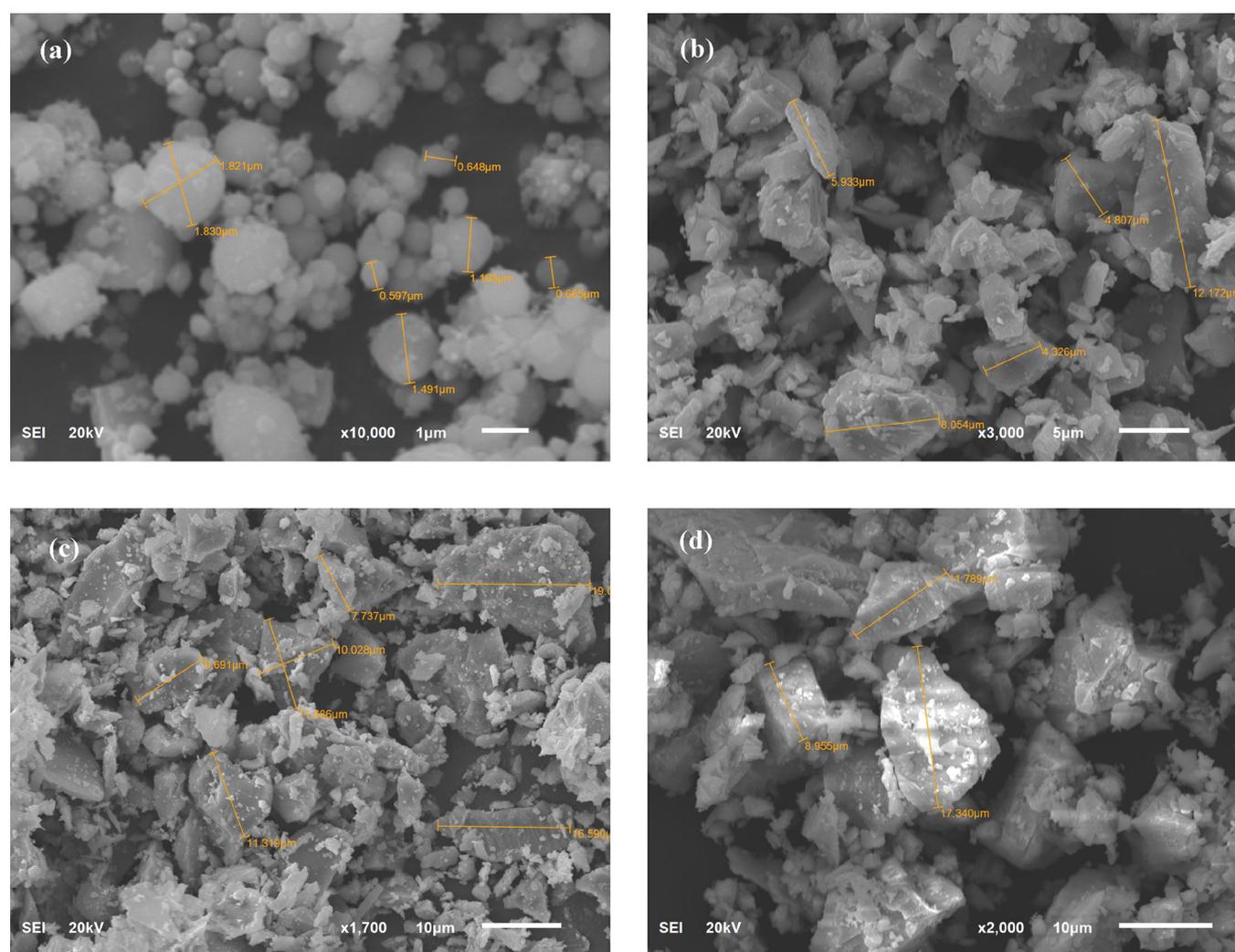


Figure 4. SEM for (a) Micromax, (b) ilmenite, (c) hematite, and (d) barite.

