Journal of King Saud University – Engineering Sciences 31 (2019) 97–103

Contents lists available at ScienceDirect

Journal of King Saud University – Engineering Sciences

journal homepage: www.sciencedirect.com

Original article

Superior fracture-seal material using crushed date palm seeds for oil and gas well drilling operations

Musaed N.J. AlAwad [a], K.A. Fattah [a,b,*]

[a] Petroleum and Natural Gas Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia
[b] Cairo University, Faculty of Engineering, Petroleum Engineering Department, Cairo, Egypt

ARTICLE INFO

Article history:
Received 20 November 2016
Accepted 16 January 2017
Available online 22 February 2017

ABSTRACT

Expenses for drilling represent 25% of the total oilfield exploitation cost. Drilling fluids represent 15–18% of the total cost of well petroleum drilling operations. The main drilling fluids problem is the loss into fractured and vugs. Prevention or mitigation of severe lost circulation is a main challenge while drilling in fractured formations where conventional lost circulation materials (LCM) will not cure these losses. Therefore, specialized treatment is required when drilling fractured formations.

In this study, a superior LCM made from crushed date palm seeds was tested at laboratory for its ability to seal artificially fractured cores under High Temperature High Pressure (HT-HP) conditions. For this purpose, the conventional 500 ml HT-HP filter press was modified to accommodate a fractured core plug of length and diameter equal to 38.1 mm (1.5 inch) instead of the ceramic disc.

Using the modified HT-HP filter press, crushed date palm seeds proved its ability to completely seal the artificially made fracture in the test core samples at overbalance pressures up to 1000 psi and temperatures up to 90 °C. The optimum mud composition was fresh water, 7% by weight bentonite, 3.5% fine crushed date palm seeds, and 3.5% coarse crushed date palm seeds in weight bases. In addition to its superior ability to seal fractured formation, the crushed date palm seeds material is cheap, locally available in commercially quantities, and environmentally friendly material.

1. Introduction

Routine drilling fluids filtration measurements are performed on a filter paper using either the API filter press (100 psi and 25 °C) or HT-HP filter press (175 ml or 500 ml). Additionally, HT-HP filtration can be performed on a ceramic disc as shown in Fig. 1. Filter papers or ceramic discs are used to simulated rock matrix in non-fractured formations. Several attempts have been performed to investigate the effect of various fluid loss control materials (LCM) on sealing fractured formations.

Sanders et al. (2008) and Contreras et al. (2014) experimentally studied the mechanisms of lost circulation materials (LCM) seal of induced fractures in thick-wall cylindrical cores. Kumar et al. (2011) developed a tapered slot to physically resembling a wedge shaped fracture for testing various types of LCM. Miller et al. (2013) developed a low-volume, laboratory-scale apparatus with multiple configurations to better model lost circulation conditions encountered while drilling through vugular and fractured zones. The apparatus has a high working pressure and high pressure differentials can be used to test plugs formed by lost circulation materials. Wang et al. (2007) used boundary element analysis (BES) to theoretically investigate the process of cracks sealing to strengthen the wellbore. They concluded that perfect sealing of cracks enhances wellbore stability. In a recent study, Chellappah et al. (2015) a real attempt was done to simulate fractured formation by replacing the ceramic disc in the HT-HP filter press by slotted stainless steel. In a recent study, Amanullahh (2016) used crushed palm date seeds as a lost circulation material (LCM) for sealing fractured formations. In his study, he used 2 mm slotted stainless steel discs fitted into 250 mm HT-HP filtration cell to test the

* Corresponding author at: Petroleum and Natural Gas Engineering Department, College of Engineering, King Saud University, Riyadh, Saudi Arabia.

E-mail addresses: malawwad@ksu.edu.sa (M.N.J. AlAwad), kelshreef@ksu.edu.sa (K.A. Fattah).

Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2017.01.003
1018-3639/

Fig. 1. HT-HP filter press (500 ml).

possibility of fracture seal by a drilling fluid containing the crushed palm date seeds. The result was a perfect fracture seal indicating the possibility of utilizing this LCM in drilling oil and gas wells.

The previous studies to simulate fractures seal with LCM have several limitations such as:

1. Large scale core samples needed to simulate wellbore using thick-wall cylinders.
2. Neglecting filtration loss from the rock matrix inside and outside the fractures when using stainless steel slotted discs,
3. Real fracture shape is not perfectly simulated, and
4. The outlet valve in the HP-HT was not modified to allow LCM to flow out of the cell in case of no seal was established.

