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Strengthening of Loose Sandstone Hydrocarbon Reservoir Formation using Saccharum Officinarum

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Abstract: *Unconsolidated sandstone formations are subject to sand production and associated problems. The cost of consolidating Niger Delta sandstone reservoir formation using conventional imported binding agents is very high, some of the binders reduce the sandstone permeability and porosity, therefore this research proposed a non-toxic novel biochemical binding agent for consolidating sandstone reservoirs which has negligible effect on the sandstone formation permeability and porosity. In this study, sugarcane bagasse (Saccharum officinarum) a locally sourced, common, cost-effective agro-waste from sugarcane mill was used in preparing a binding agent. Different concentrations of granulated bagasse (5g, 10g, 15g, 20g, 25g, 30g, and 35g) were respectively mixed with 10% caustic soda in different containers. Sandstone core samples were prepared and tested for compressive strength, porosity, and permeability before treating with respective concentrations of bagasse mixed with caustic soda solution. Finally, the core samples treated with the local binding agent were retested for changes in compressive strength, porosity, and compressive strength. The test results show that the binding agent with sugarcane bagasse concentration of 15g yielded the optimum compressive strength of 16.01mPa compared to the compressive strength of 15.05 mPa before consolidation, and the porosity and permeability deviations are 2.31% and 2.04% respectively. The study revealed that loose sandstone formation can be consolidated using locally sourced binding agents of sugarcane bagasse.*

Keywords: *Unconsolidated Sandstone, Sugarcane Bagasse, Saccharum Officinarum, Caustic Soda, Compressive Strength, Porosity, Permeability*

1. Introduction

Sand production has been recognized as a serious concern to deal with by the petroleum industry Ogolo et al., (2012). Sand production is associated with Safety, Environment, and operational problems (Kotlar et al., 2006). Generally sand production results to reduction in oil production (Karian et al., 1999). The consolidations of sandstone reservoir formations play a crucial role in enhancing the productivity and longevity of oil and gas fields. Methods, such as chemical consolidation has been used to strengthen sandstone reservoir formations. Chemical consolidation requires the injection of chemical agents such as silicate and furan resin into loose sandstone rocks to control sand production from petroleum reservoirs. These injections tend to reduce the permeability of the reservoir rock, so it is important to increase the compressive strength of the rock with an acceptable impact on the rock permeability, Fahd et al (2020) .

Talaghat et al.(2009) presented a fitting resin as a binding agent in the Asmari oil wells of the Ahwaz and Mansoori reservoirs. Considering the required properties of resins as binding agents, two epoxy resins groups, three phenol–formaldehyde resins group, and an acrylic resin were chosen for evaluation. Sand packs obtained from the oil field were treated with various percentages of the resins and the binding agents' mixture. The core samples are tested for permeability, porosity and compressive strength measurement.

The result of the experiment indicated that only phenol-formaldehyde resins consolidated the core samples with satisfactory permeability and porosity values with higher compressive strengths of more than 3000 psi.

Amjed et al. (2023) presented a new method of consolidating sandstone formation using ammonium hydrogen fluoride, calcium oxide, and magnesium oxide solutions. The effect of treating the consolidated sand pack with freshwater, toluene, and HCl was evaluated. X-ray diffraction analysis was applied to determine the rock rheology before and after treating the sand packs with the chemicals respectively. At various stages, the porosity was determined with the Nuclear Magnetic Resonance (NMR) technique, and the chemical changes within these sand packs after the treatments were also analyzed using a Scanning Electron Microscope (SEM). Lastly, the compressive strengths of the core samples were measured before and after the treatment with a scratch test. The outcome of the experiment indicates that the compressive strength of the sandstone formation was increased to 34 MPa (4931 psi) using the proposed chemical method. The consolidated rock samples showed negligible changes in properties after soaking in water and toluene, but soaking in HCl increased the samples' permeability while the compressive strength was reduced by almost 10%.

Talaghat and Bahmani (2017) Studied the loose sandstone consolidating ability of urea-formaldehyde resin, phenol-formaldehyde resin, and modified urea-formaldehyde resin. Core samples with absolute permeability of 500 to 600 mD and porosity of 15 to 20% were treated with different percentages of respective resin. The core samples were then tested for permeability, compressive strength, and porosity.