Table 2. Drilling Fluid Formulation

component	amount	unit
water	290	mL
deformers	0.09	g
XC polymer	1.5	g
bentonite	4	g
starch	6	g
KCl	20	g
KOH	0.3	g
CaCO ₃	5	g
weighting material	300	g

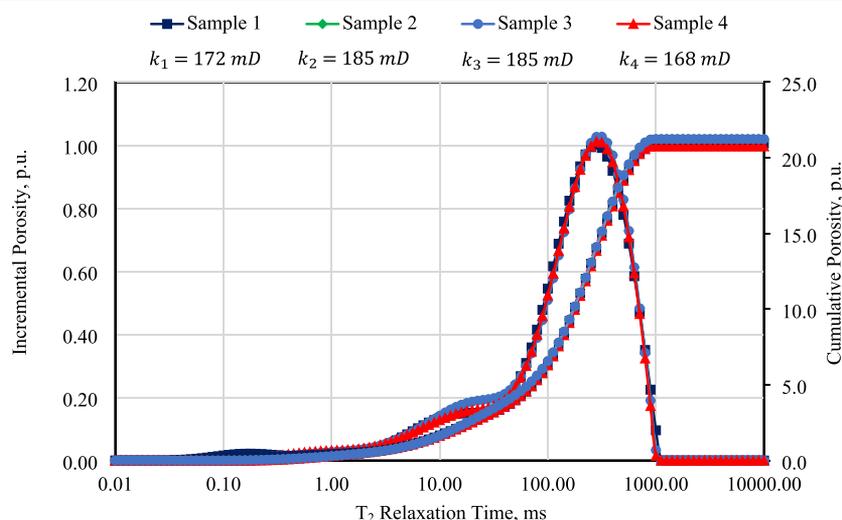
Table 3. Rheological Properties of the Drilling Fluid Formulations

property	unit	WBM-1 (barite)	WBM-2 (hematite)	WBM-3 (Micromax)	WBM-4 (ilmenite)
plastic viscosity (PV)	cP	28.1	36.6	27.5	30.5
yield point (YP)	lb/100 ft ²	32.4	25.7	48.4	35.2
gel strength after 10 s	lb/100 ft ²	11	12	10	19
gel strength after 10 min	lb/100 ft ²	21	18	16	35

is shown in Figure 7. Clearly, the figure shows two regions in the filtration behavior before and after 5 min. Each region corresponds to a filter cake layer; the early times represent the building of the internal layer while the later time shows the formation of the external layer. The reasons for the layer heterogeneity can be from the mineralogy perspective²⁹ or property perspective,⁴⁰ which is the case in this work. Moreover, the filtration rate can be used to find another important property of the filter cake, which is permeability. The desired filter cake should be impermeable to protect the formation from any solid invasion. The filtration rate can be estimated from the filtration behavior at different stages (i.e., early and late stages), as shown in Figure 7. The determination coefficient (R^2) is the same among each stage for different samples. The determination

coefficients of the linear fitting at the early and late stages are 0.8806 and 0.9288, respectively.

A deeper look at the filtration volumes at the initial and final stages (i.e., 5 and 30 min, respectively) for different weighting materials and formation types showed some noteworthy remarks. Figure 8 shows the filtration volume for each formation type and weighting material at the two stages. First, restricting the comparison at one formation type (e.g., limestone) and different weighting materials shows how the physical properties of the weighting materials can be the dominant factor. Since the core samples have similar properties, the effect mainly will be due to the weighting materials. Micromax and ilmenite have the finest particles compared to barite and hematite (see Figure 3); they showed the largest filtration volumes at both stages compared to the other weighting materials. For the limestone, the final filtration volumes are 9.4, 10.9, 6.2, and 7 cm³ for Micromax, ilmenite, barite, and hematite, respectively. The initial filtration volumes for Micromax, ilmenite, barite, and hematite are 7, 8.1, 4.6, and 5.2 cm³, respectively. Even though the core samples for both types are sister samples, there is a little difference in the permeability values, porosity values, and pore structures that need to be put into consideration. Comparing the filtration volume between the ilmenite and barite in limestone since their core samples have almost identical porosity and permeability values (i.e., to minimize the formation factor), there is an almost 76% increase in the filtration volume at both stages, which corresponds to 70% reduction in the D_{50} between the ilmenite and barite. Close trends can be observed in the sandstone cores as well, and choosing the ilmenite and hematite for comparison reveals a 32% increase in the filtration volume, which is reflected by an almost 66% reduction in the D_{50} between the two weighting materials. The difference in the filtration volume changes (i.e., 76 and 32%) could be attributed to the formation itself. The sandstone samples have almost the same pore system with approximately the same characteristics; the carbonate samples, in contrast, showed multiple and different pore systems for each core sample. These observations were made by investigating visually the NMR curves; the area under each curve can provide a quantification analysis of what was just mentioned.⁴¹ The area under the curve has no physical meaning; it is just an index that was employed to assess the variation in the pore structure among the samples of each

