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Characterization a Self-destructing Filter cake by Using Computer Tomography

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Abstract

Drilling long horizontal and multilateral wells with very low drawdown makes efficient cleaning and stimulation treatments very challenging. None of the conventional chemical cleaning methods can overcome problems for filter-cake removal in long horizontal and maximum reservoir contact wells because of limitations such as the complex geometry of wells, non-uniform chemical distribution, low contact between cleaning fluids/filter cake, and high chemical reaction rate, especially at high temperatures.

All of these challenges lead us to develop a new system of filter cake removal method that addresses several key problems inherent in the removal of drilling fluid filter cake, cleaning, and stimulation treatments of horizontal and multilateral wells. This system is a water-based drilling fluid that is weighted with calcium carbonate and has a mixture of solid-acid precursor and particulate solid-acid reactive material. This fluid has both functions of drilling and completion and can reach total depth of MRC wells. It has the ability to effectively stimulate the whole horizontal sections after drilling.

Previous work by the authors on this self-destructing drilling fluid system resulted in obtaining the best formula based on the original water-based mud (SPE 136400). High temperature high pressure filter press results (SPE 139087) showed high filter cake efficiency in cleaning the filter cake. Unlike the conventional reactive acids such as HCl, the slow reaction kinetics ensured good distribution of the generated acid across the filter cake.

The objective of this study is to determine the homogeneity of the self-destructive filter cake. Image J software and Grabit software combined with CT scan results were used to determine the filter cake properties such as porosity, permeability and thickness of the self-destructing filter cake system.

Introduction

Exposure of the fluid to reservoir rock is unavoidable during drilling and workover. In many in-situ hydrocarbon reservoir exploitation processes, cake filtration inherently occurs in these reservoirs. Overbalance drilling of wells into petroleum reservoirs is examples of the processes that cause a cross-flow filtration, which leads to a filter cake buildup over the face of the porous rock and filtrate invasion into the reservoir.

Mud fines and filtrates invade the near-well bore formation and damage this zone.

Filter cake must be removed by different chemical and mechanical means. Removing the filter cake can be accomplished by mechanical means (scraping, jetting) or by subsequent addition of a fluid such as an acid or an enzyme to dissolve at least a portion of the filter cake (Willberg and Dismuke 2009).

All technologies currently used have some drawbacks. Oxidizers and acids have been used for many years to remove filter cake produced by polymer-based drilling fluids. Although these materials could be reasonably effective in attacking individual components of the cake, they are not necessarily efficient when confronted with the tight composite cake laid down on the formation (Almond 1982; O`Driscoll et al. 1988). Therefore, in many cases unreacted polymers stay in place and degrade partially (Stanley et al. 1999).

The undesirable side effect of some breakers is its high reaction rate. In the case of strong acids, it can increase the permeability of many formations by dissolving rock minerals, but at the same time, it can cause added permeability damage if dissolved components reprecipitate (Siddiqui and Nasr-El-Din 2005; Al-Yami and Nasr-El-Din 2009). Chelating agents (Burton et al. 2000), enzymes (Hanssen et al. 1999), emulsions (Al-Riyamy 2000), solid-free brines (Al-Yami and Nasr-El-

Din 2009), in-situ generated acids (Al-Moajil and Nasr-El-Din 2007; Binmoqbil et al. 2009; Alotaibi and Nasr-El-Din 2007) are other chemicals that have been used to remove the filter cake.

But considering common limitations such as need of an additional tool or addition of another fluid to change the physical or chemical state (Todd et al. 2004), slow or incomplete filter cake removal, and non-uniform distribution of chemicals, also high reaction rate of some chemicals, especially at high temperatures prevent effective filter cake removal. Considering these limitations can lead to successful drilling and completion of wells with minimum damage to the wells. Consequently, there is a need for cleanup solutions that have a delayed effect on filter-cake integrity, allowing the cleanup solution to be circulated across the entire interval.