The results indicated that the modified urea-formaldehyde resin is a better-consolidating material than the other two brands of resin. The core samples consolidated with modified urea-formaldehyde resin had a compressive strength at the verge of 3100 and 4150 psi, permeability between 980 and 6823 mD, and porosity between 8 and 98%.

Aditi and Borgohain (2023) revealed that since the traditional gravel pack method of sand production control failed to hold fines at the Rudrasagar oilfield formation, an experimental attempt to control sand production through chemical consolidation was carried out. The core samples were treated with a new mixture of chemicals using 10% epoxy resin, 6% bitumen, and 1% bentonite which improved the compressive strength of the Rudrasagar oilfield formation core samples to 1134 psi while retaining the permeability value of 1218 mD.

Shang et al. (2019) investigated and optimized foam amino resin as a novel chemical-consolidation agent, with apparent density ranging from 0.528 g/cm3 to 0.634 g/cm3 at standard temperature. The core sample was treated with foam amino resin and the consolidated core sample compressive strength was measured, results revealed that the chemical has outstanding foaming properties and exceptional compatibility with the formation fluids. The optimization conditions for the novel consolidated chemical were: an experimental time of 720 mins, a temperature, of 60°C; and a consolidated core sample compressive strength, of 6.28 MPa.

Saurabh and Keka (2016) proposed a novel binding agent for an unconsolidated sandstone oil reservoir. The experiment was conducted in two stages, firstly the sand pack was treated with urea-formaldehyde and secondly, another core sample was treated with a mixture of nanoparticles of silica oxide SiO2 and urea-formaldehyde.

Results showed that a mixture of nanoparticle and urea formaldehyde gave a good consolidation with the sample`s compressive strength at 2180 psi and negligible reduction in permeability. The effect of pressure drawdown was also investigated and results showed that the sample can withstand a pressure drawdown of up to 2400psi.

Abanum and Appah (2013) noted that the production of sands in the course of petroleum production leads to harsh challenges in the petroleum industry. To mitigate these severe setbacks, the authors carried out laboratory evaluations of special sand binding agents that will be best fit for the Niger Delta reservoirs. Three imported chemicals; Epoxy (A&B), Phenol-Formaldehyde resin (Novolacs), Phenol Acrylic resin (Furan), and three locally formulated resins:

Rubber Latex, Evostik, and Styrofoam gum were compared, appraised and tested for their suitability in consolidating sandstone. Sandstone reservoir core samples were treated with these chemicals respectively after observing their respective permeability and porosity under various compressive pressures ranging from 500 to 3500 psi. The experiment revealed that Epoxy A&B resins had a better-consolidating capability, trailed by Furan resin and followed by the indigenous resins. The disadvantages with these traditional chemical binding agents used for consolidating loose sandstone reservoirs are high costs, permeability reduction, durability, and pumping issues. The resins that have been reported in the literature by researchers are epoxy derivatives such as furan resin, phenol-formaldehyde, Urea-formaldehyde, and furfurals alcohol (Dewprashad et al., 1997.; Keith et al., 2013.; Armbruster, 1988.; Graham, 1982). Urea-formaldehyde (UF) and melamine-formaldehyde (MF) have being applied in lumber based industries for a century now, Wasnik et al., (2005).

The traditional methods for achieving consolidation, such as cementing or mechanical methods , often come with limitations and environmental concerns, As a result, researchers have turned their attention towards exploring alternative techniques that are more sustainable, eco-friendly and cost effective. One such technique gaining considerable attention is the use of bio-chemicals for sandstone reservoir consolidation. Zhang, et al.,(2021).

Biochemical consolidation offers several advantages over conventional methods, including their biodegradability, non-toxicity, and compatibility with subsurface conditions and does not require extensive surface facilities or complex equipment. Timothy, et al., (2020).

Moreover, bio-based materials have shown promising results in terms of improving permeability reduction, rock strength enhancement and overall stability of sandstone reservoir formations. Kaminskaite , et al., (2022)

Kamal, et al. (2023) investigated the effect of using enzyme-stimulated carbonate precipitation to consolidate different types of sand samples and evaluated the outcome of high temperature on its efficiency as a consolidation agent. The influence of sand particle sizes ranging from 125 to 700 micro-metres on the consolidation efficiency of EICP was also evaluated. the experiment showed that heat is needed when EICP solutions hold more than 50,000 metal ions and plenty of urea, for medium sand particle size of 250 -425, enzyme-simulated carbonate precipitation gave an intrinsic specific energy of 9000 psi while it yielded 5,000 psi for sand particle size of 425-700 um.