**Figure 5.** Pore structure and permeability of the sandstone core samples.

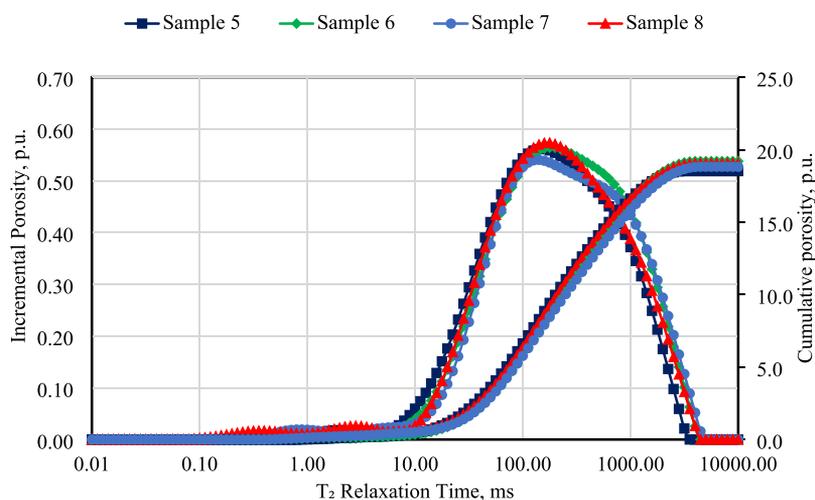


Figure 6. Pore structure and permeability of the limestone core samples.

Table 4. Porosity and Permeability Values for Each Sample

sample no.	formation type	weighting agent	porosity %	permeability (mD)
sample 1	sandstone	Micromax	20.9	172
sample 2		ilmenite	21.3	185
sample 3		hematite	21.3	185
sample 4		barite	20.8	168
sample 5	carbonate	Micromax	18.5	53.6
sample 6		ilmenite	19.2	62.2
sample 7		hematite	18.8	57.2
sample 8		barite	19.1	60.9

formation.⁴¹ The areas are shown in Figure 9 for all core samples with average areas of 1020 and 599 ms × p. u. in limestone and sandstones samples, respectively. The variation in limestone samples is 18,486 with a slandered deviation of 229 ms × p. u., while the variation in sandstone is equal to 53.9 with 94 ms × p. u. as the standard deviation. The statistical parameters reflect the high variation in the pore structure of limestone samples compared to the sandstone samples. This can explain the reasons for these differences in the filtration volume. By comparing the Micromax with barite and ilmenite with hematite in limestone since they have a relatively similar pore structure (based on the area and NMR figures), the incremental increases are almost constant with 35 and 34% in the initial and final filtration volume, respectively. Interestingly, similar results can be obtained in sandstone cores as well by comparing the same weighting materials (i.e., Micromax with barite and ilmenite with hematite) with incremental increases of 24 and 25%, respectively.

The formation role can be demonstrated further by comparing the filtration volume between the two formations for each weighting material. Even though there is an approximately constant difference in the permeability and porosity values between the two formations among all the weighting materials (i.e., the average increase in permeability is equal to 67% mD with a variation of 6.22×10^{-4} and an average increase in porosity by 1% with a variation of 2.73×10^{-4} from limestone to sandstone), the changes in the filtration volumes were controlled mainly by the weighting materials. In the weighting materials with relatively large particles (i.e., barite and hematite), their filtration volumes decreased from limestone to sandstone by 14%. On the other hand, the filtration volume of

weighting materials with fine particles (i.e., Micromax and ilmenite) decreased by 31% at the two stages as an average from limestone to sandstone. From the previous works, the dominant factor in the filtration volume seems to be the weighting material dimensions while the formation properties play a relatively smaller role.

With respect to the filter cake permeability (K_{fc}), it can be estimated by following the method that applied Darcy's equation for the pressure drop across the filter cake²³

$$K_{fc} = 14700 \frac{q h_{fc} \mu}{p_{fc}} \quad (1)$$

where K_{fc} , q , h_{fc} , μ , and p_{fc} represent the filter cake permeability (mD), filtration rate (cm/s), filter cake thickness (cm), filtrate viscosity (cP), and pressure across filter cake (psi), respectively.