This paper studies a self-destructing fluid system, which is a water-based drilling fluid system and is weighted with calcium carbonate as the solid reactive material and polylactic acid as solid acid precursor. This fluid has both functions of drilling and completion fluids. Studies on developing self-destructing fluid system to reach desired properties are discussed (Rostami and Nasr-El-Din 2010a). There are also discussions of best particle size distribution and time and temperature range for this fluid that has been addressed by (Rostami and Nasr-El-Din 2010b).

The objectives of this work are to: 1) characterize the self destructive filter cake under static and dynamic conditions, 2) determine filter cake properties, thickness and porosity using CT scan, 3) obtain the filter cake permeability, 4) determine the removal efficiency of the filter cake which formed under dynamic conditions, and 5) asses the retained permeability. A new CT technique developed by Elkatatny et al. (2011a) will be utilized in this work.

Experimental Studies

Materials

A water-based polymer drilling fluid was used in the experiments, which contained calcium carbonate (d_{50} = 50 µm) as a weighting material, bentonite was used as a viscosifier, and solid polylactic acid (d_{50} = 150 µm) that functions as solid-acid precursor. The composition of the drilling fluid is given in **Table 1**.

Ceramic disks (10 µm) of average permeability of 134 md and average porosity of 38 vol% and limestone disk (0.25 in. x 2.5 in.) of an average permeability ranged from 100 to 140 md and average porosity of 18 vol% were used to stimulate the formation for filtration process at 225 ^{o}F and 300 psi.

Drilling fluid was prepared as per **Table 1**.The drilling fluid was heated at 250 ^{o}F for 16 hrs under hot rolling and no phase separation was observed.

Properties of the Drilling Fluid

Table 2 summarizes the properties of the drilling fluid. The mud properties were measured by using mud balance, Fann 35 viscometer and pH meter. The results obtained were 70 pcf for density measured at 75 ^{o}F and 14.7 psi, 13 cp for a plastic viscosity measured at 120 ^{o}F and 14.7 psi, 11 lb/100 ft^2 for a yield point measured at 120 ^{o}F and 14.7 psi and a pH value of 9.5 measured at 75 ^{o}F.

Table 3 summarizes the results of the sieve analysis, which were made to solid components, which presented in the drilling fluid. **Fig. 1** gives the d_{50} of 0.1 mm.

Results and Discussion

HPHT Filtration

Static and dynamic (150 RPM) HTHP filtration tests were performed using a standard HPHT filter press. The cell was placed in a heating jacket and the system was heated to 225 ^{o}F. The applied differential pressure was 300 psi. The filtrate rate was measured in a 30-min period and the results are shown in **Fig. 2** for static condition and **Fig. 3** for dynamic condition.

It was noticed that the ceramic disk and limestone disk have the same spurt volume (3 cm^3) at static conditions due to setteling effect of solid. While at dynamic conditions, the ceramic disk has a 5.2 cm^3 spurt volume, which is higher than the spurt volume for limestone disk (3.5 cm^3); this was due to the large pore volume of ceramic disk (6 cm^3) than limestone disk (3 cm^3). Also, the cumulative filtrate for ceramic disk was greater than the limestone disk under dynamic conditions. The filtrate fluid viscosity was 0.6 cp at 225^{o}F and 300 psi, which was obtained using Grace M5600 – HPHT Rheometer.

CT Scan

The filter cake was scanned in wet conditions for the ceramic disk and the limestone disk. **Fig. 4** shows the filter cake heterogeneity and the formation of two layers under static conditions, one layer close to the rock surface and one layer close to the drilling fluid. **Fig. 5** shows the CT results of the filter cake heterogeneity under dynamic conditions.

The thickness of the two layers was obtained using Grabit software. **Table 4** shows that the thickness of the layer close to the rock surface is constant under static and dynamic conditions (0.05 – 0.06 in.) and the layer close to the drilling fluid is much thicker than the previous one (0.1 to 0.11 in.) and it is also constant under static and dynamic conditions. The total thickness of the filter cake ranged from 0.15 to 0.17 in.

Table 5 shows the record of the CTN of the ceramic disk, limestone disk and the filter cake layers in wet and dry conditions. The ceramic disk has a CTN of 1400 and 1150 in wet and dry condition, respectively. The limestone disk has a CTN of 2000 and 1850 in wet and dry condition, respectively.

