**Palacký University Olomouc**

**Faculty of Science**

**Department of Geology**

# Design of Electrostimulation Enhanced Oil Recovery Method to Improve Near Wellbore Reservoir Damage

**Bachelor Project**

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**Olomouc 2023**

I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

In Olomouc, Feb 27, 2023, ……………………………….

Hedi Wrya Mustafa

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## Bibliografická identifikace:

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**Abstrakt:** Pro těžbu ropy je důležité správné zacházení s podzemní geologií. Po použití primárních regeneračních technik, kdy tlak v zásobníku poklesne, následně začne sekundární regenerace a terciální regenerace. Každá nekonvenční metoda EOR se používá pro speciální účel, k řešení problémů a výrobě zbytkového oleje. Bylo však prokázáno, že některé z metod, jako je chemická metoda, mohou poškodit blízký vrt (těžební vrt) interakcí s jílem a některými dalšími vrstvami a ucpáním propustných kanálů. V takovém případě mohou metody EOR zvýšit tlak v nádrži, ovlivnit kontaktní úhel, aby se olej mokrý změnil na mokrý, a protlačit olej skrz propustné vrstvy až do poškozené zóny. Ale z poškozené vrstvy nastávají problémy s těžbou ropy. Elektrostimulační nekonvenční metoda EOR je účinná pro zlepšení poškození v blízkosti vrtu. Vstřikování střídavého proudu se slanou vodou do nádrže může ovlivnit utěsněnou vrstvu jílu a zlepšit poškození. Elektrická injektáž je z hlediska životního prostředí přijatelnější než jakékoli jiné konvenční metody EOR pro podzemní geologii a hydraulické podzemí. Z tohoto výzkumu bylo testováno, jak lze elektrický proud vstřikovat do modelu nádrže a měřit množství voltů, ampérů a wattů.

**Klíčová slova:** Zlepšená regenerace ropy, Elektrostimulace, EOR model, Poškození v blízkosti vrtu.

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**Abstrakt:** For oil Production, proper treatment with the underground geology is important. After the usage of primary recovery techniques, when the reservoir pressure decreases, secondary recovery and tertiary recovery will start consequently. Each unconventional EOR method is used for a special purpose, to solve challenges and produce residual oil. But has been proved that some of the methods, such as the chemical method, can damage the near wellbore (production well) by interacting with the clay and some of the other layers and plugging the permeable channels. In that case, the EOR methods can increase the reservoir pressure, affect the contact angle to change the oil wet to water wet, and push the oil through the permeable layers until the damaged zone. But from the damaged layer challenges occur for oil production. An Electrostimulation unconventional EOR method is effective to improve near wellbore damage. Injecting the Alternating Current with salt water into the reservoir can affect the sealed clay layer and improve the damage. An electric injection is environmentally more acceptable than any other conventional EOR methods for underground geology and hydraulic underground. From that research has evaluated that how the electric current can be injected into a reservoir model and measure the amount of volt, ampere, and wat.

**Keywords:** Enhanced oil recovery, Electrostimulation, EOR model, Near wellbore damage.

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# 1 Introduction:

Hydrocarbon generates naturally. It comes from plant and animal fossils that were created over thousands of years by the effects of pressure and temperature. They are primarily discovered in porous rock forms, such as sandstone, limestone, and shale, deep underground (Creaney and Allan, 1990). The dead creatures and residential organic matter under the sea, are covered and layered by debris and other deposits. Then, the organic matter with the rocks, are creating source rocks for hydrocarbons. After covering biological matter with a heavily deposited layer, hydrocarbons are migrating from the bottom formation (high pressure) to the upper part (lower pressure) and finally, hydrocarbons are moving through the permeable layers and porous rock formations, as long as they get the seal rock (Creaney and Allan, 1990). Seal rocks are impermeable (Downey, 1994). The hydrocarbons are accumulating under the traps or seal rock boundaries and create reservoirs (England, 1994). The amount of oil can be estimated inside the reservoir, but an estimation of the oil is impossible on the source rocks (Pepper, 1994). There is an operation to find the reservoir which is seismic surveys. To infer the characteristics of the Earth's subsurface from reflected seismic waves, reflection seismology applies seismological principles. The procedure requires a seismic vibrator, a specialized air pistol, or a controlled seismic energy source like dynamite or a Tovex burst. To record the geological formations below the surface of the land or under the seabed, seismic surveys are utilized in the oil and gas exploration industry (Ladopoulos, 2013). In onshore exploration, reflection seismology is a prominent technique that involves sending seismic waves underground (Ladopoulos, 2014). The ideal location for a drilling well must be determined when the reservoir has been discovered. The necessary equipment should be installed in the drilling rig, including the following: mud tank, shale shakers, mud pump, motor or power source, Kelly hose, traveling block, crown block, derrick, drill pipe, swivel, rotating table, blow out preventer, drill string, drill bit, and wellhead…etc. Drilling operations are when non-native liquids and machinery first contact the rock. When drilling operations are successful, the drill string is removed, and a production tube is set up. First, a good log is used to locate a potential layer for production and perforation (Ellis and Singer, 2007). The layer is distinguishable because it has the right amount of oil, permeability, and porosity.

For any nation, having a petroleum reservoir is crucial. An oil-rich nation is seen in a different light on the global stage.

Petroleum is used in a variety of products that are used daily, including plastics, medications, solvents, fertilizers, pesticides, and clothing, in addition to providing transportation energy. These products extend to the asphalt we use to carry these commodities. Petroleum engineering focuses on processes related to the production of hydrocarbons, which might be either crude oil or natural gas (Freudenrich, 2001). Exploration and production are considered to be part of the upstream sector of the oil and gas business. Exploration by earth scientists and petroleum engineering, the two main subsurface disciplines in the oil and gas business, are both geared toward maximizing economic hydrocarbon recovery from subterranean reserves. Petroleum geology and geophysics concentrate on giving a static description of the hydrocarbon reservoir rock, whereas petroleum engineering focuses on estimating the recoverable volume of this resource using a thorough understanding of the physical behavior of oil, water, and gas within porous rock at very high pressure.

## 1.1 Oil Production

Following the drilling of the production well, well completions will begin by setting up production tubes and extracting the oil from the reservoirs, which is containing known quantities of hydrocarbons. Surface and well pressures are lower than the pressure of the reservoir. Through the production well, this mechanism is forcing the liquids (oil and water) to the surface. Natural drive mechanisms refer to this. A production well is set up to produce oil inside the reservoir. Surface pressure and bottom hole pressure are lower than reservoir pressure. Through the production well, the reservoir pressure can force the liquids underground to the surface. After a while, the reservoir pressure starts to drop; to keep the pressure up, secondary, and tertiary recovery are used (Mansour et al, 2019). The original oil in place (OOIP) will stay in the reservoir, and tertiary recovery is being accomplished using EOR techniques. During crude oil production, three recovery mechanisms are playing a role.

## 1.2 Primary Recovery

Is the ability of the natural reservoir pressure to push the oil from the reservoir towards the surface through the production tube (Bhardwaj and Hartland, 1993). In the primary recovery, mechanical systems such as pumps are used to increase the pressure because after some time, the pressure draws down and will not be able to push the oil to the surface. For that purpose, the pressure should be maintained by other techniques. The hollow well shaft that was drilled to extract the oil is intended to have a lower pressure than the oil that is located deep down, and this is the key to primary recovery. Using different techniques, such as pumping water into the well, it is possible to further raise this pressure difference (Welge, 1952). This technique, called a "water drive," works by pushing the oil farther underground and raising its pressure (Birks, 1955). The so-called "gas drive," which is another well-liked technique, uses the energy of expanding subsurface gas to push oil to the surface (Welge, 2952). Oil pressure may eventually rise to a level where it rapidly rises through the well and emerges from the surface, forming an oil geyser (Birks, 1055). The pressure beneath will progressively drop as oil is gently removed from the well, which will result in a reduction in the amount of oil produced. Oil extraction businesses can counteract this by continuing output using artificial raising technologies like the rod pump. This technique uses a beam-and-crank assembly to create a reciprocating motion that uses vertical lift to pump oil out of the well using a succession of plungers and valves. It is renowned for its characteristic bobbing horse head design. At some point, even with the aid of artificial raising systems, the pressure underground will be so low that primary recovery will no longer be possible (Wan and Chen, 1986).

## 1.3 Secondary Recovery:

Is a method to maintain the reservoir pressure, by injecting water into the reservoir. Once Primary recovery has been reached, secondary recovery methods must be applied, such as more water injections that attempt to press oil to the surface (Amit, 1986). The intrinsic energy of a petroleum reservoir is supplemented via secondary recovery techniques by the injection of fluids, often water or gas. Pressure maintenance is the process of doing this in a way that maintains the average reservoir pressure, i.e., the reservoir volumetric rate of production equals the reservoir volumetric rate of fluid replacement (Archer and Wall, 1986). To reduce injection costs, the level of pressure maintained in oil production is typically just above bubble-point pressure. As reservoir pressure gradients can affect the production rate, the rate will be considered while determining the pressure maintenance level (Archer and Wall, 1986). The injected water increases the reservoir pressure and pushes the oil from an injection well toward production. The mobility ratio parameter is taking the main role in the secondary recovery, and it has been explained that how it can be improved by the EOR methods, in the future pages.