The thickness at the early stage was assumed to be equal to the final thickness of the filter cake for the sake of calculations. The filter cake thickness values are shown in Figure 10 for both formations. The permeability values at both stages for each weighting material and formation type are shown in Figure 11. Traditionally, the formation with low permeability (i.e., carbonate in this case) has lower filter cake permeability. In limestone, the final permeability values are 0.026, 0.044, 0.01, and 0.012 mD for the Micromax, ilmenite, barite, and hematite, respectively. In sandstone, the final filter cake permeability values are 0.016, 0.25, 0.006, and 0.01 mD, respectively. The fine weighting materials have considerably high filter cake permeability, while the coarse weighting materials have low filter cake permeability. This could be related to how the weighting material particles aggregate during the formation of the filter cake.

On the other hand, contrasting the filter cake permeability between the two formations for each weighting material highlights the other factor represented by formation properties (i.e., mainly the permeability and pore structure). There is an incremental reduction fall in the close range of 62–75% mD from limestone to sandstone for Micromax, ilmenite, and barite. For hematite, the reduction in filter cake permeability is almost 22% from limestone to sandstone; this could be due to the shape of the hematite particles and how they aggregate. In addition, the pore structure of the core used for the hematite has the largest area, which can be another reason. The same observations were found for the initial permeability for both formations and all