Using the CTNs from **Table 5**, the porosity of each layer of the filter cake and the filter medium was obtained using Eq. 1.

$$\emptyset = \frac{CT_{wet} - CT_{dry}}{CT_{water} - CT_{air}}, \ldots\ldots (1)$$

where

CT_{wet} = CTN of the porous medium saturated with water
CT_{dry} = CTN of the porous medium was dry
CT_{water} = CTN of water (0.0)
CT_{air} = CTN of air (-1000)

The final porosity of the ceramic disk was 25 vol% and for the limestone disk was 15 vol%. The porosity of the layer close to the disk surface was 25 vol% and the layer close to the drilling fluid has a porosity of 0.0 vol%, which lead to zero permeability after 30 minutes of filtration, **Table 5**.

Permeability Determination

Elkatatny et al. (2011b) found that the pressure drop through the layer close to the rock surface was around 40 psi. They used a drilling fluid similar to the one used in the present work. Experimental conditions were also similar.The permeability of the layer close to the rock surface can be obtained using Li et al (2005) method, Eq. 2.

$$q = k_c \frac{\Delta P_c}{\mu L_c}, \ldots\ldots (2)$$

where

K_c = average filter cake permeability, m^2
L_c = total thickness of filter cake, m
q = filtrate rate, $m^3/m^2.s$
μ = filtrate viscosity, Pa.s
ΔP_c = pressure drop across the filter cake, Pa

The filtrate rate is equal to the slope of plotting the cumulative filtrate fluid (cm^3) versus time (s), **Fig. 6**, and it was $7.4x10^{-7}$ $m^3/(m^2.s)$ for static and dynamic conditions. The filtrate viscosity was $6x10^{-4}$ Pa.s, the layer thickness was 0.0015 m, and the differential pressure was 27579 Pa. the layer permeability was calculated using Eq. 2 and it was 2.5x 10^{-18} m^2, which is 2.5 μd.

The overall permeability of the filter cake was 0.0 after 30 minutes of filtration. This was because the layer close to the drilling fluid had a porosity of 0 vol%.

Removal efficiency

The filter cake was soaked in the HPHT filter cell for 20 hrs and the removal efficiency was recorded in **Table 6**. **Figs. 7 and 8** show the limestone disk and the ceramic disk after the removal process for 20 hrs soaking with deionized water. It was noted that for the filter cake formed under static conditions the removal efficiency was nearly 79 %, while for the filter cake formed under dynamic conditions was 85%. The removal efficiency was calculated using Eq. 3.

$$Efficiency = \frac{W_2 - W_3}{W_2 - W_1}, \ldots\ldots (3)$$

Where

W_1 = the weight of the disk saturated with water, g
W_2 = the weight of the disk with filter cake, g
W_3 = the weight of the disk after removal process, g

Retained Permeability

To measure the initial permeability, a volume of 250 cm^3 of deionized water was flow through the disk at a constant pressure (60 psi) and the time was recorded. The initial permeability of the disk was measured using Darcy's law Eq. 4.

$$k = \frac{122.812 * q * \mu * h}{\Delta p * d^2}, \ldots\ldots (4)$$

Where

d = diameter through which water flow, in. (2.25)
h = disk thickness, in. (0.25)
K = permeability of the disk, md

q = flow rate, cm^3/min (250)
μ = fluid viscosity, cp (1)
Δp = differential pressure, psi (60)

The initial permeability of the ceramic disk was 134 md and for the limestone disk was ranged from 100 to 134 md. The permeability was measured after the removal process, the final permeability, was found 100 md for the ceramic disk and the limestone disk, which were used to form the filter cake under dynamic conditions. The final permeability of the ceramic disk, which was used to form the filter cake under static conditions, was 80 md and for the limestone was 72 md, as shown in **Table 7**.

The retained permeability is defined as the ratio of pre-exposure fluid permeability to post-exposure fluid permeability, which expressed as a percentage, Eq. 4

$$k_r = \frac{k_f}{k_i} x100, \ldots\ldots (4)$$

where

k_f = final permeability, md
k_i = initial permeability, md
k_r = retained permeability

Fig. 9 shows the reduction in the limestone disk and ceramic disk permeability after the removal process. The retained permeability was 60 to 65 % for the disk, which was used to do the filtration process under static conditions and 75 % for the disk, which was used to do the filtration operation under dynamic conditions.