## 1.4 Tertiary Recovery:

Often known as enhanced oil recovery, is the term used to describe the third and last step of the oil extraction process (EOR). At this stage, the oil's characteristics are changed to help with extraction (Zhang and Morrow, 2006). The use of heat, gas, and chemical injections, respectively, are the three main tertiary recovery techniques. Enhanced oil recovery works by changing the chemical makeup of the oil itself to make it easier to remove, unlike primary and secondary recovery systems that depend on the pressure difference between the surface and the underground well. It makes sense that the primary recovery stage is more affordable than the secondary or enhanced phases since primary recovery methods employ the already-existing pressure differential to drive oil to the surface from the subsurface reservoir. To assess if it is viable to extract the resources from that reservoir using a specific recovery method, oil and gas firms must compute the estimated ultimate recovery (EUR) of a given field.

For unique oil recovery purposes, tertiary recovery is an effective method. Conventional methods are used to maintain the reservoir pressure (Rao and Girard, 1996). These include (steam, chemicals, and CO2…etc.) Techniques (Shafiai and Gohari, 2020). The goal of injecting techniques is to influence the residual oil in the pores and achieve a favorable sweep efficiency to force them toward the production well. Make good oil recovery and convert oil-wet surfaces to water-wet ones.

## 1.5 EOR Methods

There are several different EOR techniques, including (Conventional and Unconventional) methods. Gas, thermal, chemical, and microbiological injection techniques are types of conventional methods (Tunio et al., 2011). The EOR techniques applied for personal gain. The reservoir still contains the remaining irreducible oil. If the residual oil is heavy oil, which has low API and high viscosity with density, to influence the leftover oil and direct it toward the production well, EOR techniques are employed. The interfacial tension between the reservoir oil and injected fluid reduced using chemical injection procedures (Betancur et al., 2019). Low viscosity allows the liquid to be swept. High-viscosity oil might make it challenging to sweep using fluid displacement. Channels or fingers may be made, and as a result, injected liquid can go through without sweeping the oil (Wei et al., 2014). To get a good sweep efficiency, polymers are used to close the channels and provide a favorable mobility ratio (Wei, Romero-Zerón, and Rodrigue., 2014). There is a good role in the mobility ratio. Due to the dependence of the mobility ratio on the viscosity of the displaced fluid to the displacing fluid, a mobility ratio larger than 1 is undesirable (Farouq et al., 1994). To achieve a good and advantageous sweep efficiency, the displaced fluid must have a lower viscosity than the displacing fluid (Ogolo, Olafuyi, and Onyekonwu, 2012). Increasing RF efficiency leads to an increase in recovery factor. What is the reservoir's main difficulty, and which EOR technique is optimal to utilize to boost sweep efficiency, to have a decent recovery factor RF (%)? Additionally, alter the viscosity of the leftover oil to push it. In an oil-wet reservoir, the oil covers the rock's surface and seeps into the pores. In that instance, both water and oil are created from the surface of the rocks. Engineers must change the oil wet to water wet. A water wet reservoir means that the surface of rocks is surrounded by water and the oil is in pores. In that case, the liquid inside the pores is produced which is oil (Kathel & Mohanty, 2013). So, the wettability alteration is an important manner to understand the situation of the rocks with the fluids inside the reservoir. To have a good recovery factor, always oil wet must be changed to water wet in the reservoir rocks. The EOR methods are used for various purposes, some of them can change oil wet to water wet by affecting the contact angle. The injected particles such as microbial are hitting the contact angle between the oil and the surface of the rocks, they are affecting the angle, decreasing it, finally changing it, and sweeping the remained oil on the rock surfaces (Liu et al., 2021). The oil will move inside the pores through permeable layers to the production well.

In situ combustion, continuous steam injection, and cyclic steam injection are the three main types of economically successful thermal oil recovery activities that are currently being undertaken all over the world. Canada, California, and Venezuela are currently where these processes are most often used. But the portion of the world's total oil production linked to thermal oil recovery is small. The need for oil is rising, which will lead to a significant increase in thermal oil production soon. The thermal methods are used mainly for heavy oil reservoirs and the purpose is to reduce the viscosity of the oil to have a good and favorable sweep efficiency. The Chemical EOR methods are mainly categorized into the following: polymer flooding, surfactant flooding, surfactant polymer flooding, alkaline flooding, and alkaline surfactant polymer flooding. In theory, a water-soluble polymer is employed to increase the viscosity of the water, which reduces the mobility ratio of the water to the oil and increases the volumetric sweep efficiency. The mechanism of polymer flooding is to reduce the permeability of the rock to water while also making water more viscous, or, in other words, bringing the water-oil mobility ratio closer to or below unity (Abidin, Puspasari and Nugroho, 2012). Polymer flooding projects have been used in a variety of situations over the past few years: reservoir temperature (46-235) $^{o}$F, average reservoir permeability (0.6-15000) md, oil viscosity (0.01-1494) cp and remaining oil at startup (39-97) % of OOIP. To enhance the efficiency of liquid injectors or watered-out producers, polymers have been used in oil production in three different ways: as near-well treatments to block off high conductivity zones, as agents that may be cross-linked in situ to plug high conductivity zones at depth in the reservoir, and as agents to reduce water mobility or the water-oil mobility ratio. Polymer flooding is appropriate for reservoirs when conventional water flooding fails because of either high heterogeneity or a high oil-to-water mobility ratio, which targets the oil in reservoir sections that have not been effectively contacted (Cankara, 2005). The primary result of the polymer is an increase in the water-oil mobility ratio, which can be estimated as the ratio of the mobility of the displacing phase to the mobility of the displacement phase using equation 1. (Abidin, Puspasari and Nugroho, 2012):

$M_{w-o} = M_w/M_o = K_w/K_o \times \mu_w/\mu_o$ …………………… eq.1

Where:

$M_{w-o}$: mobility of oil and water.

$M_w$: mobility of water.

$M_o$: mobility of oil.

$K_w$: permeability of water

$K_o$: permeability of oil

$\mu_w$: viscosity of water

$\mu_o$: viscosity of oil

From the equation, the mobility of water (displacing fluid) which is injected into the reservoir is divided by the mobility of oil (displaced fluid) which must be produced). So, the viscosity of injected fluid must be higher than the oil to sweep it. In that case, the higher number is divided by the lower number the result is positive. Due to the equation, the mobility is depending on the permeability and viscosity.

### 1.5.1 Conventional Methods

Conventional oil and gas resources are formations that may generate economic flow rates or economic volumes of oil and gas without the use of stimulation treatments or specialized recovery techniques. Conventional oil or gas is extracted from deposits that are considered "typical" or easy to work with. Fossil fuels can be economically removed from the deposit by using established technologies to extract them from certain geological formations (Bahadori, 2018). Since they don't need specialized technology and can be produced using standard techniques, conventional resources are typically simpler and less expensive to create. This ease of usage and relative affordability make conventional oil and gas some of the first industries to focus on them (Shafiai & Gohari, 2020).

### 1.5.2 Unconventional Methods

The term "unconventional oil and gas resources" refers to formations that cannot produce oil and gas at commercial flow rates or cannot produce commercial volumes of oil and gas without the use of unique recovery techniques.

Unconventional resources such as oil or gas are significantly harder to extract. Some of these resources are imprisoned in reservoirs with low porosity and permeability, making it very challenging or impossible for oil or natural gas to flow through the pores and into a typical well. Specialized methods and equipment are employed to be able to produce from these challenging reservoirs (Elturki and Imqam, 2020). For instance, hydraulic fracturing is a necessary stage in the extraction of shale oil, tight gas, and shale gas to produce gaps for the oil or gas to flow through. Steam assisted gravity drainage is required in the oil sands for in situ deposits to be able to recover thick bitumen from subsurface deposits (Bahadori, 2018). However, this stimulation enables the production of oil and gas from resources that were previously unprofitable to extract from. All these techniques are more expensive than those used to create fossil fuels from a typical reservoir. When these resources can be used profitably, they are considered reserves (Elturki and Imqam, 2020).

## 1.6 Electrostimulation EOR

Oil recovery necessitates proper treatment. Various technologies are being used by oil industry throughout the world to increase recovery with less coast and constraints. alongside oil companies, scientists are researching towards the same goal. To get acquainted and become familiar with how oil is recovered and extracted, some of research papers has been evaluated related to conventional and unconventional enhanced oil recovery methods. Advantages and disadvantages were noted in methods. Electric stimulation EOR generally identified since last century to gain the goal (Rehman and Meribout, 2012). Many types of electrostimulations to enhance oil recovery have been discussed by researchers from the biggening of last century till today by using one well (directly from A.C source) either by two wells which are anode and cathode (Rehman and Meribout, 2012). The methodology of the research that has been done in the past, here has shown, and evaluated to find the best way for oil recovery by considering less disadvantages and limitations due to low coast and high oil recovery. This review examines various types of EOR strategies, analytically. To answer many questions, like: Unconventional is more effective or conventional? Why electrostimulation EOR is focused on? Is it being able to improve near wellbore damage? How applications will be done for oil recovery? How can it affect residual oil? Microwave heating, ultrasonic stimulations, and direct contact are examples. Induction heating and current heating It also exemplifies that some of these are applicable to some specific reservoir circumstances. Unconventional methods may be more effective (Rehman and Meribout, 2012). In some specific reservoir settings, the results in terms of recovery rate outperform conventional strategies. It also covers two highly studied electrical approaches, namely, Ultrasonic stimulation and microwave heating (Rehman and Meribout, 2012).