Iqbal, et al (2020) demonstrated that water soluble polymers and chemicals have a high propensity to adsorb on the rock surface thus binding the sand face

The use of indigenous binder materials for sandstone consolidation is cost-effective and ecological sustainable . Gowida, et al., (2022), the study carried out by these researchers demonstrated that thermo-chemicals of asphalt solution saturating near wellbore can heat the wellbore area in-situ to raise the temperature for consolidating sandstone formation by reducing the time taken for treatment via low temperature oxidation without negatively imparting on the consolidation class.

Zang, et al 2021.; Chen, L.; Zang , et al (2023) examined the use of microbial induced carbonate precipitation (MICP) as a consolidation technique for sandstone reservoirs, the result of the study showed significant improvement in rock strength and permeability reduction, indicating successful sandstone consolidation through MICP, furthermore, industrial by-product and local materials-based consolidation can be employed as an eco-friendly alternative to conventional materials used in sandstone formation consolidation Almezaien, et al. 2019.; Al Bakri, et al. (2020).

Fly ash, a waste product obtained from combustion of coal is a commonly available material as a consolidation agent for sandstone oil formations Tabar, et al (2021) Natural pozzolan materials have been widely investigated as an attractive option for binding loose sandstone formations, this due to their capability to react with calcium hydroxide and form binding substance.

2. MATERIALS AND METHODS

2.1 Materials

An unconsolidated core sample from a Niger Delta sandstone reservoir was obtained for consolidation using bagasse and caustic soda. The core sample was prepared, and its initial porosity, permeability, and compressive strength were established before consolidation. Granulated bagasse was mixed in different concentrations with caustic soda solution and the core samples were respectively treated with different ranges of bagasse and caustic soda solution. The listed materials were appropriately used in the experiment.

- Bagasse
- Caustic soda
- Blender

- Beakers
- Distilled water
- Spatulas
- Core samples
- Weighing scale
- Safety equipment
- Compressive strength testing machine
- Mercury intrusion porosimeter
- Falling-head Permeameter
- Ruler
- Desiccators
- Viscometer
- Differential pressure gauge

2.2 Methods

Saccharum Officinarum known as sugarcane bagasse was air-dried for 72 hours to remove all water content in it and thereafter was ground to a powdery form using a blender to increase the surface area and ensure homogeneity of the particles. The Fourier-transform infrared spectroscope (FTIR) was set up to ensure correct calibration. A baseline spectrum was established to eliminate background interference, and then the bagasse powdered sample was introduced to infrared radiation, at each range of the radiation frequency, the detector measured the intensity of light transmitted. The determined spectrum was analyzed and FTIR data was interpreted for the chemical composition analysis of bagasse.

Bagasse was obtained from sellers at Obinze in Owerri. The bagasse was sun-dried for three days to remove all water content in it and thereafter was grated to fine powder to improve its binding properties and surface area for proper interaction with the sandstone and was weighed

Caustic soda was bought from a chemical store at Aba in Abia state, caustic soda was mixed with distilled water in various containers, each container containing 300ml solution, with caustic soda being 10% of the solution.

Sandstone core samples were obtained from Port-Harcourt in Rivers-state; the samples were cleaned and the geometry was measured with a ruler and weighed to determine the initial dry weight.

2.3 Core Sample Testing

The core samples were tested for compressive strength, porosity, and permeability. One of the prepared core samples underwent a compressive test by putting it in a lower platen compression testing system carefully aligned with the loading axis (ASTM C39). The load applied on the sample was gradually increased until it fractured, the maximum load at failure was recorded and the compressive strength was calculated

Another dried and weighed core sample was firstly submerged in water under a suspended position in a container and heated for 120 minutes , then the heat was turned off and the core remained in the container for half a day, the water-saturated core sample was gently cleaned after removal from the container of water to eliminate any excess water from the surface by using a moistened cloth. The water-saturated core sample was weighed, thereafter the porosity was determined (ASTM C20)