Conclusions

1. Self-destructive filter cake was heterogeneous, which contained two layers, one layer close to the rock surface and one layer close to the drilling fluid
2. The layer close to rock surface has a 25 vol% porosity, 2.5 μd permeability, and it was less thick than the layer close to the drilling fluid
3. The layer close to the drilling fluid has a 0 vol% porosity, which lead to 0 permeability after 30 minutes of filtration
4. The removal efficiency of the filter cake was 85% under dynamic conditions, which was higher than under static conditions
5. The retained permeability of the disk, which used under dynamic conditions was higher than that under static conditions

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Table 1: Laboratory formulas to prepare the equivalent of 1 bbl.

Component	Description/Function	Amount, g	Mixing Time, minutes
Water	Base Liquid	319	…..
Bentonite	Clay for viscosity/API filtrate control	18	20
Carboxymethylcellulose	API/HP/HT filtrate control	0.25	5
Highly oxidized leonardite	API/secondary thinner	4.0	5
Caustic soda	Alkalinity agent	0.6	
Calcium carbonate (50 microns)	Weight material/bridging agent	38	10
Calcium montmorillonite clay	Simulated solids	10	5
Solid acid precursor	Self-destructive solid	21	

Table 2: Properties of the self-destructive drilling fluids.

Property	Conditions	Value	Units
Density	75 ^oF	70	lb/ft^3
Plastic viscosity	120 ^oF	13	cp
Yield point		11	$lb/100\ ft^2$
10 s gel strength		4	$lb/100\ ft^2$
10 s gel strength		10	$lb/100\ ft^2$
pH	75 ^oF	9.5	………

Table 3: Sieve analysis of different sold mixes that were used to prepare self-destructive drilling fluids.

Sieve number	Sieve Size (mm)	Retained Weight percent %	Cumulative weight percent %
20	> 0.85	0.14	0.14
30	0.85 - 0.6	0.12	0.26
40	0.6 - 0.425	0.19	0.45
50	0.425 - 0.3	0.57	1.01
70	0.3 - 0.212	2.20	3.22
100	0.212 - 0.15	4.31	7.53
140	0.15 - 0.106	6.83	14.35
170	0.106 - 0.09	4.92	19.27
200	0.09 - 0.075	6.00	25.27
325	0.075 - 0.045	25.21	50.48
Pan	< 0.04	49.52	100.00

Table 4: Thickness determination for the layer close to rock surface and the layer close to drilling fluid for different disks.

disk Name*	Condition	Thickness of Layer Close to rock surface (in.)	Thickness of Layer close to drilling fluid (in.)	Total Thickness (in.)
LM1	Static conditions	0.05	0.1	0.15
LM2		0.05	0.1	0.15
CD1		0.06	0.1	0.16
CD2		0.06	0.1	0.16
LM3	Dynamic conditions	0.06	0.1	0.16
LM4		0.06	0.1	0.16
CD3		0.06	0.1	0.16
CD4		0.06	0.11	0.17

*LM: limestone disk and CD: ceramic disk

Table 5: CTNs for ceramic disk, limestone disk and the two layers of the filter cake in wet and dry conditions.

	LM1			**CD**		
	Disk	Layer close to rock surface	Layer close to drilling fluid	Disk	Layer close to rock surface	Layer close to drilling fluid
Wet Conditions	2000	1050	500	1400	1100	500
Dry conditions	1850	800	600	1150	850	650
Porosity, vol%	15	25	0	25	25	0

Table 6: Filter cake removal efficiency under static and dynamic conditions.

	condition	W_1* (g)	W_2*(g)	W_3*(g)	Efficiency %
CD3	Static	46.40	59.41	49.19	78.55
LM2		38.88	51.65	41.50	79.48
LM4	Dynamic	43.70	57.53	46.00	83.37
CD4		47.20	52.00	47.90	85.42

*W_1 = the weight of the disk saturated with water
*W_2 = the weight of the disk with filter cake
*W_3 = the weight of the disk after removal process

Table 7: Permeability calculation of the disk before and after the filtration operation.