The objectives of this study are of two folds:

1. Firstly to overcome the above mentioned limitations by developing an accurate, simple, and cheap experimental setup to really simulate fractured formations during drilling operations. This development is based on using real core plugs with artificially induced fractures.
2. Secondly to test a new superior lost circulation control material made from crushed date palm seeds for fractures seal.

2. Experimental work

2.1. Experimental set-up

In this study the conventional 500 ml HT-HP filter press was modified to accommodate fractured rock plug by the developing of a special core holder made from durable rubber to replace the ceramic disk normally used in this apparatus as shown in Fig. 2. The core holder is designed to perfectly accommodate 38.1 mm core plug with 38.1 mm thickness. The developed core holder proved its integrity under temperatures up to 90 °C and pressure up to 1000 psi.

To verify there is no leakage from the developed core holder, stainless steel cylindrical plug of 38.1 mm diameter and 38.1 mm thickness was fitted into the holder and placed inside the HT-HP filter press and a real test at 90 °C and 1000 psi was performed with perfect seal result.

2.2. Testing materials

2.2.1. Drilling fluids

Water based mud formulated from fresh water plus 7% by weight bentonite was used as a base mud for all experiments in this study. Crushed date palm seeds sieving produced two groups based on grain size distribution, fine (from 0.25 mm to 1 mm) and coarse (from 1 mm to 3 mm) as shown in Figs. 3 and 4. Details on date palm tree, fruit, and seeds are presented in the appendix. The granulometric analysis of the crushed date palm seeds (fine and coarse) are taken as the bases for selecting the geometry of the induced fracture in the test cores as shown in the next section. The basic properties of the base mud are shown in Table 1.

2.2.2. Core samples

Core plugs of 38.1 mm diameter and 38.1 mm thickness were cored from an artificial sandstone blocks. The properties of this sandstone are shown in Table 2. After coring and trimming to the required dimensions, a single fracture was performed in each core with an opening (top) size of 3.0 mm until half way of the core length, then a tip (bottom) size of 1.0 mm along the remaining thickness up to the bottom of the core as shown in Fig. 5 and Eqs. (1) and (2).

$$\text{Fracture maximum width (top)} = \text{Coarse LCM maximumgrain size} = 3.0\ \text{mm} \tag{1}$$

$$\text{Fracture minimum width (bottom)} = \text{CoarseLCM minimum grain size} = 1.0\ \text{mm} \tag{2}$$

Fig. 2. The developed core holder and the testing cores.

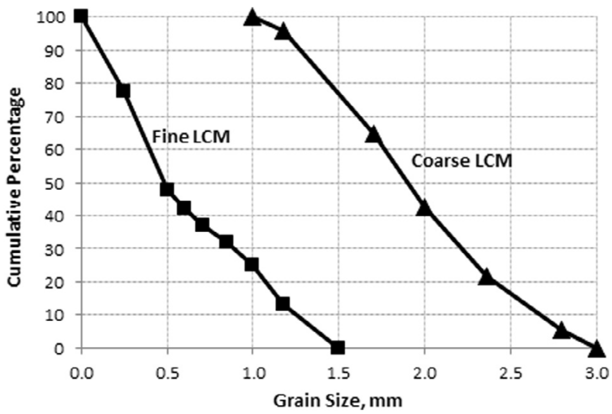

Fig. 3. Granulometric analysis of the crushed date palm seeds.

The fracture dimensions was selected based on the LCM grain size distribution shown in Fig. 2 so that the coarse LCM materials can enter the fracture and accumulate in the middle resulting in a potential fracture seal as shown in Fig. 6. Both fine LCM and bentonite in the base mud contribute to the developed seal as well in the fractured and non-fractured parts of the core plug.

2.3. Testing procedure

Experimental work for the verification of the potential fractures seal ability of crushed date palm seed was designed to investigate the effect of the following factors for potential fracture sealing:

1. Coarse LCM in base mud.
2. Fine LCM in base mud.
3. LCM mixture (fine + coarse) in base mud.
4. Temperature.
5. Pressure difference (ΔP).