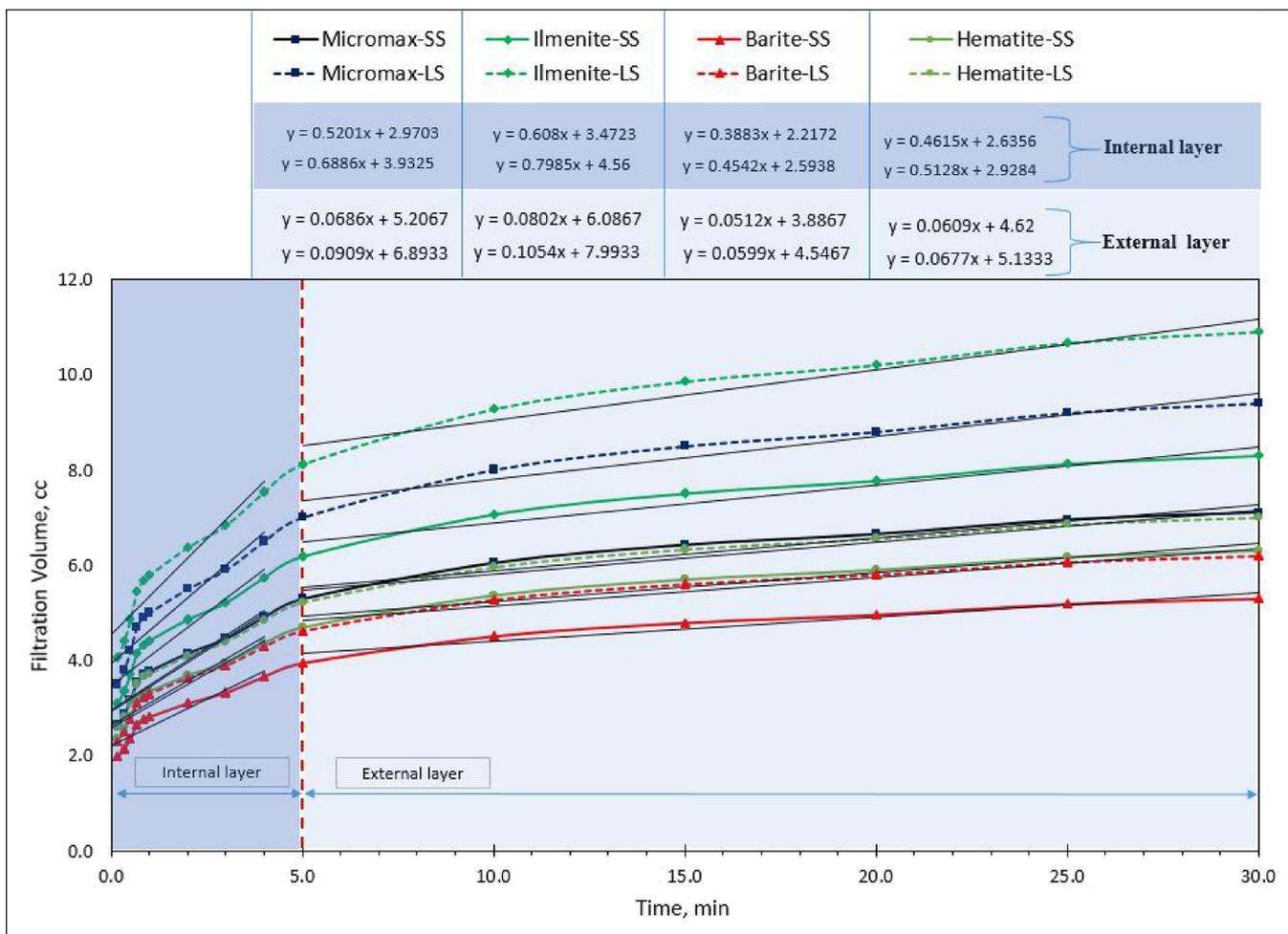


Figure 7. Filtration behavior for every weighting material and the corresponding formation.

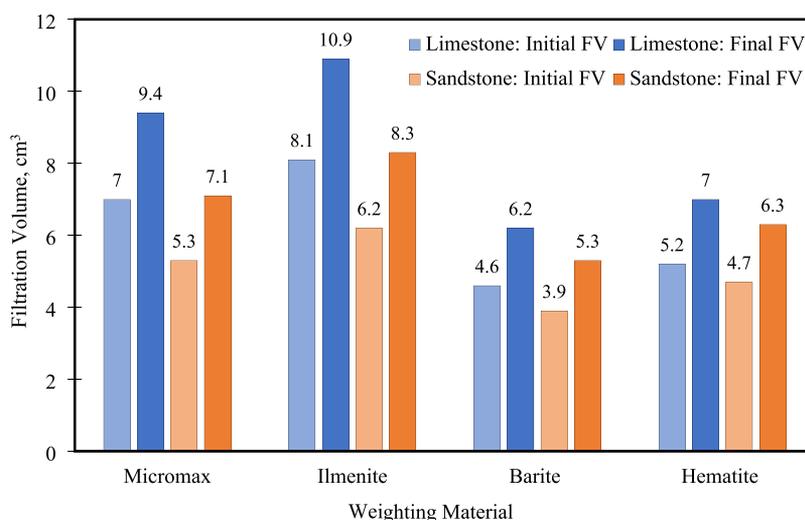


Figure 8. Filtration volume for the different weighting materials and formation types at both stages.

weighting materials. This could indicate that the formation properties are not the key factors in the filter cake permeability compared to the weighting material properties. However, a deeper investigation is needed to confirm this conclusion.

Filter Cake Porosity. The filter cake porosity is an important criterion in determining the sealing properties of the filter cake. There are different methods to estimate the filter

cake porosity, and the gravimetric method will be used in this work.²³ The formed filter cake porosity (ϕ_{fc}) can be calculated as follows:⁴²

$$\phi_{fc} = \frac{V_p}{V_b} \tag{2}$$

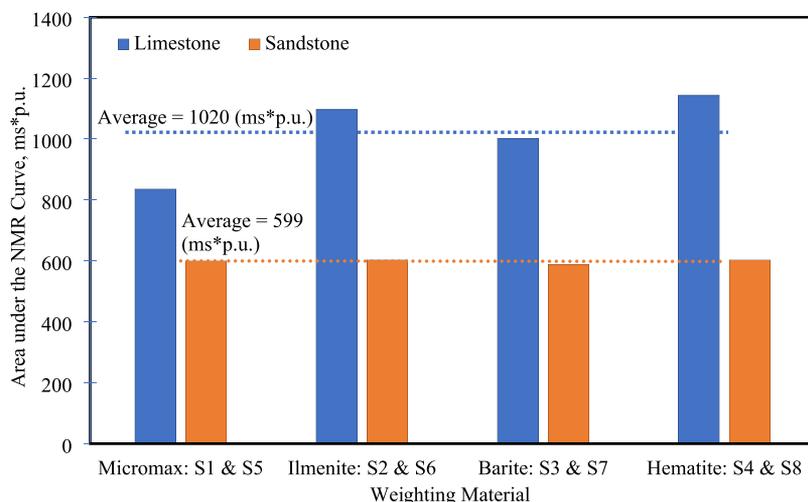


Figure 9. Area under the NMR curve in each formation.