Disk	**Initial permeability, md**	**Final permeability, md**
LM2	108	72
CD3	134	80
LM4	134	100
CD4	134	100

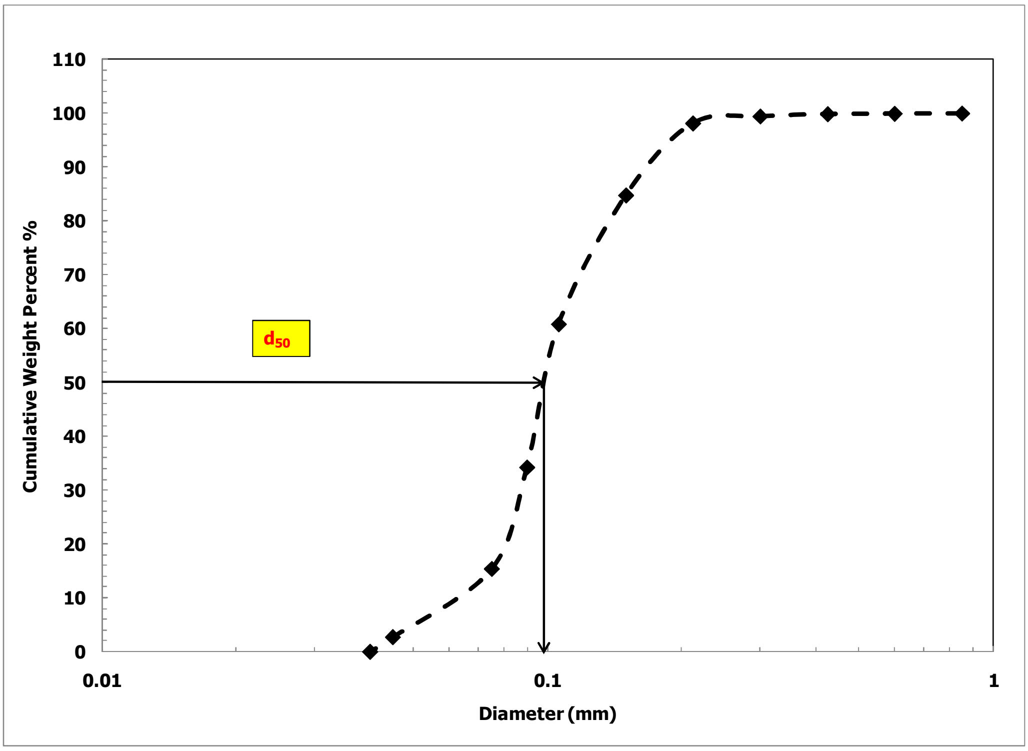


Fig. 1: Grain size distribution of drilling solid mixes that were used to prepare the drilling fluid.