Each experiment was repeated two to three times to validate the obtained results. The drilling mud prepared by mixing 7% by weight bentonite and the required LCM in fresh water. The test core plug was perfectly fit into the rubber sleeve using a temperature resistant adhesive tap as shown in Figs. 5 and 6. Then, the mixed mud was poured into the 500 ml HT-HP filter press cell. After that, the sleeve was placed over the O-ring and the cell cover was firmly tight with the six screws. At this stage the cell with its contents (drilling fluid and the fractured core plug) was placed upside-down in the heating well until reaching the required temperature.

The filtration test was then started by opening the nitrogen cylinder valve to apply the required pressure difference on the top of the mud. Then, the modified bottom valve (Fig. 7) was opened at atmospheric pressure and spurt as well as filtrate volumes were recorded with time. At the end of the test, the cell was left to cool to laboratory temperature, then the cell pressure was released and the core plug was extracted for inspection.

The experimental design (mud composition and LCM type and concentration, temperature, pressure difference, and experiments replication) used for the verification of the potential use of crushed date palm seeds to seal fractured formations while drilling is summarized in Table 3.

To avoid LCM trapping in the outlet, the top part of the outlet valve was cut to enlarge its opening to allow fine LCM and bentonite to flow smoothly. The coarse LCM grains are trapped in the fracture made in the core plug as mentioned earlier and shown in Figs. 5–7.

3. Results and discussion

In experiment 1, the base mud (fresh water +7% bentonite by weight) without LCM was tested for its potential ability for fracture sealing at pressure difference of 200 psi and 25 °C. The result was a complete loss of the mud within one minute. The inspection of the core plug after the test (Fig. 8A) showed that a mud cake has formed and sealed only the core matrix while the fracture is remaining open. This result indicated the need for the LCM to seal the fracture.

In experiments 2 and 3, 5% coarse and 5% fine crushed date palm seeds are added to the based mud respectively. Base mud with 5% coarse crushed date palm seeds failed to seal the facture and a complete loss of the mud within one minute was the result (Fig. 8B). Similar result was occurred when a base mud with 5% fine crushed date palm seeds was used (Fig. 8C). Therefore, it was decided to test a mixture of equal amounts of fine and coarse crushed date palm seeds for potential fracture sealing as shown in Table 3.

In experiments 4 through 9, mixtures of fine and coarse crushed date palm seeds of 4%, 5%, 7%, 8.5%, 10%, and 13% by weight of fresh water were tested (Fig. 8D through I). The 10 min filtrate volumes for these experiments are plotted in Fig. 9. As shown in Fig. 9, the optimum crushed date palm seeds mixture was 7% (3.5% fine +3.5% coarse) which gave 2.5 cc filtrate within 10 min with a perfect seal of the fracture as shown in Fig. 10. It must be noticed that all the previously mentioned experiments (1 through 9) was performed at a pressure difference of 200 psi and a temperature of 25 °C.

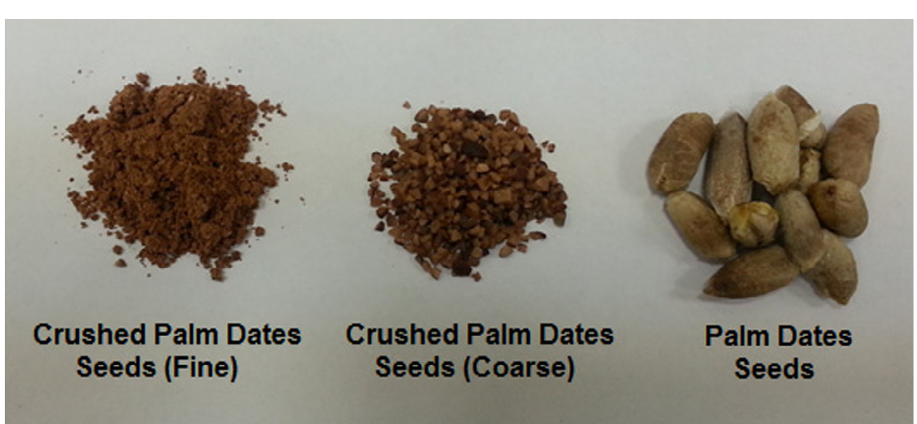

Fig. 4. Date palm seeds before and after crushing and sieving.

Table 1
Properties of the base mud used in this study.

Properties	Measured value
Density, ppg	8.7
pH	7.2
Apparent viscosity, cp	5.0
Yield point, lb/100 ft^2	7.8
10 s Gel strength, lb/100 ft^2	6.4
10 min Gel strength, lb/100 ft^2	10.7

Table 2
Properties of the used sandstone.

