Experimental Study of Vibration Effect on Porous Media

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Abstract

The evolution of techniques required to mobilize reservoir fluids at critical saturation is important because of global needs for petroleum, and because of the necessity to conserve the subterranean water that deteriorated because of the slowness of the dismantling of persistent organic pollutants. The acoustic waves of low frequency are one of these methods, but until recently the absence of understanding of the vibration effect to displace oil prevent vibration application in the field. This paper proves that oil permeability increased when the vibration induced in porous media; that vibration makes resorting to the rock grains, which stimulate passage for liquid moving through the reservoir. The capillary pressure and reservoir pressure should be taken in consideration in order to make optimum validation for vibration stimulation.

Key words: Reservoir, Vibration, Core sample, Permeability, Porosity, Grain, and Elastic waves.

List of symbols

The units used in petroleum engineering are British units

Vp: pore volume (ft^3); **Vb**: bulk volume (ft^3); **K**: permeability (md); **Q**: flow rate, **μ**: viscosity (c.p.); **A**: cross sectional area; **Δp**: pressure drop; **L**: length of the porous media in the device; **Ø**: porosity (fraction).

Introduction

Porous media are present in natural and in artificial accumulations – such as aquifers, petroleum reservoirs, and infiltrations in buildings or implants in organisms for a continuous liberation of drugs .Capillary forces control imbibition, being the permeability one of the basic properties of the porous medium. Permeability is a measure of the capacity of the medium to transmit fluids, and is proportional to the conductivity of the porous medium to the flow of a fluid. In the definition given by Darcy's law (Amyx, 1960), analogous to Poiseuille's law, permeability relates the pressure gradient, which causes a liquid with a certain viscosity to flow with a given velocity. Absolute permeability is that determined when a single-phase fluid that occupies the whole void volume of the porous medium, flows through it under conditions of viscous flow. Some references in the literature mention the dependence between the absolute permeability and the frequency of vibration of a porous medium. The importance of gaining a better understanding of such variation lies in the fact that this might contribute to the development of yet other techniques for the additional recovery of fluids stored in porous media. Changes in the permeability itself or in the flow rate through porous media under vibration range from the behavior of water or oil wells after earthquakes to laboratory scale [1], [2].

There are also a wide variety of conditions under which the observations may have been made, such as, under constant flow rate or under constant pressure; under conditions of single-phase flow or under some proportion of multiphase flow; vibrating the sample supported over the vibration source or by the vibration source coupled to the sample's inlet face, such as the configurations used by Fairbanks and Chen (1971) or by Poesio et al. (2002). The idea is that supporting the sample over the vibration source constitutes a way of simulating the transmission of vibrations produced in the surface to the subsurface reservoir rock. Coupling the source to one of the faces of the sample would simulate bottom hole applications [3].

In the area of applications of the surface of the wide range are usually used for the revitalization of the reservoirs of the moderately deep to 1500 of meters. The sonic wave to accumulate like vibration, by mobilizing and strengthening a promising method to remove the besieged NAPLs (Non-Aqueous phase liquid) that happen in multi-phase flows through the reservoir, especially the prevention of groundwater pollution and improve oil recovery from oil formation with great efficiency, environmental safety and low-cost compare with mobilization by conventional means [4].

A century ago, fluid flow through porous media studied both theoretically and experimentally. Most of laboratory studies achieved by using Darcy equation with some required modification. Beresnev and Johnson (1994) these two scientists studied elastic waves vibration both theoretically and experimentally the conclusions of their study is that the elastic wave can increase permeability which resulted in increasing petroleum recovery from reservoir [5].

The evolution of the elastic wave theory- to study the sonic wave advance in the fully saturated reservoir formation- increase the research connected with flow of fluid in reservoir. Biot (1956) made a description of the elastic waves movement in the reservoir layer which result in widely known equation named Biot equation; that became the principle for the solution of problems waves movement in the hydrocarbon formations.

Bredehoeft (1967) showed that the analyzing of change in the water level because of tsunami land can be used for determination of storage capacity of aquifer. Brace et al. (1968) provide a method of un-steady state to calculate permeability of core sample [6].

Freeman and Bush (1983) illustrated that the un-steady state permeability determination is sensitive to the compressibility at low pressure and the litho-static pressure should be taken into consideration during permeability determination to get precise results. Simkin (1985) and Kuznetsov et al. (1986) stated that oil recovery by vibration will be enhanced if the vibration accompanied with water or gas injection in the reservoir.