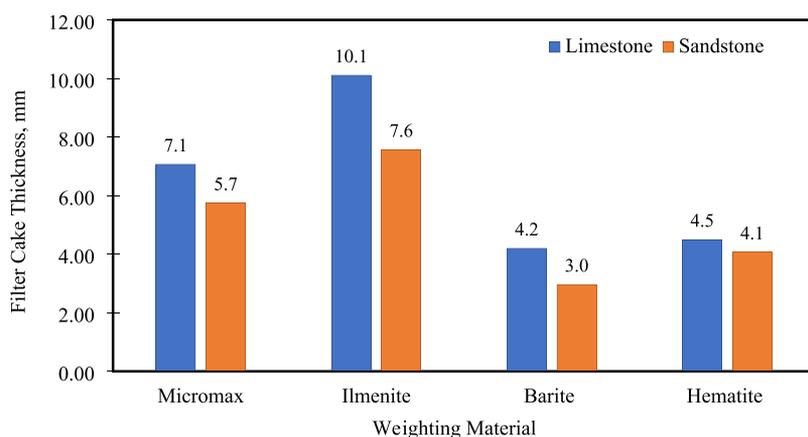


Figure 10. Filter cake thickness for the different weighting materials and formation types.

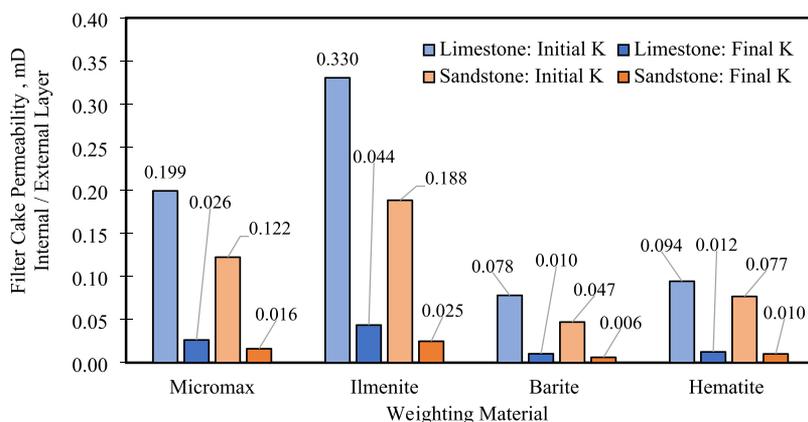


Figure 11. Filter cake permeability at two layers (internal and external) based on filtration data for the different weighting materials and formation types.

where V_p and V_b are the pore volume and bulk volume of the filter cake, respectively. Both volumes can be estimated using the following equations:

$$V_p = \frac{FC_{nww} - FC_{ndw}}{\rho_f} \quad (3)$$

$$V_b = \frac{\pi}{4} (D^2)_{FC} (h)_{FC} \quad (4)$$

where FC_{nww} , FC_{ndw} , ρ_f , $(D)_{FC}$, and $(h)_{FC}$ are the net wet weight of the filter cake (g), net dry weight of the filter cake (g), density of the filtration fluid (g/cm^3), filter cake diameter (cm), and filter cake thickness (cm), respectively.

The filter cake porosity values for the weighting materials in both formation types are shown in Figure 12. For the weighting

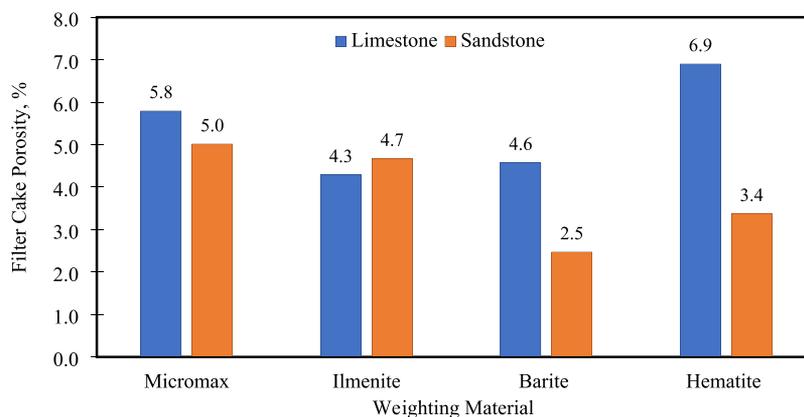


Figure 12. Filter cake porosity for the different weighting materials.