First scientist who thought about electro-stimulation EOR as a useful manner was Workman. At (1930) Workman conducted research (Rehman and Meribout, 2012). This system refers to a technique of recovering and enhancing oil production, and more specifically to the development of a gas within a well that will combine with the oil and impact the oil-bearing strata (Workman, 1930). To enhance the flow from oil-bearing sands, it entails increasing the temperature of the oil by increasing the viscosity of the oil or increasing the gaseous pressure on the oil-bearing sands. Electrical heating devices have been used in the past to attempt this art, which effectively induce a distillation of the oil while only affecting the surrounding strata without causing any material reaction. Also, at (1950) s application of high-density DC electric current for EOR has been proposed by some scientist such as John H Bruninga (Rehman and Meribout, 2012). Other techniques have been proposed at (1970) for decreasing the viscosity of the oil to enhance the recovery, such as alternating current to heat up the oil. For near well bore heating a technique was demonstrated which was electromagnetic heating at (Chute and Vermeulen, 1988). Because of paraffin accumulation near the well bore and entry of outside liquids and solids for various types of production activities Paraffin deposition may potentially reduce the permeability of the formation. Furthermore, these thermal oil recovery processes may drive accumulated paraffin into the formation, potentially causing pore throat clogging and production loss. Conventional methods are destroying formation for long term heavy oil production (Bailey, Kenney and Schneider, 2001). From around 2001 various types of electrical EOR have been proposed such as (sound waves, RF waves, inductive heating, DC heating) and determined that oil can be recovered from reservoirs at a significantly reduced cost utilizing electrical techniques. Moreover, as compared to the traditional EOR approaches, it is more efficient. The primary function the goal of the EEOR procedure is to increase the oil's mobility. lowering its viscosity, which would aid the oil's flow It's simple to go to the producing well. Because of this, the reservoir will be supplied with electrical energy in one of two ways. produce vibrations in the oil or raise the temperature of the oil molecules of hydrocarbons. Depending on how often electrical current is used, Low-frequency electric reservoir heating is also known as Ohmic/Joule heating because it involves passing an electric current through a formation and producing heat because of power dissipation, which then heats up the reservoir. This approach can be used with two oil wells: one as an anode and the other as a cathode; a potential difference is created between these two electrodes, and a current is permitted to flow through a salty water-rich formation that can conduct electricity fairly, as can be shown in the fig (1) bellow:

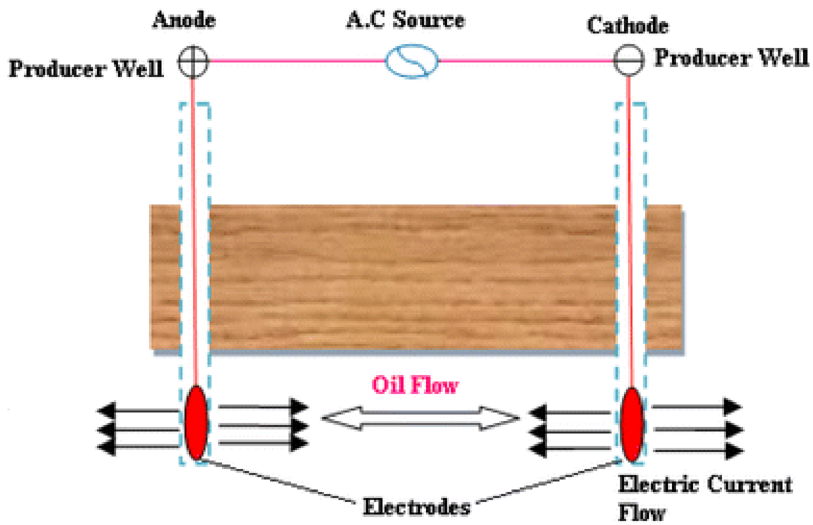


*Figure (1) Low-frequency heating, ohmic heating (Rehman and Meribout, 2012).*

It can be used in a variety of reservoirs with varying formation depth, porosity, and permeability, as well as temperature, pressure, and thickness (Sierra et al., 2001).

Also, one well can be used which sends a cable to the production well for near-well bore heating and vertical wells. The production tubing opposing the production zone has an inductor linked to it. To heat the good bore's surroundings, the production casing is used as an inductively heated element. Induction heating with a power of 5–8 kW was used at Bahrain oil fields from 1998 to 2001, resulting in a threefold increase in production output (Sierra et al., 2001). Current flow depends upon the dielectric loss factor and resistivity distribution of the reservoir. According to Akfhampour (1985), Commercially available mineral-insulated (MI), cables can be utilized to generate heat. This approach does not require the use of brine to conduct electricity; instead, two conductors insulated with graphite and polymer are employed. The mineral resistance increases as the temperature rises, which in turn raises the temperature even more. It is possible to create a self-regulating mechanism that prevents overheating. These heater wires are available in lengths ranging from 300 to 1,000 meters and can be used to heat horizontal and shallow reservoirs. This task demands a 480 V AC power supply.

In (2008) three primary types of electric heating systems have been categorized. Electric current with a low frequency is optimal While high-frequency electric heating is ohmic or resistive, Microwave heating methods can make use of current. For inductive heating, on the other hand, a variety of low- and high-powered devices are available. Depending on the application, medium-frequency electric currents can be used. on the availability of energy (Hascakir, Babadagli, and Akin, 2008). But a long time before has been proven that one drawback of this technique is that when the volume of water drops, the quantity of heat lost reduces, especially if the majority of the water is turned to steam as a result of heating. One possibility is to combine this approach with water injection (Harvey, Arnold, and El-Feky, 1979).

## 1.7 Near Wellbore Damage:

Near wellbore damage is a flow limitation, caused by near-well flow capacity reductions. This damage is believed to be the result of solids or mud filtrate invasion brought on by drilling, as well as reductions in near-well permeability brought on by perforating debris (Xu et al., 2016). In recent decades, near wellbore damage has received a lot of attention. Skin factor (S), a hydrodynamic measure that characterizes increased resistance to fluid flow in the near borehole zone of the reservoir, is a common indicator of formation damage since it results in lower production (yield) than with excellent (ideal) wells (Xu et al., 2016). This subject has received a lot of attention since it directly affects the productivity of the formation fluid from the relevant well. As shown in the figure (2), there are three main mechanisms that affecting near wellbore (Xu et al, 2016). Three main mechanisms are:

1. Mechanical mechanisms: Such as fines migration, phase trapping, solid invasion, mechanical damages, perforating induced and geomechanically induced.
2. Biological mechanisms: Are such as polymer secretion and corrosion.
3. Chemical mechanisms: Such as rock-fluid interactions, for instance clay swelling and adsorption. wettability alterations, fluid-fluid interactions such as emulsions and paraffins, are also a type of chemical mechanisms.