Charlaix et al. (1988, 1991) achieved numbers of laboratory measurements on the movement of reservoir fluid in capillary path. The permeability was determined at frequencies ranged from (0.1 Hz-1 Hz). Sharma (1995) proved that the acoustic waves are able to treated altered zone near well-bore that invaded by drilling mud and increase flow capacity of the layer around the well.

Nikolaevskiy et al. (1996) stated that reservoir rock type, gas and liquid saturation, and type of layering are greatly altered frequency of vibration in the reservoir; which in back affect characteristics of reservoir deliverability and would be able to improve oil and water production near critical saturation. Kouznetsov et al. (1998) point out that the oil relative permeability and the interfacial tension (IFT) should be reduced in order to increase oil recovery. They also stated that oil production improved if a surface vibrosiesmic waved generator is used.

Westermark, Brett and Maloney (2001) illustrated some practical and laboratory experiments and explain that vibration waves are able to induce compressive and shear waves with magnitudes led to improve recovery of reservoir fluids [7].

The obstacles that vibration techniques counter, is the propagation of acoustic waves through the reservoir is also not obvious there are no verified modeling techniques to estimate stimulation in the porous media or to initiate valid field measurements. Several equations have been derived from practical and simulation researches were proved that the vibration induced in porous medium increase fluid recovery.

The vibrations cause some re-sorting of the grains, which may lead to improve permeability. The vibration pulse may change the mechanical properties of solid material, which may lead to reduce the adhesion force between the solid material and fluid. Support production and improve the performance coefficient of the reservoir [8].

Finally, the researchers find no literature about effect of vibration on oil mobilization in porous media after 2002.

[1] Aim of current study

Study vibration effect that induced by motor on porous media and evaluate the change in petrophysical properties of the clean sand and sand that mixed with bentonite.

[2] Apparatus Description:

The design and manufacture of the device that used in the current experiment are done localities by the researchers with the assistance of mechanics. The design of the equipment is moderately simple, can be used easily, and can be used with all types of reservoir liquids of low viscosity figure (1). The device was designed on a mechanical scale and consists of the following:-

1- A hollow steel tube length of (50 cm) and inside diameter of (10 cm).
2- A rectangular stand (80*50) cm.
3- Electric motor to create elastic wave vibration; 220 voltage and 50 Hz; it is air cooling motor as shown is figure (1-B).
4- Springs to increase vibration.
5- Pressure gages at inlet and outlet from (0 psi – 5 psi) degree of measurement.
6- Valves for opening and closing.
7- Fluid pump consists of (container& electric motor). The working fluids are water and oil, while the core sample that simulate the reservoir consist of sand and sand polluted with bentonite.