The viscosity of water for the test was measured and then pumped with a fluid injector at a steady rate through the prepared dry core sample fastened on the core sample holder of the PMI Steady State Permeameter, the sample was allowed some sufficient time for water to fully penetrate the core. The pressure differential was measured through the pressure gauge and flow time was measured using a stopwatch. The results were recorded. Then permeability was calculated using Darcy`s equation (ASTM D4525)

2.4 Consolidation Of The Sandstone Core Samples

Caustic soda was mixed with distilled water to form the caustic soda solution in 6 different containers; each 300ml solution of caustic soda in a container has 10% caustic soda. Various weights of bagasse were added to each container. The weights of bagasse in the six containers were 10g, 15g 20, 25g, 30g

35g. The baggage was mixed with a caustic soda solution and stirred very well, the caustic soda reacted with the bagasse and the fibre swelled up.

Nine core samples of the same geometry were used for this experiment, one of the core samples was used for the compressive test, and another core sample was used for the porosity and permeability test before consolidation. The other six core samples were soaked respectively in different containers of consolidators containing different sugarcane bagasse concentrations, precautions were taken to ensure that the consolidators covered the entire core samples, and they were allowed to remain soaked for 3 hours.

Thereafter the six core samples were removed from the beakers containing the consolidators for drying at ambient conditions. The samples were retested after drying, and the new compressive strengths, porosities, and permeability of the six core samples were recorded

The results were compared to the values of these parameters measured before consolidation.

3. RESULTS AND DISCUSSIONS

3.1. Results

The results are presented with graphs and tables

Compressive Strength, Porosity, and Permeability Test before Consolidation

3.1.1 Compressive strength

Maximum load on a sample before failure = 0.02408 N

Cross-sectional area of sample with dimensions of 0.04m x 0.04m x 0.04m =0.04 *0.04 = 0.0016m2

Compressive strength = 0.02408/0.0016 = 15.05 mPa

3.1.2 Porosity (ϕ)

Dry weight =20gram

Saturated weight = 25.5gram

Porosity = 25.5-20.025.5*100 = 21.6 %

3.1.3 Permeability (K)

The viscosity of water (μ)= 0.98 cp

Flow rate = 500ml/min (Q)= 0.083333m3/sec

Area of core sample (A) = 1600mm2 = 0.0016m2

Length (L) = 0.04m

Pressure Drop (△P) = 2.523psi

Using Darcy`s Formula to calculate permeability K = QμL/A△P

Where:

Q is the flow rate (m3/s)

A is the cross-sectional area (m2)

L is the length of the core sample (m)

△P is the pressure drop (psi)

K = (0.08333 x 0.98 x 0.04)/0.0016 x2.523 = 0.8099 darcy

Conversion to millidarcy = 0.8099 x 1000 = 809.1 mD

Table 3.1.1. *core sample compressive strength, porosity, and permeability before consolidation*

PARAMETERS Of CORE SAMPLE	BEFORE CONSOLIDATION
Compressive strength (mPa)	15.05
Porosity (%)	21.60
Permeability (mD)	809.1

Table 3.1.2. *core sample compressive strength, porosity, and permeability after consolidation with Bagasse and Caustic Soda*

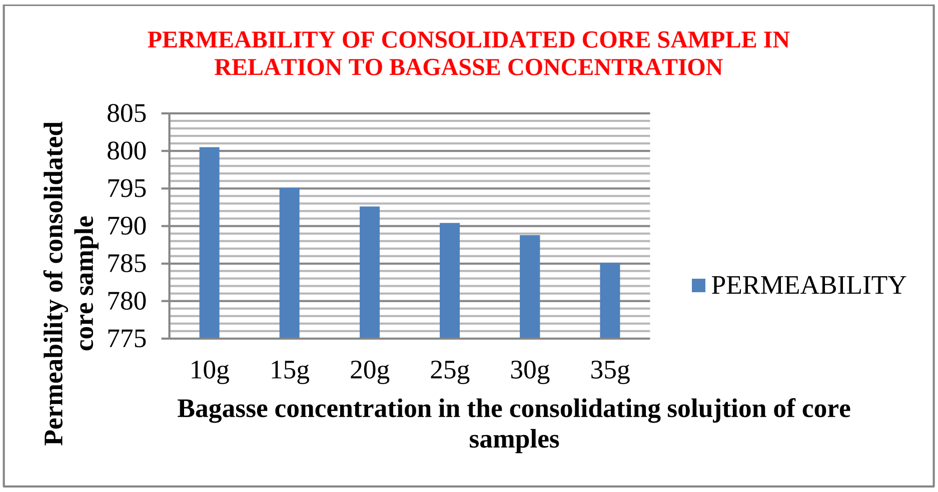
Consolidating solution with Bagasse concentration (g)	Compressive Strength (mPa)	Porosity (%)	Permeability (mD)
10 g Bagasse	15.07	21. 53	800.5
15g Bagasse	16.01	21. 35	795.1
20g Bagasse	16.75	21.10	792.6
25g Bagasse	19.23	19.50	790.4
30g Bagasse	21.87	18.95	788.8
35g Bagasse	24.09	16.76	785.1