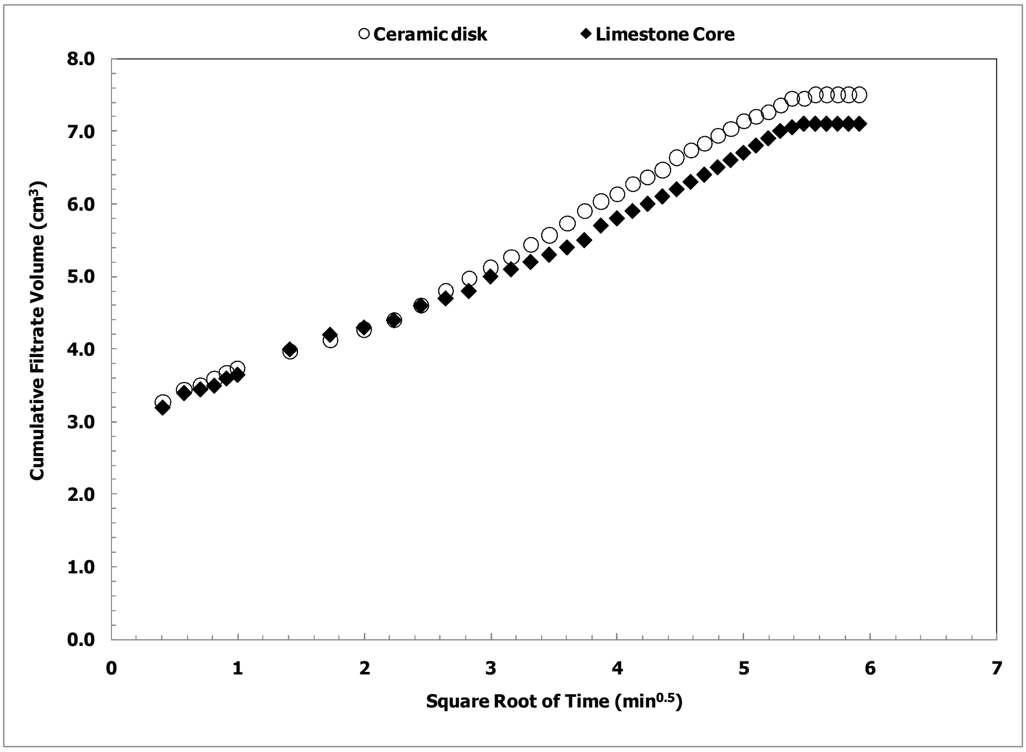


Fig. 2: Cumulative filter volume as a function of the square root of time, static conditions.

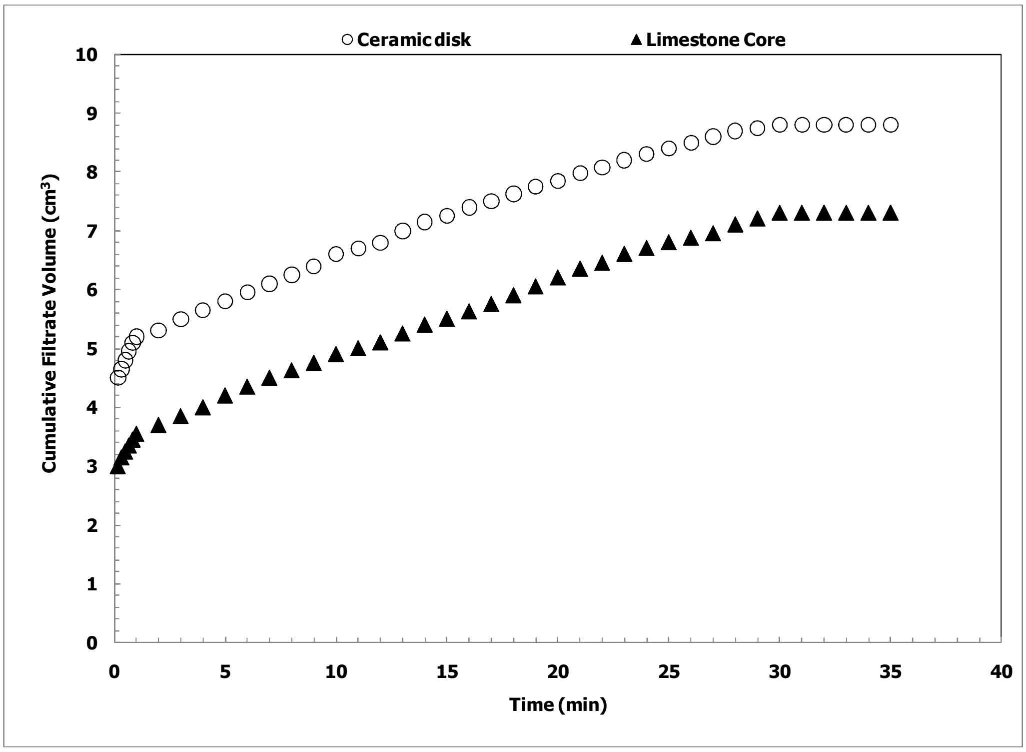
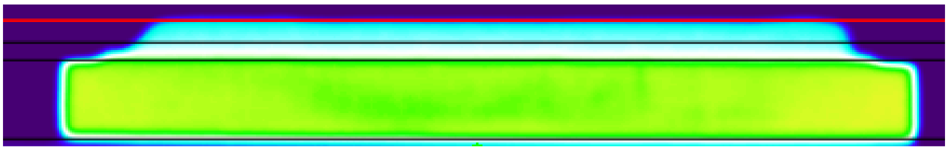
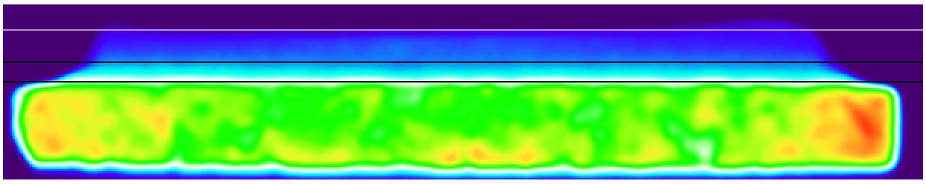