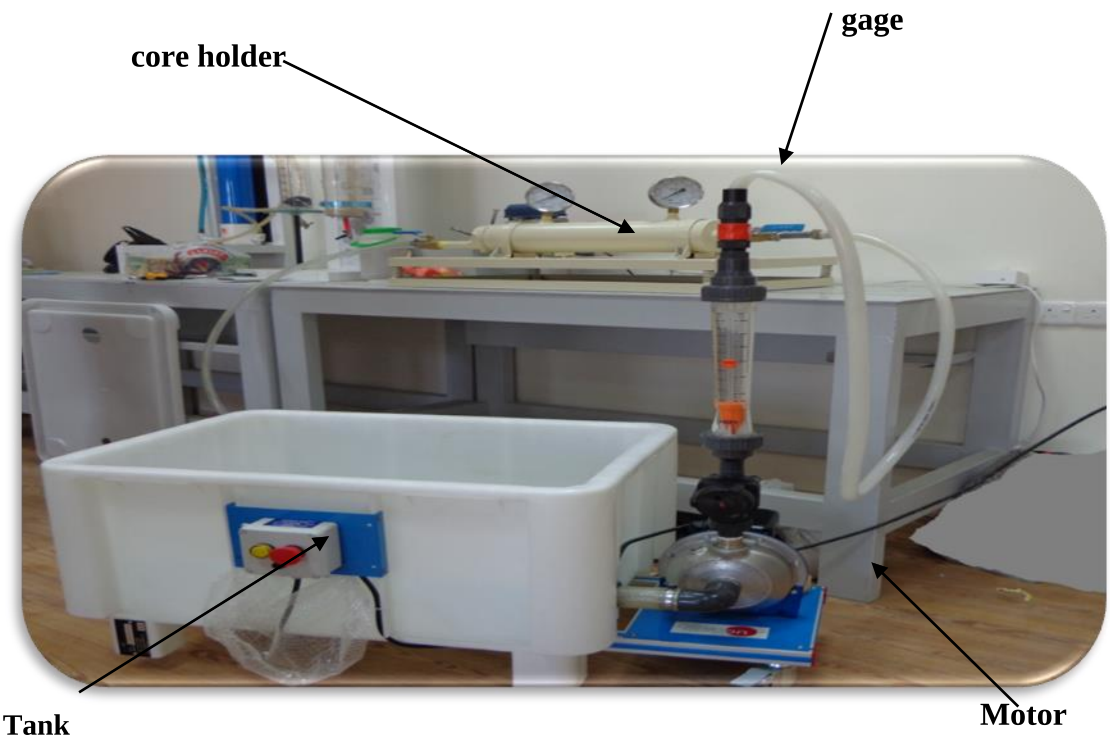

Figure (1-A) Measurement System

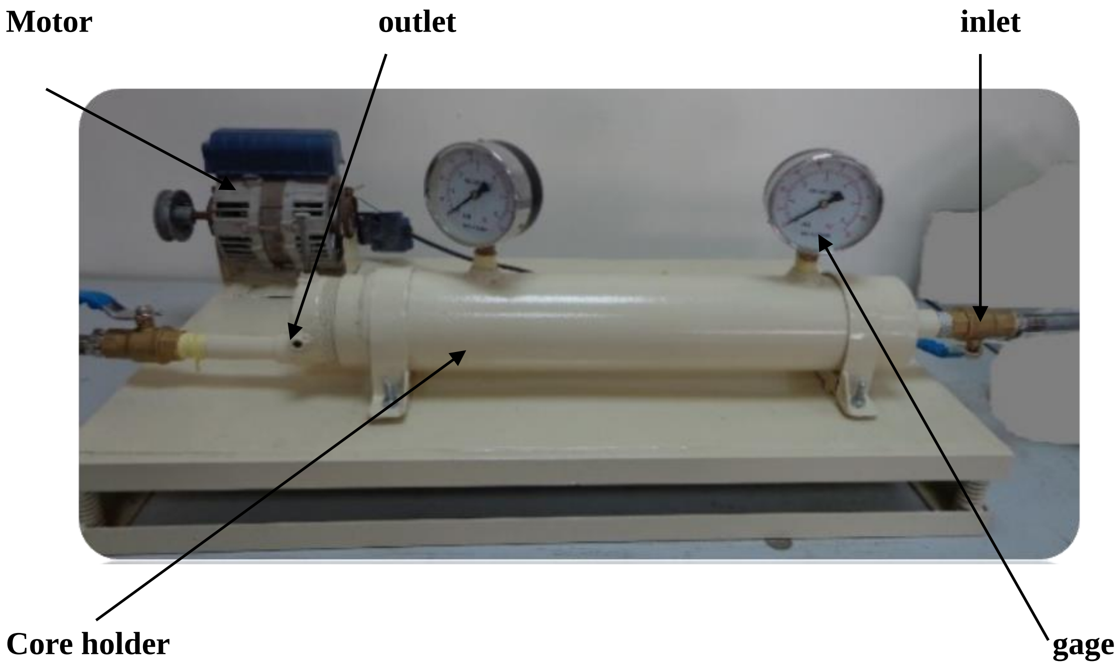

Figure (1-B) Measurement System

[2-1] Experimental preparation

1- Take mesh number 8 of 2.36 mm, the pan in the bottom and start vibrating the sieve to get the sand particle of required diameter for the core sample. Figures 2 and 3.
2- Fill the tube with the core sample (the porous medium is sand and sand with bentonite).
3- Start pumping the fluid until the samples get saturated.
4- Maintain the pumping speed, then pumping again for maintaining the flow.
5- Apply the vibration by generating the electric motor at the optimum speed required and the required number of nets that put on the motor shaft to produce the vibration effect. The vibration induced by a motor based on spring, the vibration controlled by fan speed switch in order to have multiple speeds and multiple vibration magnitudes. The experiment achieved in laboratory of college engineering- Misan University.
6- Take out the fluid in a container for the flow rate calculation.
7- Open and close the valve to control the flow
8- Read the pressure gages during the flow and record the readings.
9- Determine the time of the flow.