Table 3.1.3 *Compressive Strength, Porosity, and Permeability of core samples after consolidation with different bagasse concentration*

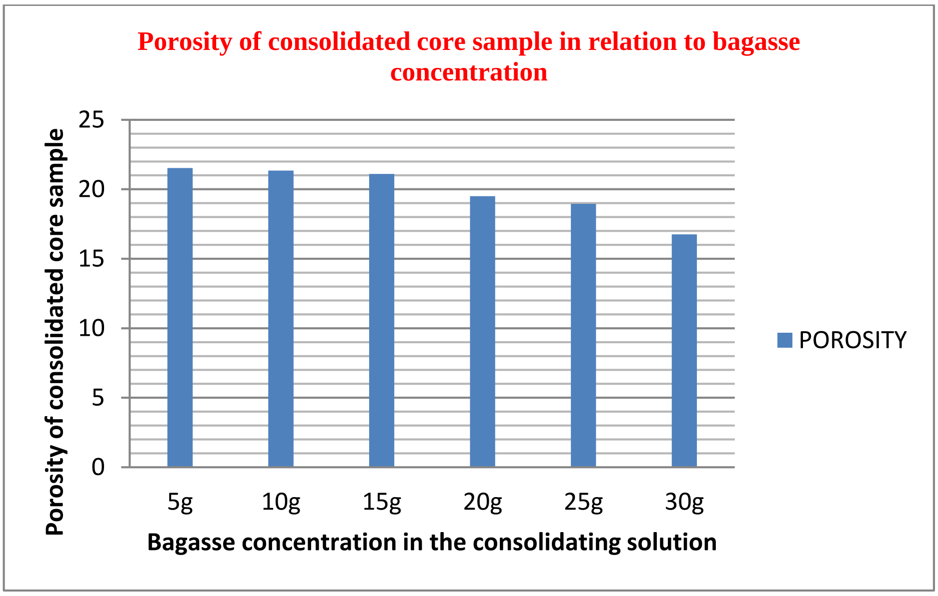
PARAMETER	BEFORE CONSOLIDATION WITH BAGASSE	AFTER CONSOLIDATION WITH DIFFERENT CONCENTRATION OF BAGASSE					
		10g	15g	20g	25g	30g	35g
Compressive strength (mPa)	15.05	15.07	16.01	16.75	19.23	21.87	24.09
Porosity (%)	21.60	21.53	21.35	21.10	19.50	18.95	16.76
Permeability (mD)	809.1	800.5	795.1	792.6	790.4	788.8	785.1

Table 3.1.4 *percentage Deviation core samples` Porosity and permeability percentage after consolidation with \Bagasse*