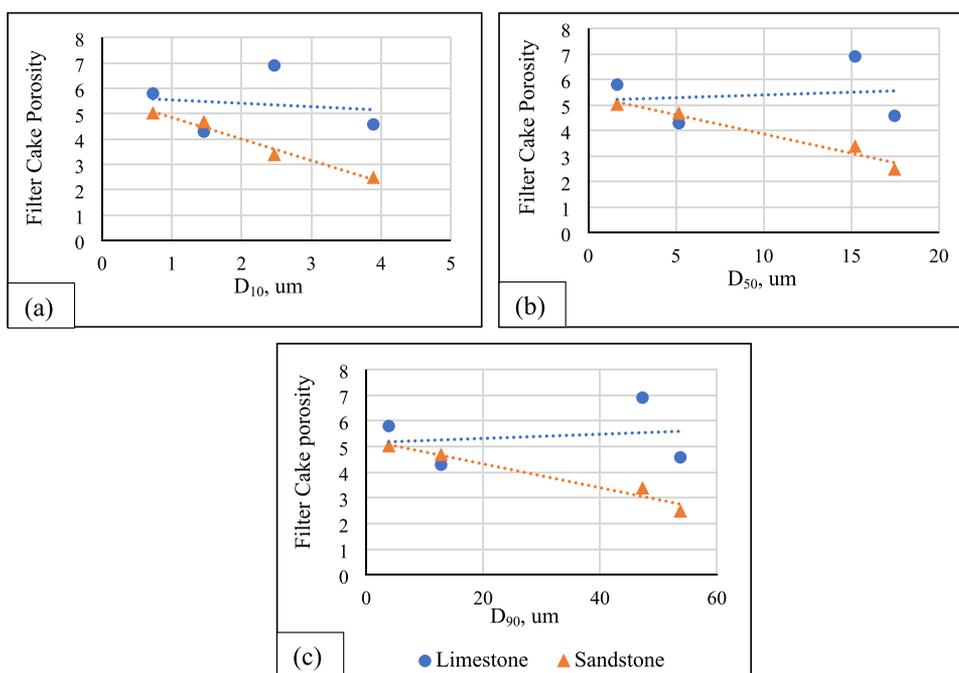


Figure 13. Filter cake porosity as a function of the particle sizes ((a) D_{10} , (b) D_{50} , and (c) D_{90}) for sandstone and carbonate cores.

materials with relatively fine particles, they have close filter cake values in both formation types; the Micromax filter cake has porosities of 5.8 and 5% while ilmenite has filter cake porosities equal to 4.3 and 4.7% for limestone and sandstone, respectively. On the other hand, the coarse weighting materials have a large difference in their values between the two formations with higher porosity in the limestone formation. Barite drilling fluid showed filter cake porosities equal to 4.6% in limestone and 2.5% in sandstone. Similarly, the hematite drilling fluid forms a filter cake with porosities equal to 6.9% in limestone and 3.4% in sandstone. These might indicate that the filter cake porosity dependency on the weighting material properties (i.e., how they aggregate, particle edges, dimensions, etc.) is higher than the formation properties. Nevertheless, the pore structure of the formation has some impact on the filter cake porosity. This can be seen clearly by plotting the average particle sizes of the weighting materials with filter cake porosity for each formation. Even though there is an excellent correlation between D_{10} , D_{50} , and D_{90} with filter cake porosity in sandstone as shown in Figure 13, this is not the case in the carbonate formation. This can lead to an initial conclusion with respect to the main contributor in

the filter cake porosity, in which both factors (weighting material type and formation characteristics) play an important role in the filter cake porosity.