Fig. 3: Cumulative filter volume as a function of filtration time, dynamic conditions.

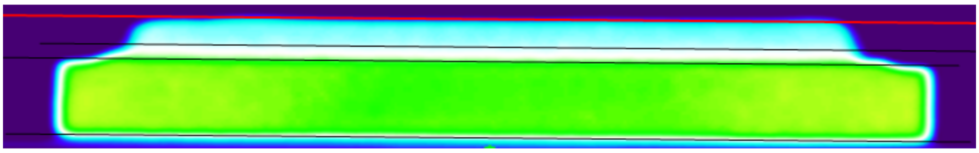


a. 10 microns ceramic disk

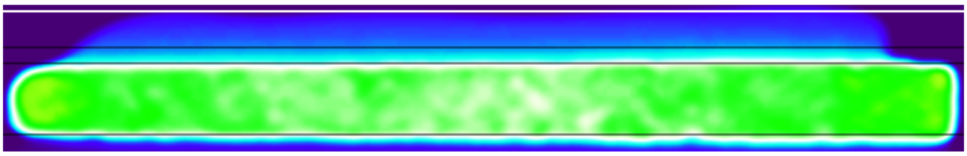


b. limestone disk

Fig. 4: Filter cake heterogeneity as shown by the 2D CT scan under static conditions, a) ceramic disk and b) limestone disk.



a. 10 microns ceramic disk



b. limestone disk

Fig. 5: Filter cake heterogeneity as shown by the 2D CT scan under dynamic conditions, a) ceramic disk and b) limestone disk.