Figure (2) Mesh operation **Figure (3) Mesh no.8**

[2-2] Porosity measurement

For porosity measurement, we need to calculate the bulk volume of the core sample by knowing the cross sectional area and the length of the core holder (tube) and calculate the pore volume by knowing the total volume of the fluid in the container before and after pumping an amount of it (calculating the length, width and height of the fluid in the tank) where [9] :-

$$\varnothing = \frac{Vp}{Vb} \quad (3\text{-}1)$$

Vp: pore volume; Vb: bulk volume.

[2-3] Permeability measurement

For permeability measurement, Darcy equation used to determine permeability of the core sample by pumping water (the viscosity of water should be known) at constant rate and measuring pressure difference between the inlet and outlet of the system by using gage readings where [9] :-

$$k = \frac{Q\ \mu\ L}{1.127 * 10^{-3} * A * \Delta P} \quad (3\text{-}2)$$

K: permeability; Q: flow rate, μ: viscosity; A: cross sectional area; Δp: pressure drop; L: length of the porous media in the device.

[2-4] Vibration wave generation

By determination of sample petrophysical properties (porosity and permeability), the vibration effect experiment was started, as in the following steps:

1- Running the function generator and tuning to multiple frequencies.
2- Turn on the power amplifier and gradually increasing the supplied current.
This procedure is valid, except the accuracy of wave signal is somewhat low.

[3] Calculations

[3-1] First experiment

"Sand +water without vibration"

The first experiment: This involves calculation of the permeability and porosity of the reservoir. Default consists of sand and water only

[3-2] Second experiment

"Sand + bentonite + water without vibration"

In second experiment was the reservoir (core sample) tainted with bentonite by 3sand:1 bentonite. Bentonite clay is composed of ash made from volcanos.

Sand - Bentonite Percent = 1:3

[3-3] Third experiment

Crude Oil + sand

We have to ease the specific gravity of the oil from (0.43-0.83) by broking blocs asphalt using polar solvents oxygenic using methanol for being the most practical sink, where specific gravity decreased significantly . The experiment was not, unfortunately, fully and this is due to technical errors dating back to the pump's inability to withstand high pressures and the lack of special accessories of pump.

Table [1] Physical properties of the samples without vibration effect

Rock	D(ft)	L (ft)	Vb (ft^3)	Vp (ft^3)	Ø (%)	K(md)	Q (bpd)
Sand	0.3280	1.0006	0.0845	0.002600749	30.7	4196. 75	2.79711661
Sand+Bentonite	0.3280	1.0006	0.0845	$1.300374*10^{-3}$	15.3	2742.20	0.52219

Table [2] Physical properties of the samples under vibration effect

Rock	D (ft)	L (ft)	Vb (ft^3)	Vp (ft^3)	Ø (%)	K(md)	Q (bpd)
Sand	0.3280	1.0006	0.0845	0.002600749	61.4	6527.25	2.4859
Sand+Bentonite	0.3280	1.0006	0.0845	$2.600749*10^{-3}$	31.4	1592.12	0.6063

[4] Discussion:

1- The sand in tube as porous medium has a porosity of 30.7% that mean it's a wide-packed system.
2- The performance of sand system increase in the presence of the vibration effect, the reason behind that is the core sample consist mainly of sand the grains of sand have different shape and different size due to the so called sorting, so vibration lead to resorting of these particles which lead to increase porosity by 53% and permeability by 63%.
3- The sand and bentonite system have a porosity of 15.3% that mean it's a wide-packed system.
4- The performance of sand and bentonite system decrease in the presence of vibration effect and that belongs to the water absorption and swelling property of bentonite; which can be expressed as follows: bentonite is absorbed water and expands which lead to increase the porosity by 100% and reduction in permeability by 44%.
5- Coefficient of permeability with void ratio exhibited similar trend by slurry and compacted specimens. Preparation methods had no effect on permeability. Permeability sharply decreased when values of void ratio was less than 2. Permeability noticeably decreased by the increasing rate of bentonite in bentonite-sand mixture. At the same mixture ratio due to types of bentonite permeability varied distinctly under loading or without loading conditions.