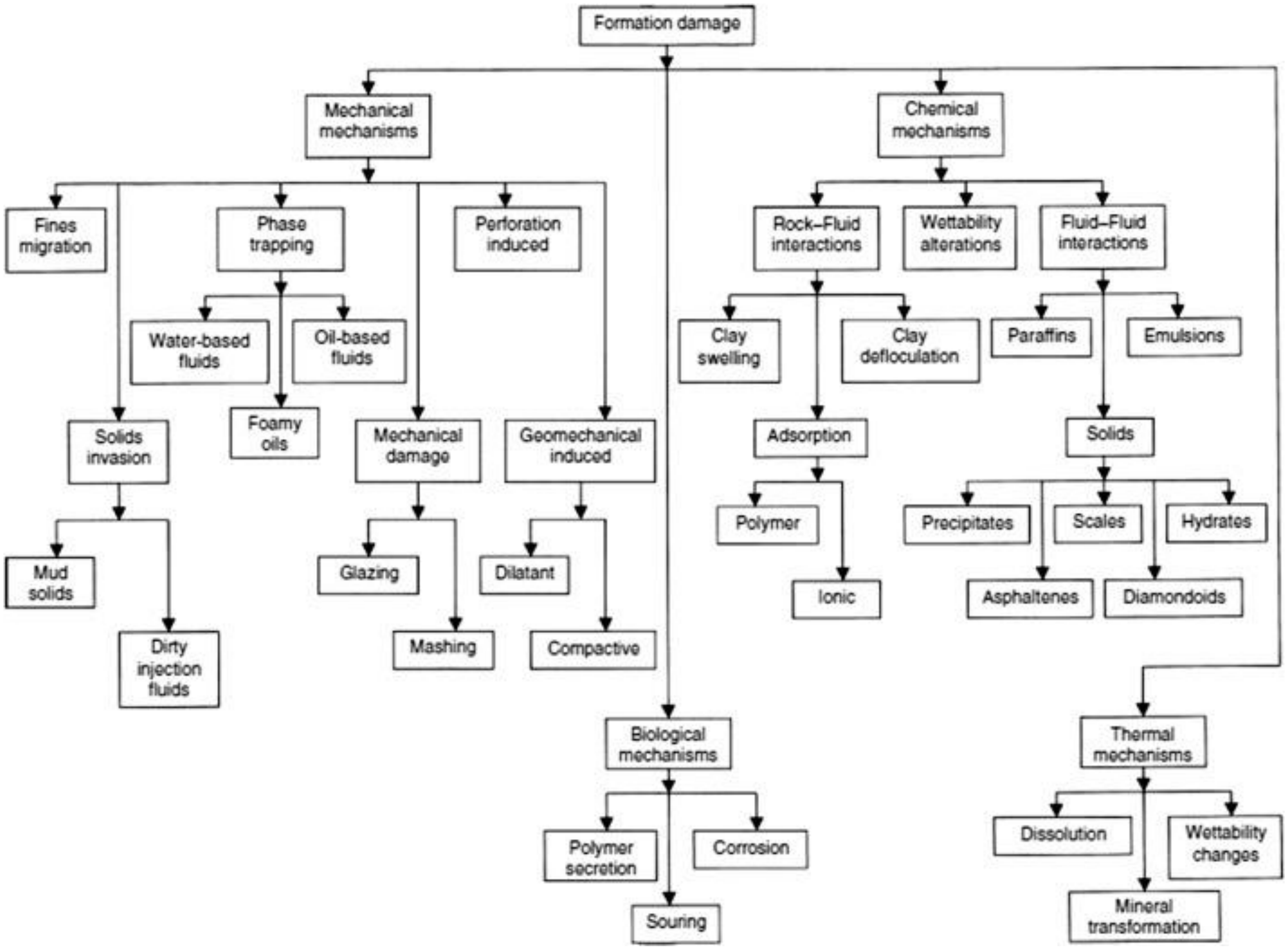

*Figure (2), the three mechanisms of formation damage, which are causing to decrease the permeability of the formation, even near the wellbore (Xu et al., 2016)*

Clay particle swelling, fluid loss or changes in formation water saturation, wettability reversal, emulsion blockage, mutual precipitation of soluble salts in the wellbore-fluid filtrate and formation water, deposition of bowls of paraffin or asphaltenes and fines migration are some of the mechanisms that can cause this damage (Patel and Singh, 2016). These activities are frequently brought about by a variety of operations, including drilling, cementing, well completion, work-over operations, fluid production, fluid injection, and operations to isolate water production (Patel and Singh, 2016). Zones behind the well are so-called flash zone, transition zone, and uninvaded zone. The drilling mud is applied to the well while drilling is taking place. The purposes of the drilling mud are to remove cuttings from the well, suspend and release cuttings, control formation pressures, seal permeable formations, maintain wellbore stability, minimize formation damage, cool, lubricate and support the bit and drilling assembly. Invasion occasionally takes place in the permeable layer. The permeable layer's mud is encroaching on the flash zone as zones are shown in fig (3) below:

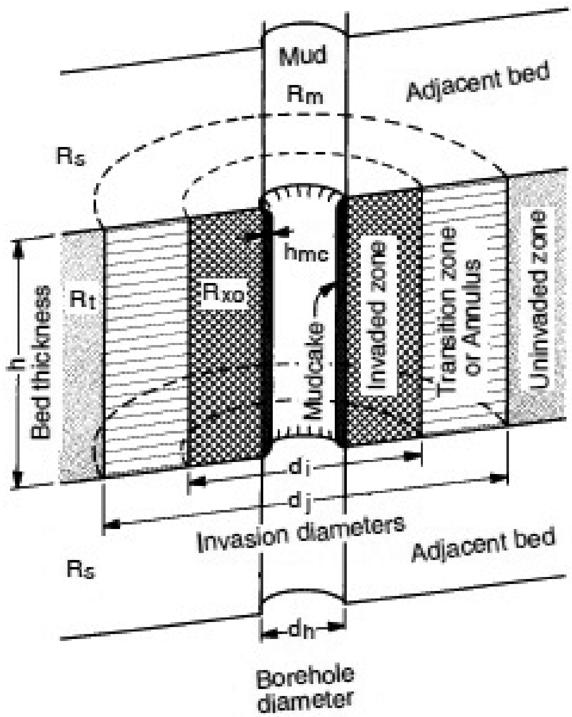


*Figure (3). Borehole environment is showing the well with invaded, transition and uninvaded zone. Which an invaded zone is behind the wall of the well and it contains the filtrated mud (Riberio and Carrasquilla, 2013).*

Various operations are affecting flash zone and they damage the permeable zone. Any kind of damages are challenge for production rate because the crude oil is producing through the permeable layer to the surface, through the wellbore. The suspended particles asphaltenes damage the near-wellbore formation when the thermodynamic conditions there during oil production come inside the reservoir fluid's envelope for asphaltene deposition. In terms of mathematics, formation damage is a decrease in the effective mobility of hydrocarbons. There are some potential pathways of asphaltene-induced formation damage. Asphaltenes can decrease the effective permeability to oil, ko, by adsorbing to the rock and changing the formation's wettability from water-wet to oil-wet, decreasing the effective permeability to oil, and b) adsorbing to the rock and increasing the reservoir fluid viscosity by forming water-in-oil emulsions (Leontaritis, 1998). When an under-saturated oil is produced without the use of water, the most common scenario for asphaltene-induced formation damage, the most important damage mechanism is the obstruction of pore throats by asphaltene particles, which results in a decrease in rock permeability k.

Due to very low matrix permeability and severe damage from drilling, completion, stimulation, and production of wells, tight gas reservoirs typically have production issues. Without sophisticated production enhancement measures, they might not flow gas at their optimum rates. In tight gas reservoirs, liquid leakage into the formation during fracturing operations, liquid leakage into the formation due to filtrate invasion, water blocking, skin due to wellbore breakouts, and damage associated with perforation are the main damage mechanisms and the factors that have a significant impact on total skin factor. Mechanical damage to formation rock is another important factor (Bahrami et al., 2011).

The key to repairing formation damage in a fractured gas reservoir is to locate the location of damage so that acidizing, fracturing, and sidetrack horizontal wells can repair it. Calculating the amount of acid, the fracturing scale, and the length of the horizontal section may all be done using the radius of the formation damage zone (Xu et al., 2016).

From the experiment model, near wellbore damage happened by affecting the cement on the sand particles. The EEOR is applied into the model. The electric vibrates the formation and heating it up…

# 2 Data Collection

Eight samples of reservoir rocks such as sandstone and carbonate are taken in the Carpathian Mountains in the eastern Czech Republic in (Chvalčov), which is a municipality and village in Kroměříž District, in the Zlín region of the Czech Republic. At first, sandstone samples are taken at the following address: (437 768 72 Chvalčov Czechia), coordinates are: (49,377 43o N, 17,72530o E), Zone: (33U), Easting: (697820), Northing: (5472996), Accuracy: (+/- 5 m), Altitude: (453 m), Speed direction: (0 km/h), Odometer: (249.0 km).

The sediments in Olomouc so-called foredeep, are tertiary unconsolidated sediments, like mudstones and sand gravels (Nehyba and Sikula, 2007). Due to the location of the region on the geological map of Czechia, which shows Oligocene and Miocene rocks, the place of the taken samples is on the west side of the Carpathians. The majority of rocks are Eocene sandstone, which implies they were deposited in the deep sea roughly 50 million years ago. Thus, these were turbidites; a turbiditic system often refers to layers of sandstone that are roughly 1 m thick with mudstone inside (Lucchi and Valmori, 1980). The sandstones were separate turbiditic beds or switching-like mud deposits between individual overlaunches. The majority of the time, it's just typical mud sedimentation, but occasionally, sand is picked up and dumped, and then it happens again due to slope instability.

Both fine-grained and coarse-grained rocks can be found in the region. After that, some other sandstone samples are taken at the following address: (768 72 Chvalčov), coordinates: (49, 39309o N, 17,71800o E). Finally, two carbonate samples are taken at the following address: (4361 751 05 Kokory Czechia), coordinates: (49, 49264o N, 17,38394o E), as shown in fig (4).


*Figure (4) is the map of Czech Republic, specifically the (kokory & Chvalčov) where the samples are taken from in west of the Carpathian Mountains*

Next, heavy oil is used as the reservoir oil. The API of the oil sample is (14-20). The oil sample is from the Kurdistan region of Iraq, Zey Gawra oil field, well number 3 as shown in fig (5). In the Kurdistan Region of northern Iraq, the Zagros fold and thrust belt are thought to hold up to 45 billion barrels of oil. However, there hasn't been much geological research done on the fold and thrust belt in Iraqi Kurdistan in recent years. Due to the collision of the Iranian and Arabian plates during the Cretaceous, the region saw considerable tectonic activity. Pre-drowning reefal/lagoonal dolomitic limestone is represented by the Qamchuqa Formation (Early Cretaceous), a transitional phase, and a post-drowning phase of sedimentation with the deposition of the deep-water facies of the Kometan Formation (Late

Cretaceous - Turonian-Santonian) are the characteristics of the depositional history of the studied area (Bellen et al., 1959; Buday, 1980).