Properties	Measured values
Rock Type	Artificial White Sandstone
Porosity	30%
Permeability	266 md
Unconfined Compressive Strength	14 MPa
Tensile Strength	2.7 MPa
Plug Diameter	38.1 mm (1.5 inch)
Plug Length	38.1 mm (1.5 inch)
Fracture Top	3.0 mm
Fracture Bottom	1.0 mm
Fracture Length	38.1 mm (1.5 inch)

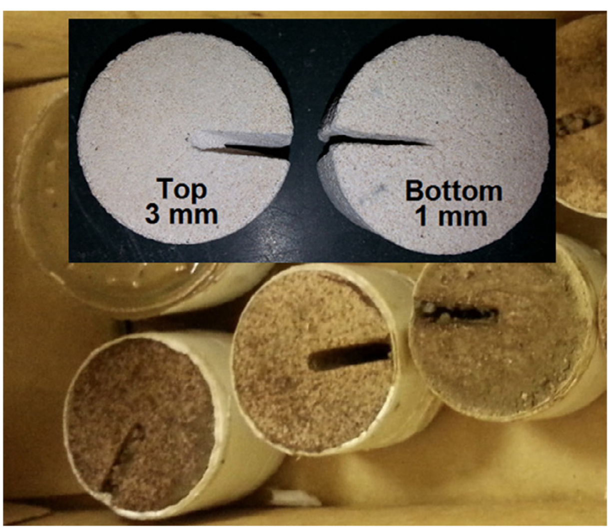

Fig. 5. Sandstone core plug with artificial fracture.

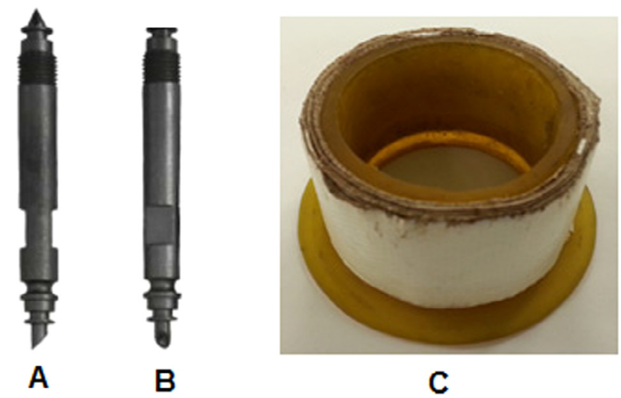

Fig. 7. HT-HP cell valves before (A), after modification (B), and the developed core holder (C).

Table 3
Experimental work details.

#	Experiment details	Replication
1	Base mud (BM): Fresh water + 7% by weight bentonite@25 °C and ΔP = 200 psi	2
2	BM + 5% coarse LCM@25 °C and ΔP = 200 psi	2
3	BM + 5% fine LCM@25 °C and ΔP = 200 psi	2
4	BM + 4% LCM (2% fine LCM + 2% coarse LCM)@25 °C and ΔP = 200 psi	3
5	BM + 5% LCM (2.5% fine LCM + 2.5% coarse LCM)@25 °C and ΔP = 200 psi	3
6	BM + 7% LCM (3.5% fine LCM + 3.5% coarse LCM)@25 °C and ΔP = 200 psi	3
7	BM + 8.5% LCM (4.25% fine LCM + 4.25% coarse LCM) @25 °C and ΔP = 200 psi	3
8	BM + 10% LCM (5% fine LCM + 5% coarse LCM)@25 °C and ΔP = 200 psi	3
9	BM + 13% LCM (6.5% fine LCM + 6.5% coarse LCM)@25 °C and ΔP = 200 psi	3
10	BM + 7% LCM (3.5% fine LCM + 3.5% coarse LCM)@65 °C and ΔP = 200 psi	2
11	BM + 7% LCM (3.5% fine LCM + 3.5% coarse LCM)@90 °C and ΔP = 200 psi	2
12	BM + 7% LCM (3.5% fine LCM + 3.5% coarse LCM)@25 °C and ΔP = 400 psi	2
13	BM + 7% LCM (3.5% fine LCM + 3.5% coarse LCM)@25 °C and ΔP = 600 psi	2

Fig. 6. Demonstration of the coarse date palm seeds trapping in the induced facture.