[5] Conclusions

1- The vibration causes some re-sorting of the grains which lead to improve the permeability. In addition, the vibration pulses change the mechanical properties of solid material, which lead to reduce the adhesion force between solid material and fluid (crude oil).
2- The effect of vibration waves increases flow rate at certain frequencies; that means the influence of vibration increase oil recovery to efficient levels.
3- Phase behavior of porous media fluids and pressure drop are not similar in bentonite and sand that stated: flow characterizations are changed from reservoir rock to another.
4- For Sand; increasing the frequencies lead to increase the flow, which leads to increase the permeability as well as the porosity.
5- The shape and size of reservoir rock particles are an influential factor in explanation of vibration effect on the mobilization single liquid phase flow in the reservoir. If the reservoir rock consist mainly of coarse grains vibration impact can be explained by a change in dynamic viscosity. If rock lithology consists of fine particles, the vibration effect can be understood by both change in acoustic waves and dynamic viscosity.

[6] Suggestions

1- Further laboratory testing, must provide a crude oil pumping system capable of withstanding high pressures.
2- Application of vibration in the open holes so as to ensure the concentration of vibration waves in the selected zone.
3- Practical application in the field is done by dropping off ultrasound device by wireline and frequencies are controlled from the surface.
4- Increase the range of current vibration effect test by turning on multiple frequencies with greater values which increase vibration influence.

7 Figures of results

[7-2] Sand mixed with bentonite

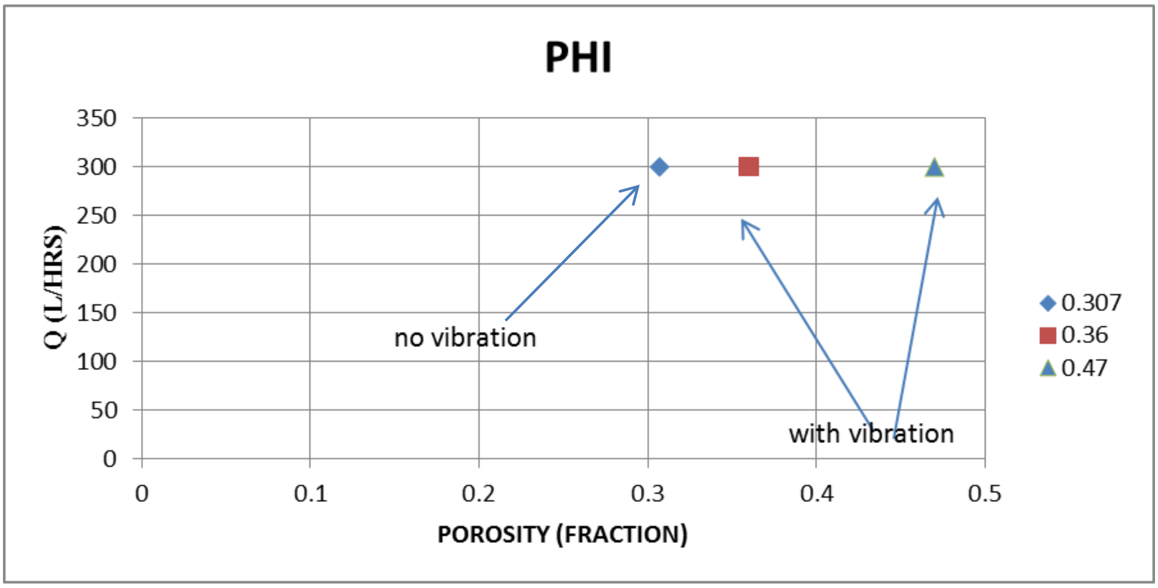

Figure (7- 1) flow rate versus porosity with and without vibration for sand.

The increase of magnitude of vibration resulted in increasing of porosity and porosity and permeability as seen in figures (7-1) and (7-2) for sand core sample.