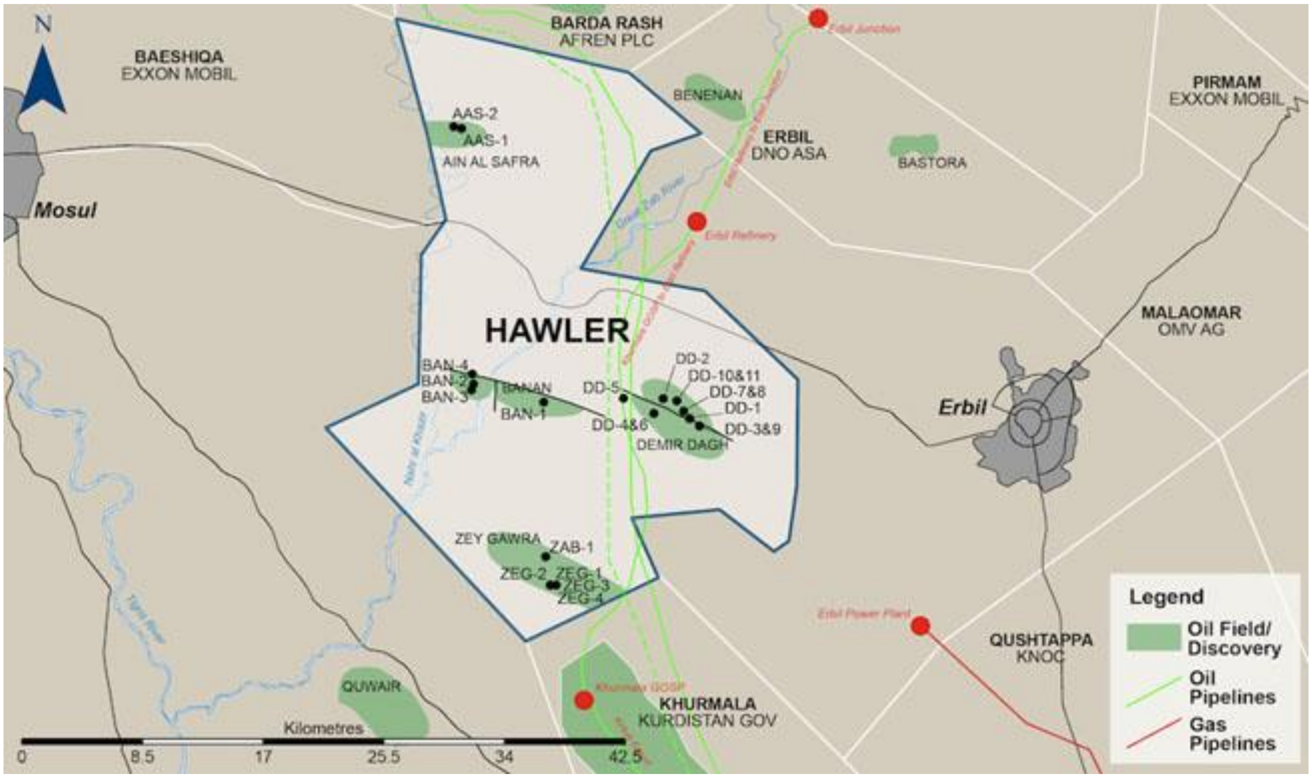


*Figure (5), Zey Gawra oil fields located in the east of the capital city of Kurdistan Region (Erbil) (www.keyfactsEnergy.com, n.d.).*

## 2.1 Experimental Section

From the project, the electrostimulation EOR has tested to find out its behavior and effect on near-wellbore damage and increasing oil recovery. For that purpose, a cubic EOR model has created, that consists of a glass box with (1) m length, (20) cm width, and (1) m high. The box is containing two wells which are the injection well & production well. The high of both wells are (1) m with (2) in diameter. Later than the design changed due to necessities and challenges. The diameter of each perforated hole in the production well is (5) mm. Decided, to scientifically choose soil rocks for the layer between both wells, to act as a reservoir rock layer and seal rock or cap rock layer, which comes from different types of stones like reservoir rocks, claystone, sandstone, etc. To increase the reservoir pressure, the unconventional tertiary recovery method involves an electrical current with saltwater injection. The electrical current maintained by salt water. The residual oil was monitored by how it was pushed and affected by the current. Also, the decreased permeability of clay, is monitored, if it can be increased by the current.

Sample of reservoir rocks, like sandstone and carbonate, are taken from the Carpathian Mountains, in the eastern of the Czech Republic. Eight samples of these rocks chosen to make thin sections and core plugs on them. Samples observed under a microscope. Then, the formation is set up to the model by the required soil rocks. After that, heavy oil used as the reservoir oil. The API of the oil sample is (10-14). The simulation and electrostimulation test started with the injection of salt water, through the injection well to the reservoir layer. The behavior of the unconventional method on the residual oil will is observed, with calculating the required parameters as well. The required parameters are the number of volts, production rate, time, coast, permeability, etc.

## 2.2 Laboratory Experiments:

### 2.2.1 Sample preparation for thin sections:

Eight samples of these rocks were selected to make thin sections and core plugs on them. Two of them are carbonate rocks. At first, each sample has cut by a cutter machine, shown in fig (6, a). Next, the cutting sample has graded by coarse abrasive and fine abrasive. Corser abrasive was applied to the glass bride, and water was added. Then, cuttings were moved to get a uniform surface, as shown in fig (6, b). After that, a finer abrasive is used by the same process as a coarser abrasive. Then, ultrasonic cleaning for porosity has done for each uniform cutting sample. Finally, samples are polished by water-based diamond, as shown in fig (6, c), and prepared thin sections can be seen in fig (6, d) below.

*Figure (6, a) is the cutter machine.*

*Figure (b) is fine abrasive with water are applied to glass bride.*

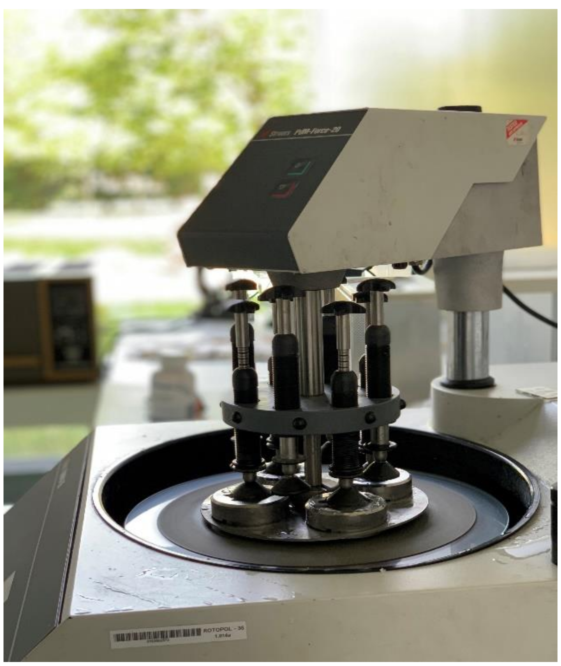

*Figure (c), polish machine by water-based diamond.*

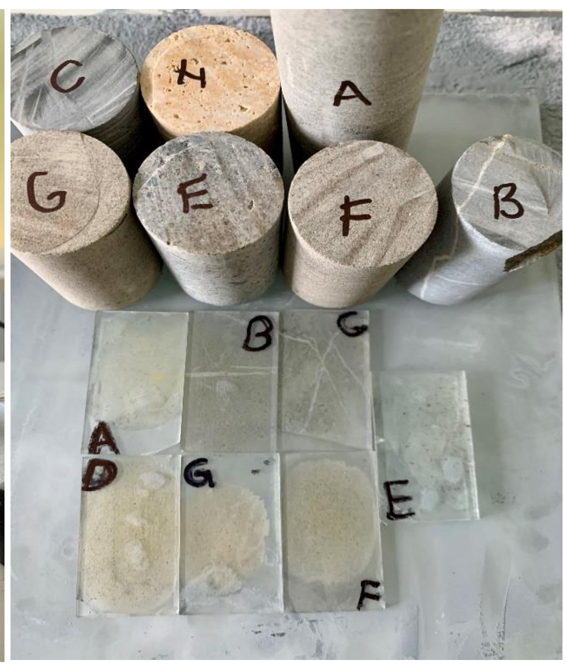


*Figure (d) is finished thin sections with core samples.*

The result section of a page (38) is showing that samples are observed under the microscope, to know their property of them. Then, scientifically choosing the sand grains as the reservoir layer.

### 2.2.2 Model preparation for circulation:

A reservoir model is created, which consists of a box with (1) m length, (20) cm width, and (1) m high, as shown in fig (7). The box is containing two wells which are the injection well & production well. The height of both wells is (1) m, with (2) in diameter. The production well is perforated which is started from (2) cm upper than the bottom point to (6) cm upward. The diameter of each perforated hole is (5) mm as shown in fig (8).