Filter Cake Thickness. Thickness is another important property of the filter cake, and a similar approach will be followed to assess the impact of the weighting materials and formation properties. The filter cake thickness values are presented in Figure 10 for each weighting material and formation type. Initially, the comparison will be focused on the different weighting materials for limestone. A similar behavior to the effect of the weighting materials on the filtration behavior was observed where the weighting material with fine particles exhibited the largest thickness and vice versa for the weighting material with large particles. The filter cake thickness values are 7.07, 10.11, 4.2, and 4.5 mm for Micromax, ilmenite, barite, and hematite, respectively. Nevertheless, it seems that the formation properties (i.e., in particular, the pore structure) play a larger role in the filter cake thickness. By comparing the filter cake thickness within each formation type among the weighting materials with close D_{50} among themselves (i.e., Micromax with ilmenite and barite with hematite), some notes can be drawn. In

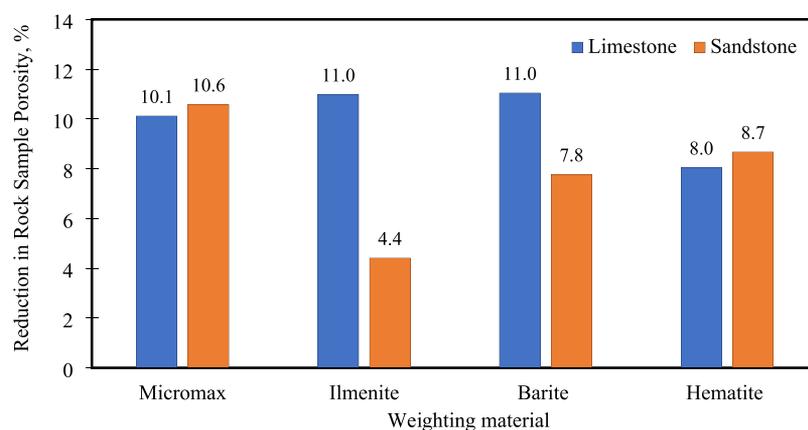


Figure 14. Core porosity reduction for each weighting material.

the sandstone formation where the pore structure is almost identical among all core samples, the difference in the thickness as the percentage between the Micromax and ilmenite is 24% while the percentage between the barite and hematite is 27%. The difference between the two percentages highlights the contribution from the weighting material properties when the formation properties are almost identical. For the limestone sample, on the other hand, the pore structure is somehow different, which is reflected in the thickness increase as a percentage. There is a thickness increase by 30% from Micromax to ilmenite, while the percentage increase in the filter cake thickness is equal to 7% from barite to hematite. The difference is almost 23%, which shows the impact of the formation properties, especially the pore structure. In addition, shedding light on the performance of each weighting material by itself in different formations supports what was mentioned previously. The incremental reduction (42 %) in the barite filter cake thickness was the largest followed by ilmenite with a 36% reduction from limestone to sandstone. After that, the Micromax and hematite follow with 23 and 10.6% reduction, respectively.

Core Properties. The impact of the filter cake formed by different weighting materials on the core is assessed through the change in the core porosity. Figure 14 shows the core porosity reduction due to the filtration for each weighting material in limestone and sandstone. In limestone, the porosity reduction values were estimated to be equal to 10.12, 10.98, 11.05, and 8.05 for Micromax, ilmenite, barite, and hematite, respectively. For sandstone, the porosity reduction values were 10.58, 4.41, 7.77, and 8.67 for the same order of weighting materials. There were no clear trends between the weighting material properties and the porosity reduction in both formation types.

CONCLUSIONS

In this work, four different weighting materials, namely, Micromax, ilmenite, hematite, and barite, were used to assess the effect of their physical properties on filtration volume, filter cake thickness, filter cake porosity and permeability, and solid invasion. Based on the results obtained, the following conclusions can be drawn:

1. The filtration volume and filter cake thickness and permeability were higher in limestone as compared to those in the sandstone formation.
2. The weighting material is the dominant factor in the filtration behavior, with a slight contribution from the

formation properties, specifically the permeability and porosity.

3. The initial and final filter cake permeability depends mainly on the weighting material dimensions and shape.
4. For the filter cake porosity, both the formation and weighting material dimensions and shape are important. They contribute almost equally to the filter cake porosity.
5. There is no clear trend found between the solid invasion (reduction in core porosity) and the weighting material type.

For future work, the role of the formation and the weighting materials can be evaluated for higher mud density, which is extremely important for ultradeep wells.

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Notes

The authors declare no competing financial interest. The data used to support the findings of this paper are included within the article.

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