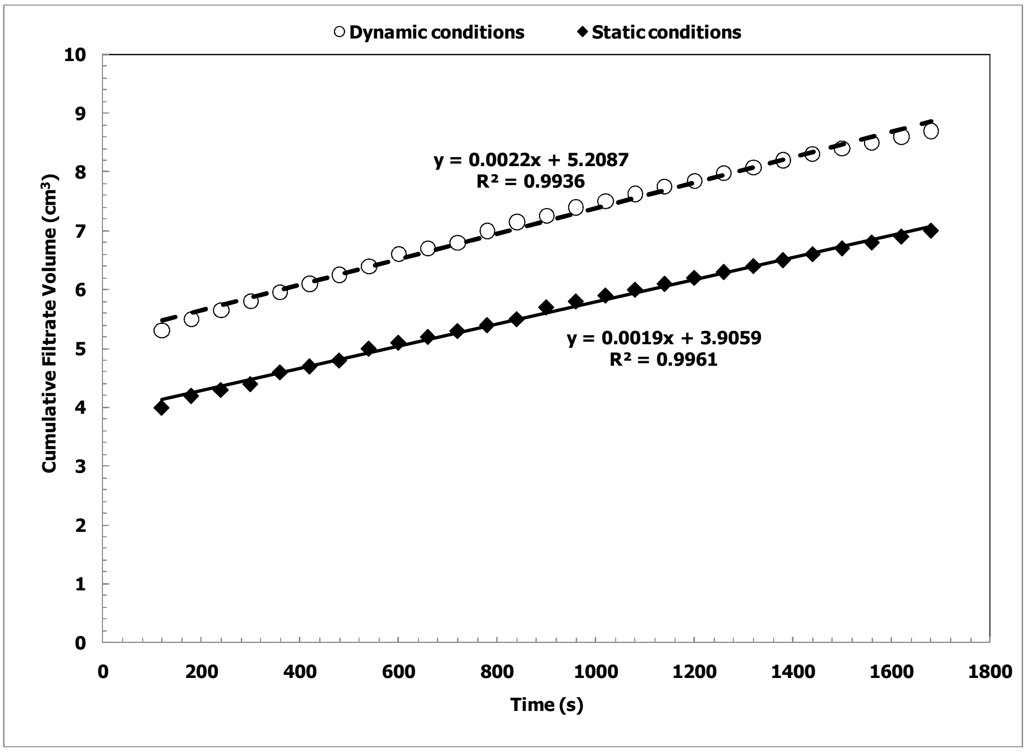


Fig.6: Li et al. (2005) method used to determine the filter cake permeability by plotting the cumulative filtrate volume versus time.

a: effect of removal process on limestone disk.

b: Effect of removal process on 10 microns ceramic disk.

Fig. 7: The removal process for a filter cake formed under static conditions for 20 hrs soaking, a) limestone disk, b) ceramic disk.

a: effect of removal process on limestone disk.

b: Effect of removal process on 10 microns ceramic disk.

Fig. 8: The removal process for a filter cake formed under dynamic conditions for 20 hrs soaking, a) limestone disk, b) ceramic disk

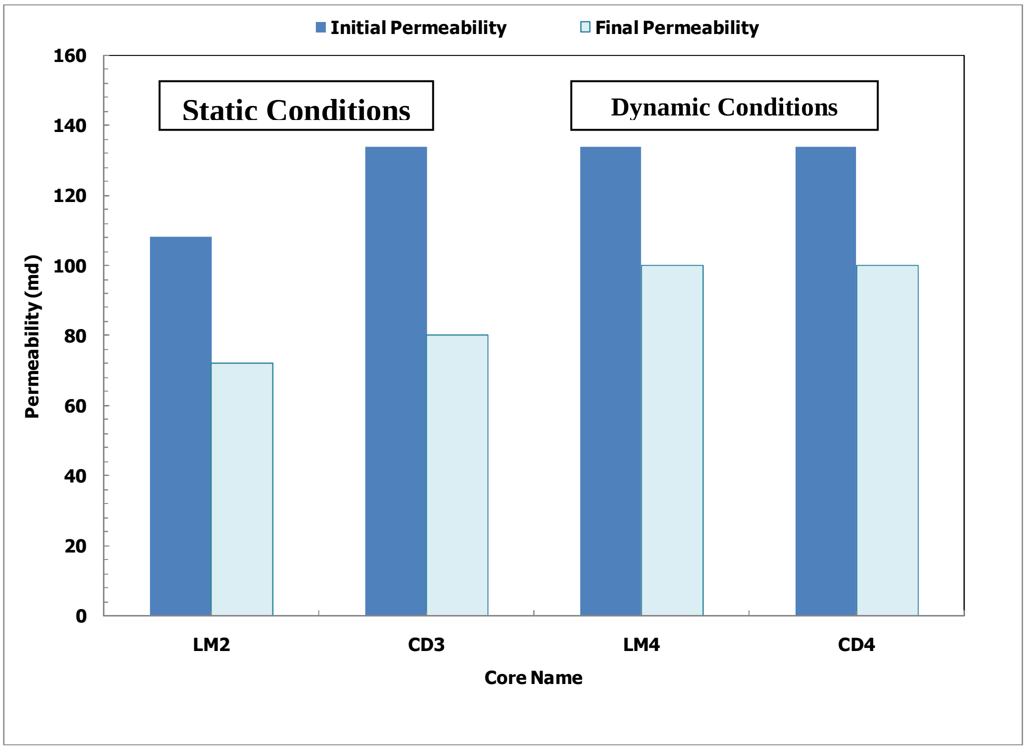


Fig. 9: Reduction in limestone disk and ceramic disk permeability after removal process.