#### 2.2.2.1 Before the Electrostimulation:

For the first test, bottom face of the model sealed by clay particles mixed with water. The medium grain sands are put into the model in the case of making 40% porosity. So, the volume of the sand layer measured as (20) L. After that, both of injection and production wells are applied into the model vertically, perpendicular to the sand and clay layers inside the model. The perforated zone of the production well is set up inside the sand layer. Then, the injection holes from the well are setup into the sand layer. After that, the upper part is sealed by the clay particles mixed with water. The thickness of the sealed clay in the surface was approximately 10 cm, as shown in the fig (9). The flowrate of the pump is 18 L/min. The flow rate can be decreased and increase by the regulator. Also, 20 litters of water are put into the water tank. Finally, circulation is started.

*Figure (7) is the prepared cubed EOR model in the lab which it has two wells (injection and production), water tank and sand reservoir layer.*

*Figure (8) is showing that the production well is perforated and dropping it to be applied onto the sand medium grains as a reservoir layer. From the figure, the sand layer has yellow color.*

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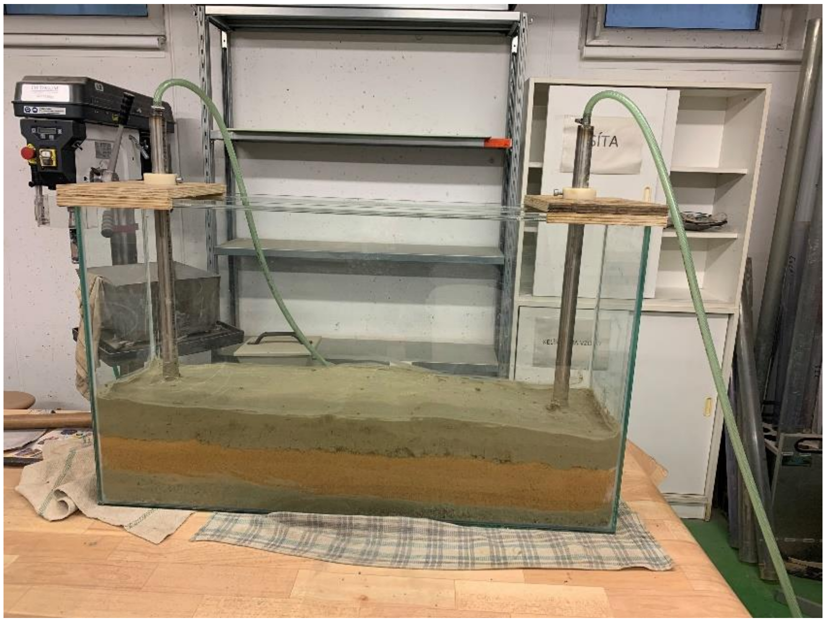



*Figure (9) is showing the cubed EOR model, which the perforated zones in both of wells are applied onto the reservoir sand layer and it covered by sealed clay layer with (10) cm of thickness.*

For the second test, due to getting successful circulation, the thickness of the sealed clay layer of the upper part is increased by more than (12) cm. Then, wood is fitted to the model and placed above the clay layer on the surface area and four rock samples are placed above the wood, as shown in fig (10). The weight of the rock samples was near (60) kg. After that, circulation is started.

*Figure (10) is showing preparation for the second test of the model before the Electrostimulation in order to get successful circulation. The thickness of the sealed clay layer is increased, and the compacted wooden layer is placed above with rock samples.*

For the third test, the thickness of the permeable sand layer is increased from (10) cm to (15) cm as shown in fig (11), and the length of the production well is reduced from (100) cm to (30) cm as shown in fig (12). In that case, the upper level was (40) cm in height from the bottom of the model. The length of the production well is shortened, and a small hole is drilled from the glass model near the same level as the head of the production well as shown in fig (13), said (40) cm from the bottom of the model. Also, the wooden compacted layer is fitted to the model and placed above the polycarbonate layer. After that, four samples of the non-light rocks are placed above the wood layer as presented in fig (11).

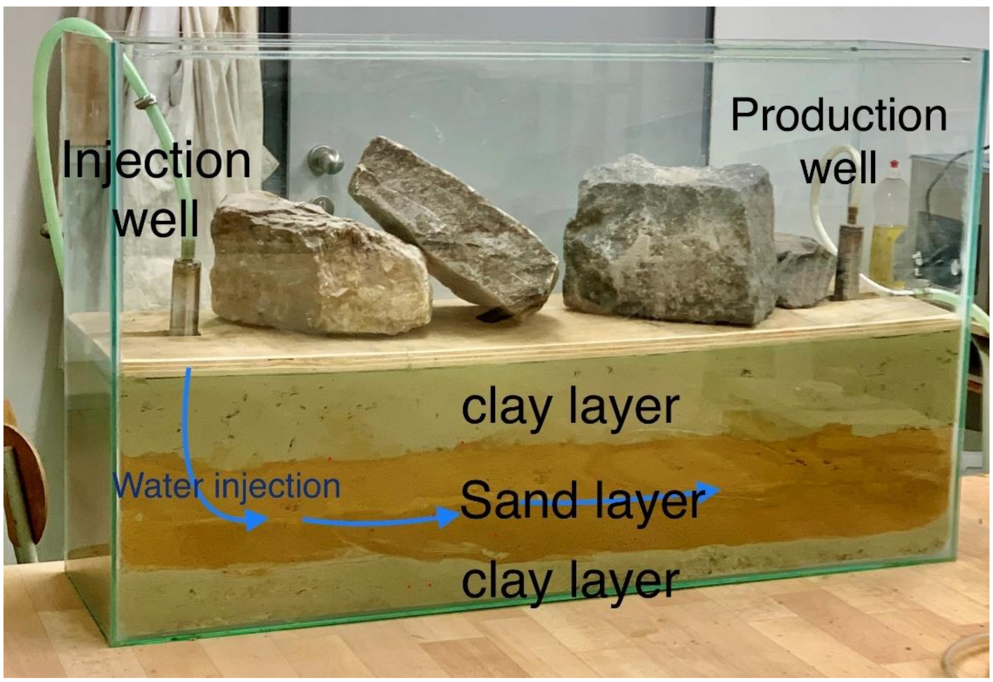



*Figure (11) is showing the increased thickness of the permeable sand layer from (10) cm to (15) cm, as can be seen in yellow color. Also, four heavy rock samples are placed above the compacted wooden, polycarbonate and sealed clay layer.*

*Figure (12) in showing both of shortened production and injection wells which the length of them reduced from (100) cm to (30) cm.*

*Figure (13) is showing the drilled glass and interlinking the hose from the head of the shortened production well to the water tank in the lower height level.*

For the fourth test, coarse gravels (2-4) mm are placed around both the injection and the production wells in the perforation zone, as shown in fig (14) and the reason is clarified in the discussion section.

*Figure (14) is showing that coarse gravels are placed around both injection and the production wells in the perforation zone.*

The length of the production well is decreased more, as shown in the fig (15). The sealed thick clay layer in the upper part is removed and polycarbonate (plastic) is placed along the surface area. Between the thick permeable sand layer and the polycarbonate was a thin clay layer. Above the polycarbonate, four rock samples are placed, as shown in the figure (15) bellow.

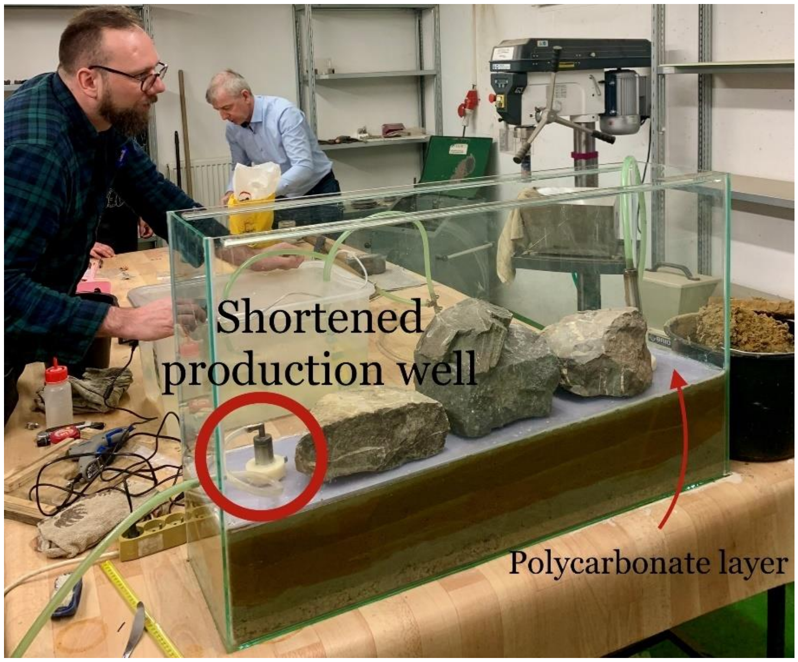



*Figure (15) is showing that the production well is shortened more and the sealed thick clay layer in the upper part is removed, and polycarbonate (plastic) is placed along the surface area.*

For the fifth test, the sand layer is changed to the new (0-1) mm sand layer. The model is updated and designed as follows: The 5 cm of the clay layer has stayed in the bottom. The new 12 cm of the sand layer is placed as a reservoir layer, as shown in fig (16). The bottom parts (perforated zone) of both injection and production wells are placed inside the sand layer and the perforated zones are surrounded by coarse gravel (2-4) mm, the same as the previous test. The surface of the sand layer is uniform. The polycarbonate is placed in the surface area. The edges (spaces between the polycarbonate and the glass model) are sealed by the silicone as shown in fig (17). Also, spaces between the wells and the polycarbonate are sealed by silicone. Two long parallel irons are horizontally placed above the polycarbonate, and four rock samples are placed above it as presented in fig (17). Finally, circulation is started.