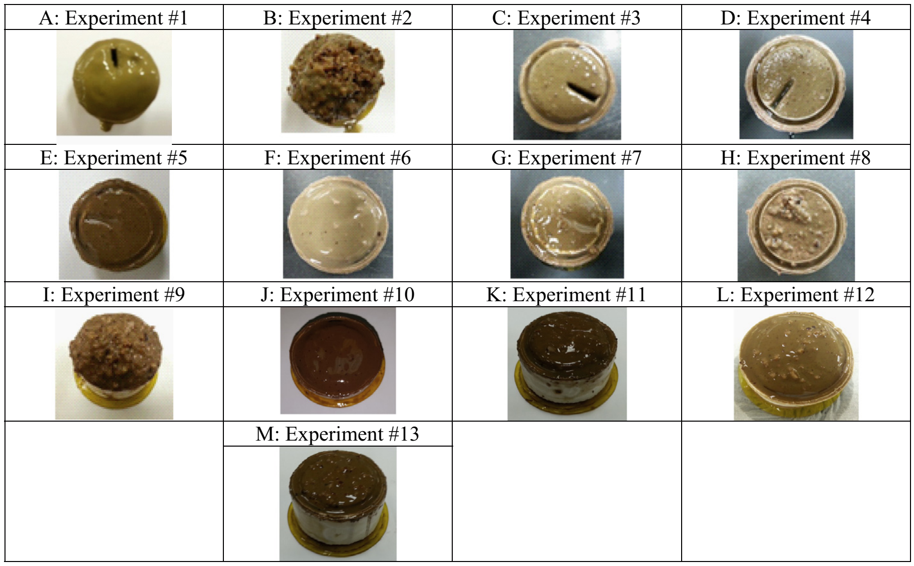

Fig. 8. The fractured sandstone core plugs at the end of experiments.

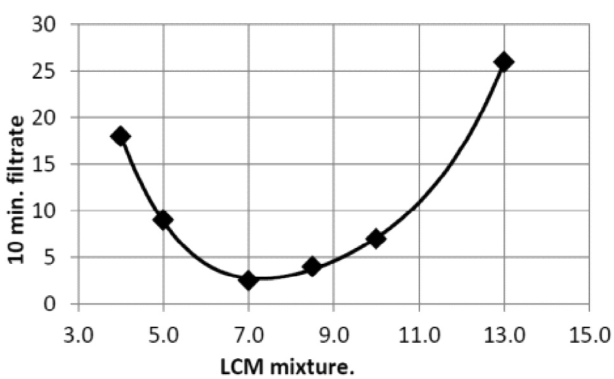

Fig. 9. Relationship between LCM weight percent and 10 min. filtrate loss at ΔP = 200 psi.

The optimum mud composition (fresh water +7% bentonite +3.5% fine crushed date palm seeds +3.5% coarse crushed date palm seeds in weight bases) was used in experiments 10 through 14 to test the effect of higher pressure and temperature on the ability of the optimum mud composition to seal the test core plug fracture. Table 4 shows the properties of the optimum mud.

Table 4
Properties of the optimum mud used in this study.

Property	Measured value
Density, ppg	8.6
pH	7.2
Apparent viscosity, cp	10.5
Yield point, lb/100 ft^2	43
10 s Gel strength, lb/100 ft^2	4.2
10 min Gel strength, lb/100 ft^2	5.6

In experiments 6, 10, and 11, the relationship between the temperature (25 °C, 65 °C, and 90 °C) and the 10 min filtrate volume at 200 psi pressure difference was tested as shown in Fig. 8F, J and K. The 10 min filtrate volumes of these experiments are plotted in Fig. 11. It can be noticed from Fig. 11 that the filtrate volume increases as the temperature increases. The change of temperature from 25 °C to 90 °C increases the volume of the mud filtrate from 2.5 cc to 18 cc indicating 3.6% total loss from the whole tested mud sample.

The relationship between the pressure difference (200 psi, 400 psi, and 600 psi) and the 10 min filtrate volume at 25 °C