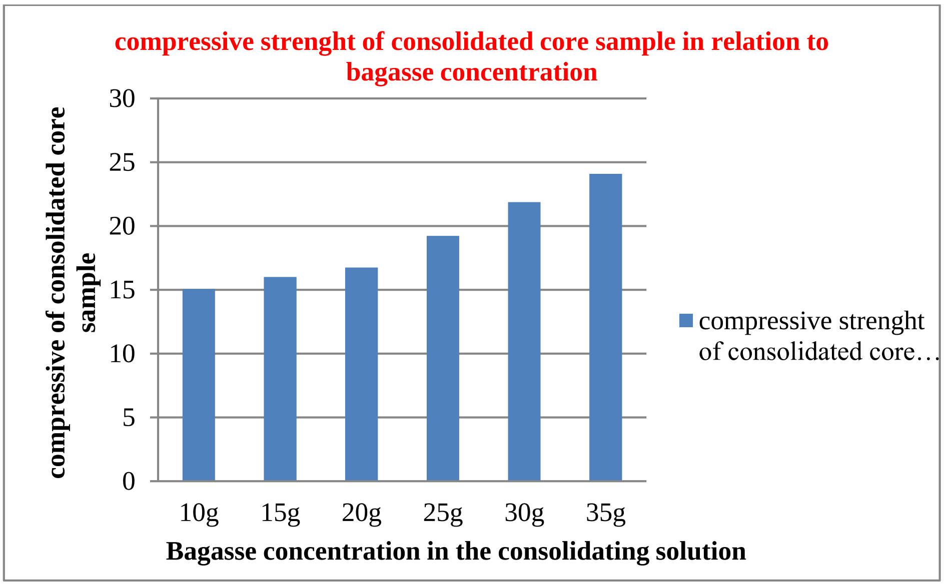
BEFORE CONSOLIDATION		AFTER CONSOLIDATION				
POROSITY (%)	PERMEABILITY (mD)	BAGASSE CONCENTRATION (g)	POROSITY (%)	POROSITY DEVIATION %	PERMEABILITY mD	PERMEABILITY DEVIATION %
21.60	809.1	5g	21.53	0.32	800.5	1.06
		10g	21.35	1.12	795.1	1.73
		15g	21.10	2.31	792.6	2.04
		20g	19.50	9.72	790.4	2.31
		25g	18.95	12.3	788.8	2.51
		30g	16.76	22.4	785.1	2.97



Graph 3.1.1 *permeability of consolidated core sample in relation to Bagasse concentration*



Graph 3.1.2 *porosity of consolidated core sample in relation to Bagasse concentration*



Graph 3.1.3 *Compressive strength of consolidated core sample in relation to Bagasse concentration*

DISCUSSIONS

Sugarcane bagasse is a byproduct of the sugarcane industry, its chemical characterization revealed that it contains lignin, hemicelluloses, and cellulose which are the natural polymers with the ability to bind and bridge the particles in sandstone, enhance the inter-particle bonding and increase the compressive strength of the sandstone rock. (Xu, Q., et al., 2018; Mahmud, A and Anannya, F.R. 2021; Ajala, E.O et al., 2021). The use of bagasse for sand consolidation offers an eco-friendly and sustainable solution, It is readily available in the Niger Delta. The experiment has revealed that the effectiveness of consolidating agent for oil and gas reservoirs can be judged by the changes in reservoir rock porosity and permeability.

Consolidation using sugarcane bagasse increased the compressive strength of sandstone samples but decreased the porosity and permeability of the sand formation Alakbari, F.S et al.,(2020). The results from this experimental consolidation of the sandstone formation sample shows that with bagasse the reduction in porosity and permeability is a function of bagasse concentration in the consolidation solution, but the percentage of deviation of porosity and permeability of the consolidated core sample from the initial values before consolidation can be used as key indicator to evaluate the efficiency of bagasse. Bagasse has proven effective in consolidating sandstone reservoirs. The percentage deviation of permeability (1.06% – 2.97%) is within the acceptable limit (Table 5). The percentage deviation of porosity is optimum when the consolidating solution has a bagasse concentration of 15g. (Table 5), bagasse concentration greater than 15g gave a porosity percentage deviation greater than the acceptable limit, which actually suggest proper evaluation of the concentration of baggase that will not affect the porosity and permeability of the sandstone to be consolidated.

CONCLUSION

Sugarcane Bagasse has demonstrated the potential for consolidating sandstone formations. The natural polymers present in bagasse can consolidate sandstone formation with negligible alteration of the sandstone porosity and permeability therefore, it is effective in consolidating sandstone reservoirs which is dependent on the concentration of bagasse in the consolidating solution which entails proper optimization of the concentration to be used in consolidating the sandstone reservoirs. Sugarcane bagasse is a very common agro- waste product in the Niger Delta region hence it is cost effective, and as a bio chemical, it does not require much surface equipment for its application in the field. Further research and experimentation are still needed to optimize the consolidation process and understand the long term effects of bagasse on sandstone properties as well as is to determine the particle size of granulated sugarcane bagasse in consolidating sandstone reservoirs to reduce any minute occupation of baggasse in the sandstone formation pore space.

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Nomenclature

ASTM……………American Society for Testing and Materials

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