*Figure (16) is showing the reservoir cubed model which the sand layer is changed to the new sand layer which grain sizes were between (0-1) mm.*

*Figure (17) is the uniformed sand surface and interlinked with the polycarbonate layer.*

For the sixth test, new sand grains which were mixtures of various grain sizes from (0-1) mm, are sieved by a (1) mm sieve for coarse grains, and sieve (0.5) mm for finer grains as shown in the fig (18).

*Figure (18) is showing both sieves which used for sand grains. The upper one is (1) mm and the lower one is (0.5) mm.*

The design of the model is reupdated, by changing the size of the production well to (8) cm, and it is applied horizontally. Also, the perforated holes from the production well are redesigned as shown in fig (19).

*Figure (19) is new production well which is applied to the model horizontally inside the permeable sand grains, with new a shape of the perforation holes.*

The glass is drilled in the lower height to interlink the wellhead with the outside of the model in lower level of height. The sieved sand grains are applied to the model. The thickness of the sand layer was (12) cm. The same gravel grains as previous tests are applied to surround the perforated zones of the production and the injection wells. After that, the thick layer of clay is applied to the upper part of the formation. Then, rock samples are applied and placed above the clay layer as presented in the fig (20). Finally, circulation is started.

*Figure (20) the new design of the model can be seen by increasing thicknesses of both of sand layer and sealed clay layer. Coarse gravels can be seen near production well by white color inside the permeable sand layer.*

After successful circulation, the sand layer is saturated with water. Then, ink is injected as a tracer. (50) ml of blue ink is mixed with (20) L of water as shown in the fig (21).

*Figure (21) tracer ink added to the water.*

The ink is injected into the sand layer through the injection well, it reached the coarse sand gravels around the injection well as can be seen in fig (22).

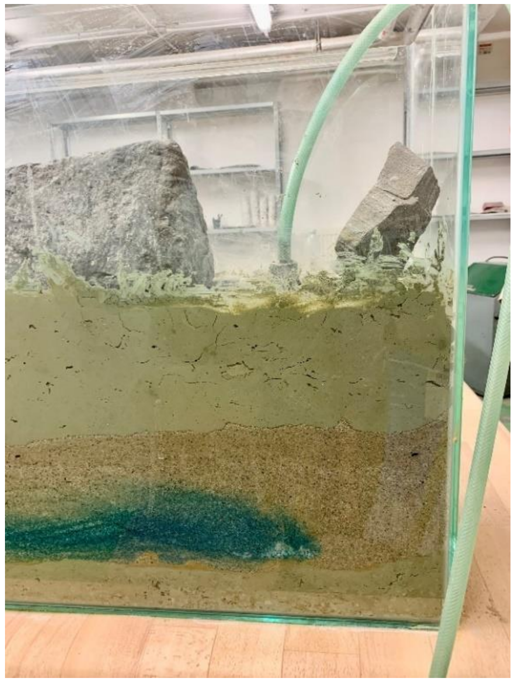


*Figure (22) is during the ink injection to the permeable reservoir layer in the cubed EOR model. The ink is already reached the coarse gravels around the perforated zones of the injection well and go towards the production well through the sand particles.*

#### 2.2.2.2 Electrostimulation by Direct Current:

From the project, the electrostimulation EOR has been used. For test seven, clay is added to the sand layer especially to the coarse gravels near the perforated zone of the production well, for the same level where the ink (tracers) showed the highest permeability, in the sixth test, as shown in fig (23). The amount of added clay to the gravels near the production wellbore was (50) g. After that, the electric supply is used to apply a direct current (DC) of electricity as shown in fig (24). A wire is interlinked with the injection well and another with the production well. Both wells acted as electrodes as presented in both figures (24 and 25). The distance between electrodes is (80) cm. The electric power supply had a limited number of volts to send to the sand layer. The resistance of the layer between electrodes is decreased, by adding (600) g of salt, to the injected water. Then, the maximum number of volts and amperes became higher. Finally, the circulation is started.

*Figure (23) is the added clay around the perforated zone of the production well to damage it and decrease the permeability. Then, monitored that, if it can be improved by electrical currents.*

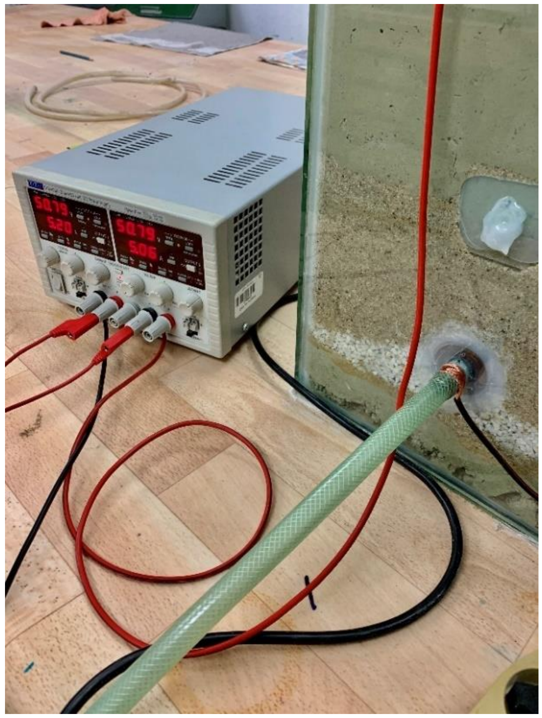


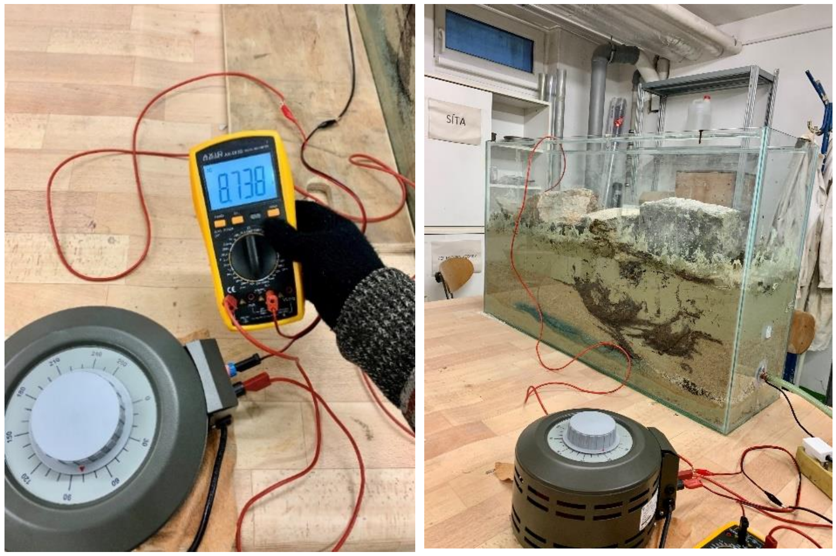
*Figure (24) is the electric supply which providing direct current. From the picture approximately (101) V are applied to the model with (5.2) A. Production well is acting as an electrode and interlinked with the power supply by wire.*

*Figure (25) is showing the DC power supply which applied to the model by interlinking electrodes with the power source by two wires.*

#### 2.2.2.3 Electrostimulation by Alternating Current:

For the test eight, permeability of the layer in near production well is decreased to (0) md and it damaged by clay. Then, (1) L of heavy crude oil (10-15) API is placed inside the sand layer as it is presenting in the fig (26). The reservoir layer is saturated with the crude oil as shown in the fig (26). Alternating current is used, and it generated by auto transmitter. The force of the auto transmitter was able to provide (260) V in maximum value. The application design from the auto transmitter to the model was as follows: The auto transmitter with the multimeter is interlinked by a short wire. Then, by a long wire transmitter is connected to one of electrodes (injection well). After that, by another long wire the multimeter is connected to other electrode (production well), as shown by figures in number (27) bellow. Finally, circulation is started.

*Figure (26) is presenting that the sand layer inside the EOR lab model, is saturated with the heavy crude oil. Then, sealed clay layer is placed above.*



(a) the auto transmitter & multimeter. (b) the electric source with the EOR model.

(c) wire in interlinked with production well. (d) wire is interlinked with injection well.

*Figures (27) is showing the Auto Transmitter which it has grey color, and it generates electromotive force (Volts). The drawing is designed such a way that current goes through the Multimeter then to the model. The electric currents (Amperes) are measure.*

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## 2.3 Simulation

### 2.3.1 Circulation before Electrostimulation:

For the first test, the circulation is started. The regulator turned on. The pump pushed the water from the tank to the injection well through the hose. The sand layer is saturated with water from the injection to the production well, as shown in fig (28). The water pushed the air inside the sand pores to the perforation zone of the production well. Then, to the surface through the well. After that, to the water tank through the hose. Some bubbles appeared in the water tank which connected with the production well by the hose. The bubbles were a sign of sealed layer above and under the sand layer. The injected water reached the perforated zone, and a challenge was, the perforated holes were filled with sand particles.