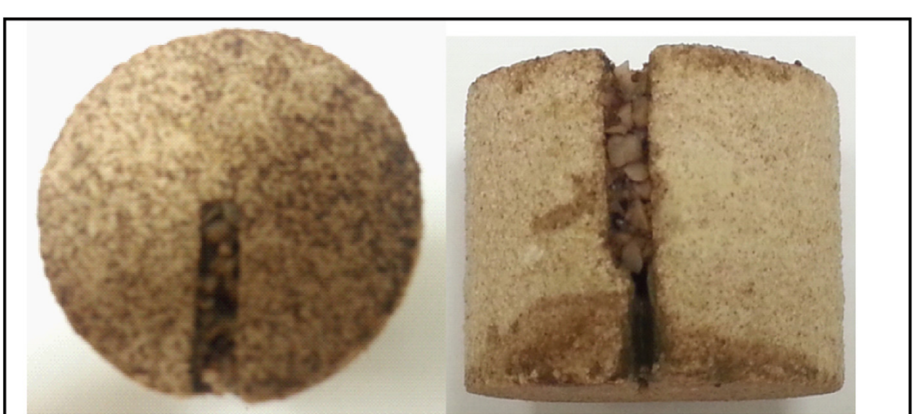

Fig. 10. The sandstone core plug after experiment showing the sealed fracture.

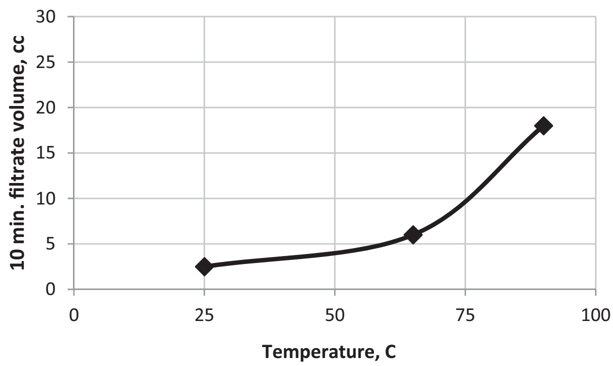

Fig. 11. Relationship between temperature and 10 min. filtrate volume at ΔP = 200 psi.

performed in experiments 6, 12, and 13 is shown in Fig. 12 and Fig. 8F, L, and M. It can be noticed from Fig. 12 that the filtrate volume increases as the pressure difference increases. The change of pressure difference from 200 psi to 600 psi increases the volume of the mud filtrate from 2.5 cc to 9 cc indicating 1.3% total loss from the whole tested mud sample. Furthermore, the pressure difference was increased gradually to 1000 psi in each experiment where no more filtrate loss was noticed indicating the excellent integrity of the performed fracture seal.

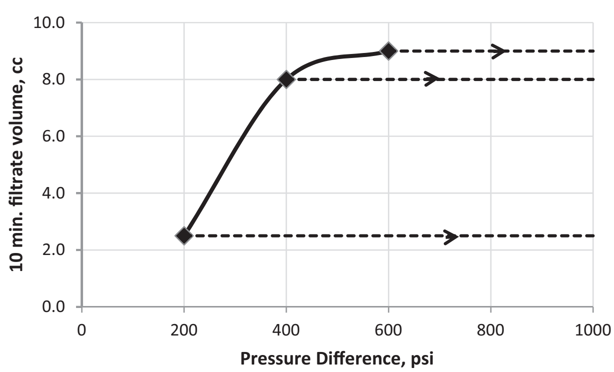

Fig. 12. Relationship between pressure difference and spurt volume at 25 °C.

Therefore, the optimum mud (fresh water +7% bentonite +3.5% fine crushed date palm seeds +3.5% coarse crushed date palm seeds in weight bases) used in this study proved its ability to seal fractures perfectly up to 1000 psi pressure difference and 90 °C temperature.

4. Conclusions

Based on the analysis performed in this study, the following conclusions can be made:

1. The HT-HP 500 ml filter press has been modified to accommodate real core sample of 38.1 mm diameter and 38.1 mm length with an artificially made fracture.
2. An optimum mud composition of fresh water mixed with 7% bentonite, 3.5% fine, and 3.5% coarse crushed date palm seeds perfectly sealed an artificial fracture of 3 mm top and 1 mm bottom made in a sandstone core sample of 38.1 mm diameter and 38.1 length.
3. Crushed date palm seeds proved its superior ability to seal fractured core plugs at temperatures and pressures up to 90 °C and 600 psi respectively.
4. Fracture sealing mentioned in the previous point was experimentally proved to withstand pressures up to 1000 psi without any further filtrate loss.

Appendix A.