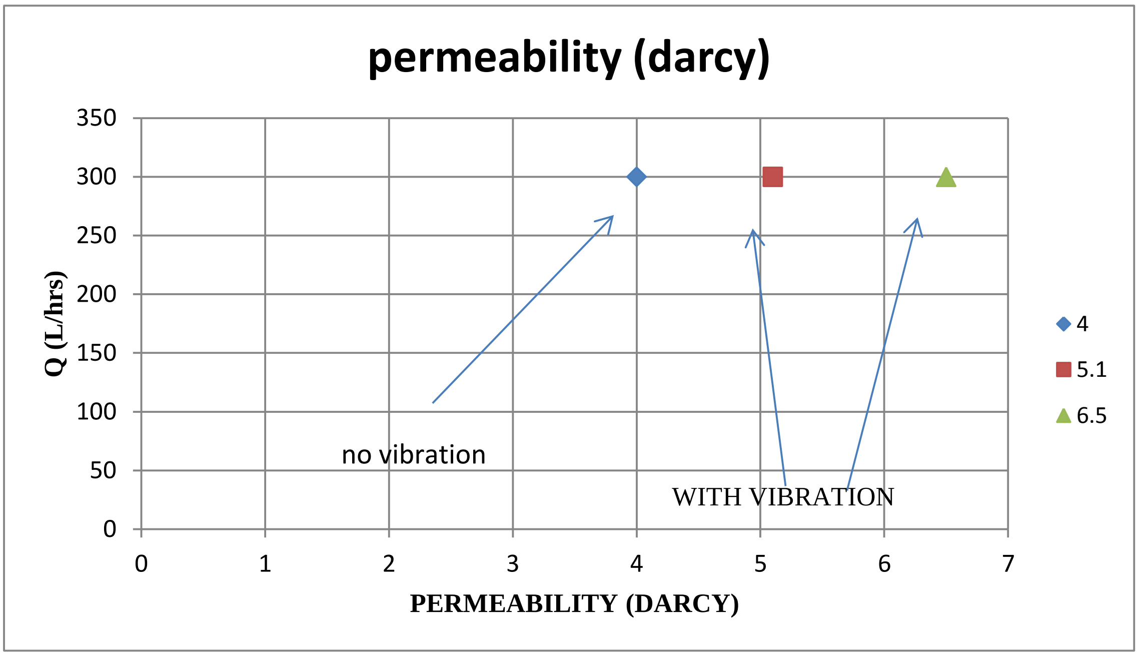

Figure (7- 2) flow rate versus permeability with and without vibration for sand.

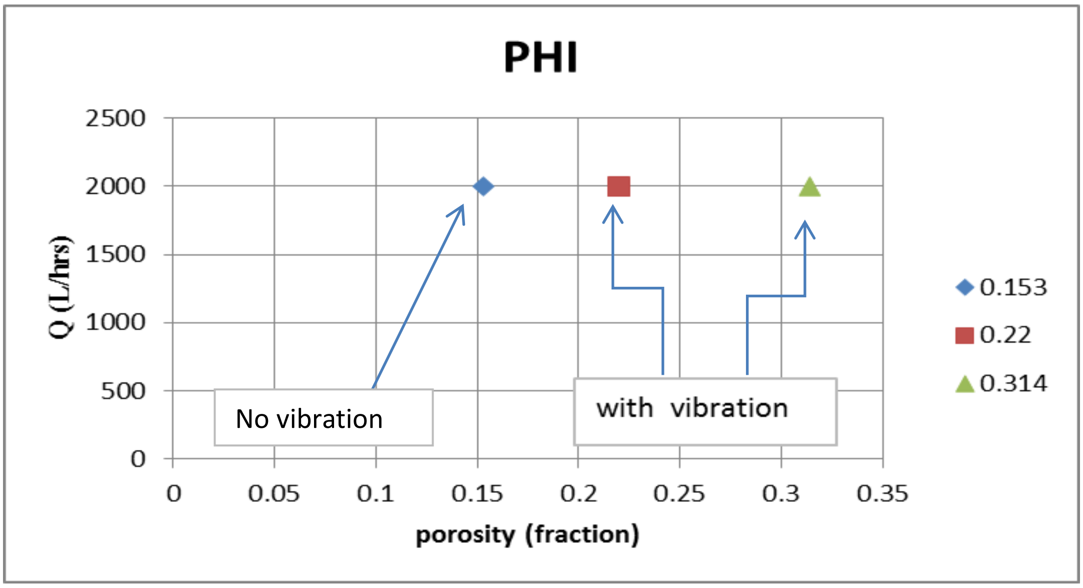

Figure (7- 3) flow rate versus porosity with and without vibration for sand and bentonite.