According to Feedipedia (2016) date palm seeds are the by-product of date stoning, either for the production of pitted dates or for the manufacture of date paste (see Fig. 13). The date seed is a hard coated seed, usually oblong, ventrally grooved, with a small embryo. Date seed weigh 0.5 g to 4 g and represent 6 to 20% of the fruit weight depending on maturity, variety and grade. Date seeds are traditionally used for animal feed. They can also be used as a source of oil (which has antioxidant properties valuable in cosmetics), as a coffee substitute, as a raw material for activated carbon or as an adsorbent for dye-containing waters as shown in Table 5. Date by-products are usually fed to animals during winter, though they can be used at any time of the year.

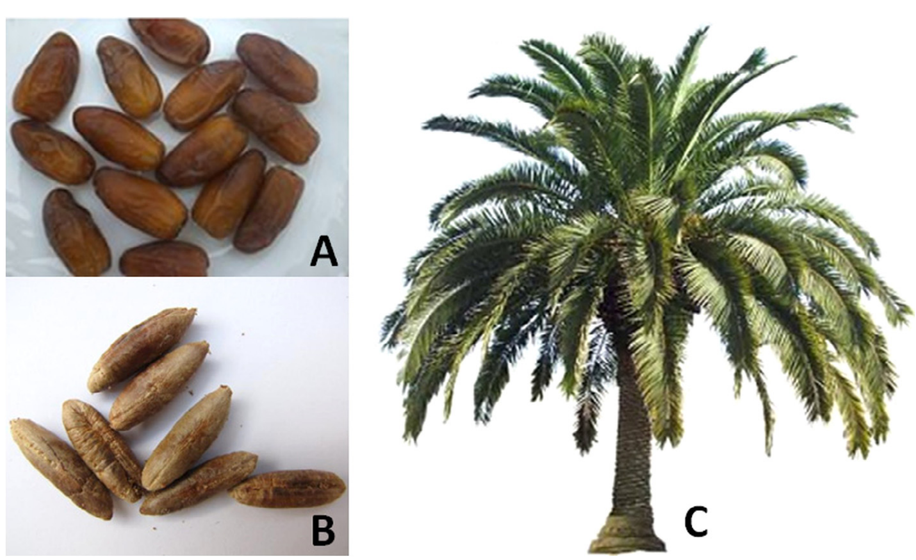

Fig. 13. Dates fruit (A), Date palm seeds (B), and Date palm tree.

Table 5
Approximate composition of date palm seeds.

Moisture	5–10%
Protein	5–7%
Oil	7–10%
Fibers	10–20%
Carbohydrates	55–65%
Ash	1–2%

References

Amanullah, Md. 2016. Characteristics, behavior and performance of ARC Plug-A date seed-based sized particulate LCM. In: SPE paper no. 182840-MS presented at the SPE-KSA Annual Technical Symposium and Exhibition held in Dammam, Saudi Arabia, April 25–28.

Chellappah, Kuhan, Kumar, Arunesh , Aston, Mark 2015. Drilling depleted sands: challenges associated with wellbore strengthening fluids. In: A paper presented at the SPE/IDAC drilling conference, London, U.K., 17–19 March.

Contreras, Oscar, Hareland, Gier, Husein, Maen, Nygaard, Runar, Alsaba, Mortadha 2014. Wellbore strengthening in sandstones by means of nonoparticles-based drilling fluids. In: A paper presented at the SPE deepwater drilling and completions conference, Galvestone, Texas, USA, 10–11 September.

Feedipedia website, http://www.feedipedia.org/node/5368, 2016.

Kumar, Arunesh, Savari, Sharath 2011. Lost circulation control and wellbore strengthening: looking beyond particle size distribution. In: AADE-11-NTCE-21, A paper presented at the 2011 AADE National Technical Conference and Exhibition, Houston, Texas, April 12–14.

Miller, Matthew L., Jamison, Dale, Murphy, Robert J.2013. Laboratory apparatus improves simulation of lost circulation conditions. In: AADE-13-FTCE-09, A presented at the 2013 AADE National Technical Conference and Exhibition, Oklahoma City, OK, February 26–27.

Sanders, Mark W., Young, Steven, Friedheim, James 2008. Development and testing of novel additives for improved wellbore stability and reduced losses. In: AADE-08-DF-HO-19, A paper prepared at the 2008 AADE Fluids Conference and Exhibition, Houston, Texas, April 8–9.

Wang, Hong (Max), Towler, Brian F., Soliman, Mohamed 2007. Fractured wellbore stress analysis: sealing cracks to Strengthen a wellbore. In: A paper presented at the 2007 SPE/IDAC Drilling Conference, Amesterdam, The Netherlands, February 20–22, 2007.