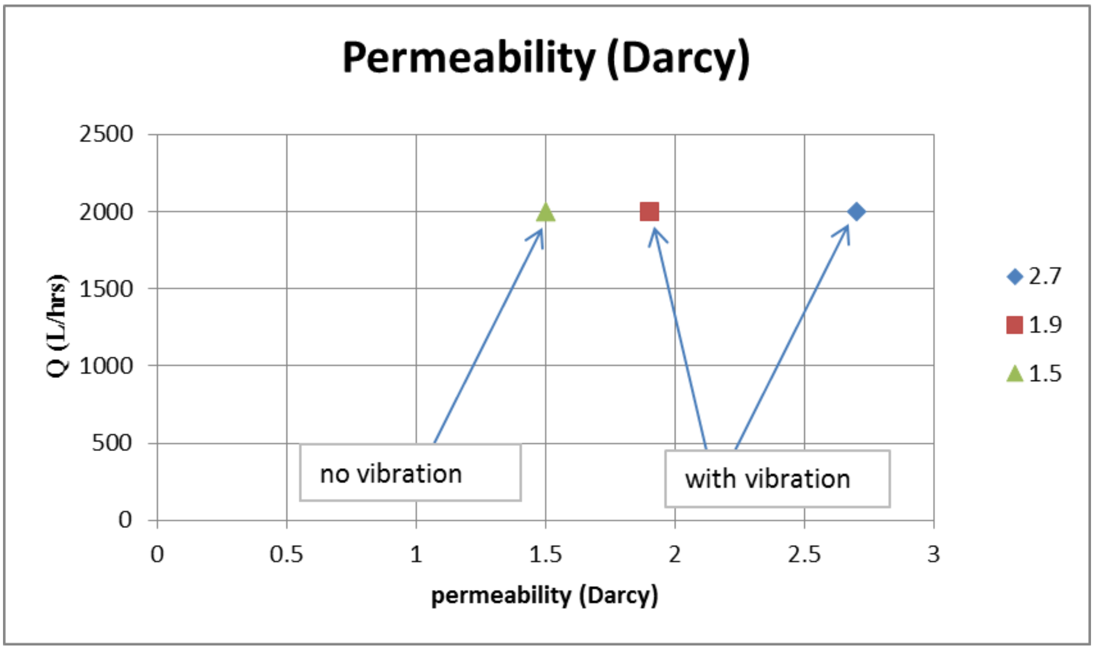

Figure (7- 4) flow rate versus permeability with and without vibration for sand and bentonite

When a core sample of sand and bentonite used the porosity increase with application of vibration effect but the permeability show different trend that the permeability reduced when vibration induced during fluid flow through the core in the holder.

The porosity increased in the four experiments while the permeability decrease in the sand-bentonite porous medium.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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دراسة مختبريه لتاثير الاهتزاز في الوسط المسامي

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الخلاصه:

ان تطور الطرائق اللازمه لدفع السوائل الهيدروكاربونيه الغير قابله للازاحه بالطرق الاعتياديه والمحصوره في الوسط المسامي اصبحت مهمه جدا وذلك لازدياد الطلب العالمي على النفط وايضا لمعالجه المياه الجوفيه بابطاء ذوبان الملوثات العضويه. الانعاش بواسطة الموجات المرنه ذات التردد القليل هي أحد هذه الطرق او التقنيات، لكن الفهم القليل عن ميكانيكية تاثير الاهتزاز على الوسط المسامي على حركة التجمعات النفطيه منع من استخدام هذه الطريقه حقليا. حديثا تم تطوير طريقه لتوضيح حركة الطور العضوي غير المبلل في الوسط المسامي. التوقعات من هذه الطريقه ان الاهتزاز سيكون فعالا لتحريك التجمعات النفطيه المتبقيه عندما تكون سعة التعجيل بامثل القيم اعتمادا على القوى الشعيريه وتدرج الضغط السكوني المسلط ولترددات اهتزاز قليله وكافيه. لقد اثبت البحث ان النفاذيه تزاداد باحداث الموجات الاهتزازيه في الوسط المسامي بسبب اعادة الفرز للمساميه.

كلمات الداله: المكمن، الاهتزاز، عينة لباب، النفاذيه، المساميه، الحبيبات، والموجات المرنه.