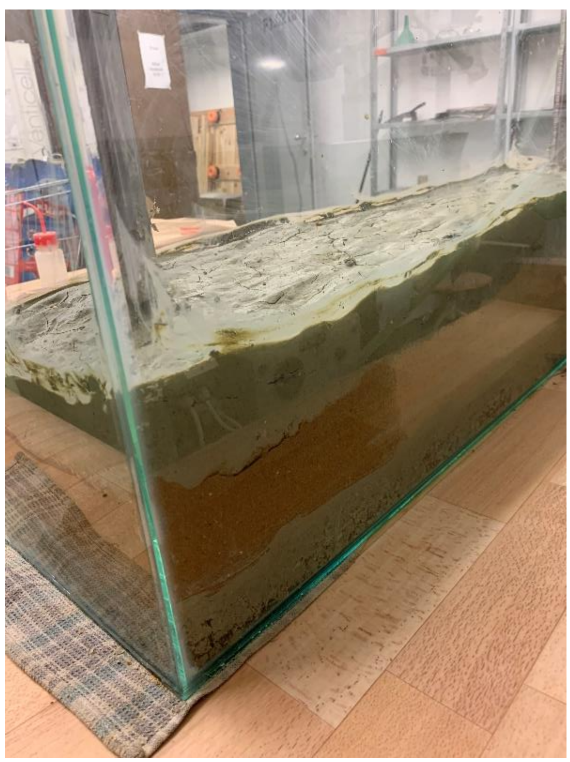


*Figure (28) is showing the front during water saturation of the permeable sand layer, in the first test. The water is injected from the injection well to the production well.*

For the second test, the pump is turned on, the layer already was saturated by the first test. It pushed the water from the water tank to the reservoir (permeable sand layer), through the injection well. The pressure of the reservoir built up. The pressure affected the surface area of the reservoir, water leaked.

For the third test, the circulation is started, the regulator turned on slightly. The pump pushed the water to the reservoir layer of the model. The sand layer is saturated with the water. After 100% of water saturation, the first water drop appeared from the production well. The flow rate is measured manually by the pile with setting time.

For the fourth test, the water is injected slightly, and the layer is saturated by water. When the water reached the production well, the pressure built up inside the reservoir model. The water raised up inside the production well, but until the specific height. The pressure affected the glass model and the glass bulged from the sides as shown in the fig (29).

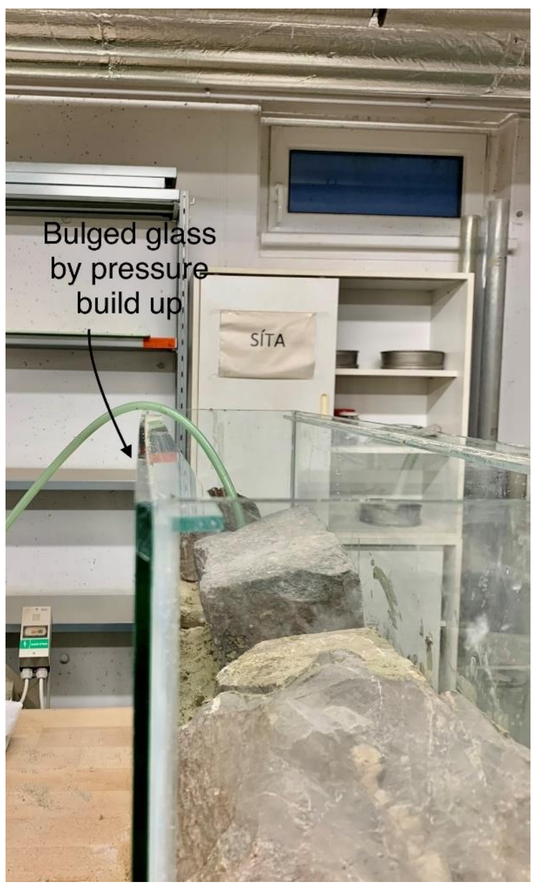



*Figure (29) is presenting that the glass is bulged from the sides. The intake pressure was higher than the intake flow rate. The weight on the sealed clay layer was approximately (60) kg. The pressure inside the reservoir, built up and it wasn't affected.*

For the test number five, the water is injected slightly, the pressure of the pump is not much increased. The sand layer is saturated by water, as the front can be seen in the figures number (30). After 10 minutes the front closed to the production well and water infiltrated to the gravels as shown in the figures (30). The water raised up inside the production well until specific level. After that, the intake pressure is increased. Finally, the water is leaked in the injection well area between the polycarbonate and injection well. Also, in the water found some channels between the plastic (polycarbonate) and the glass model, the silicone destroyed, as shown in the fig (45).


a b

*Figure (30) is showing the sand layer saturated by water. The water goes from the injection well towards the production well. the fronts and fingers can be seen clearly. White coarse gravels which surrounded the perforated zone in the production well are*

For the sixth test, the sand layer is saturated, and front is moved from the injection to the production well, as can be seen in the figures number (31). After 15 minutes, the front reached the production well area, it infiltrated to the gravels. Finally, water is produced through the production well. The flow rate is measured manually. The produced water flow is dropped to the bucket. The volume of the bucket is measured, and the time is set up. The produced flowrate is linked to the water tank by the hose and water circulation is successfully prepared for the EOR model.


a b

*Figure (31) is showing the simulation. Water is injected to the EOR model. The injected water is going towards the production well. Fronts and fingers can be seen. Finally, the water reached the production well and to the water tank through the hose.*

After the sand layer is 100% saturated by water, blue ink is injected as a tracer. At first, the regulator of the pump is turned on. After that, the ink is slightly injected into the reservoir model, with low pressure and low intake flow rate. After (2) minutes, the coarse gravel around the injection well saturated with the ink as shown in fig (32). Then, the ink moved to the production well slightly from the higher permeable channels. The water inside the model is produced and replaced by ink. The circulation continued. Finally, the ink reached the perforated zones of the production well and showed the highest permeable zone from the reservoir layer.

*Figure (32) is showing the ink injection as a tracer. The ink in showing the highest permeable zone from the sand reservoir layer, by blue color.*

### 2.3.2 Improve near wellbore damage:

#### *2.3.2.1 Electrostimulation by Direct Current:*

For test seven, the circulation is started. The out-take flow rate is measured manually by the out-take flow hose, which is interlinked with the production well, is taken out from the water tank; it is put into the bucket, and time is set up. Then, measured. After that, the regulator is set up stably to make constant pressure from the pump to the reservoir. For the first (20) minutes, (24) volts are applied to the model as shown in fig (33). The flow is continuously produced at the same rate, from the production well to the water tank, then from the water tank injected to the reservoir model by the injection well. Next, the number of volts increased to (101.4) and amperes were (5.2). Finally, the produced flow rate is increased the reason for the increased flow rate is checked and evaluated in the discussion section, which the cause of increasing the produced flow rate was not by improving near wellbore damage by direct currents.

*Figure (33) is showing the electrostimulation by using the DC current. The circulation is started as a stable manner. The power supply relates to the EOR lab model by two wires. The wires are interlinked with the electrodes (injection and production wells) separately.*

#### *2.3.2.2 Electrostimulation by Alternating Current:*

For the test eight, the salt water is injected to the sandy reservoir layer in the EOR laboratory model. The layer didn't 100% saturate with water and the water was not able to push the heavy oil and produce it through the production well. The water injection is stopped, and electrostimulation is started by applying AC current to the model. At first, (5) V is applied from the auto transmitter to the model, for (20) min. After that, water circulation is started. Again, water was not able to produce the heavy oil. Then, the circulation is stopped, and electrostimulation is started with approximately (30) V for (20) min. The current is measured by the multimeter, which the current was (2.6) A for (30) V of electric force, as shown in the fig (34). Next, the electrostimulation is stopped, and the circulation is started. The salt water is injected to the model and after 5 minutes, noticed that liquid is produced in drops. From the out-take flow rate, oil drops appeared with water. After that, the in-take pressure is increased by the regulator and the out-take flowrate is changed from drops to thin liquid flow. Then, the circulation is stopped, and the electrostimulation is applied for (20) min with the force of (60) V and electric current is measured by the multimeter as (5.5) A as shown in the fig (35). Then, the electrostimulation is stopped, and the circulation is started. The produced flowrate (water and oil) is increased and measured in milliliters per minute. Finally, the circulation is stopped, and the electrostimulation is applied for other (20) min with the force of (80) V and electric current is measured by the multimeter as (8.4 - 8.8) A as shown in the fig (36). Then, the electrostimulation is stopped, and the circulation is started. The produced flowrate is changed.


*Figure (34) is showing Both of auto transmitter with the multimeter. Approximately (30) V is applied to the model during the electrostimulation. For the force of (30) V, (2.6) A of electrical current are generated. For (20) min the electrostimulation is continued by that value.*


*Figure (35) is showing Both of auto transmitter with the multimeter. Approximately (60) V is applied to the model during the electrostimulation. For the force of (60) V, (5.5) A of electrical current are generated. For (20) min the electrostimulation is continued by that value.*

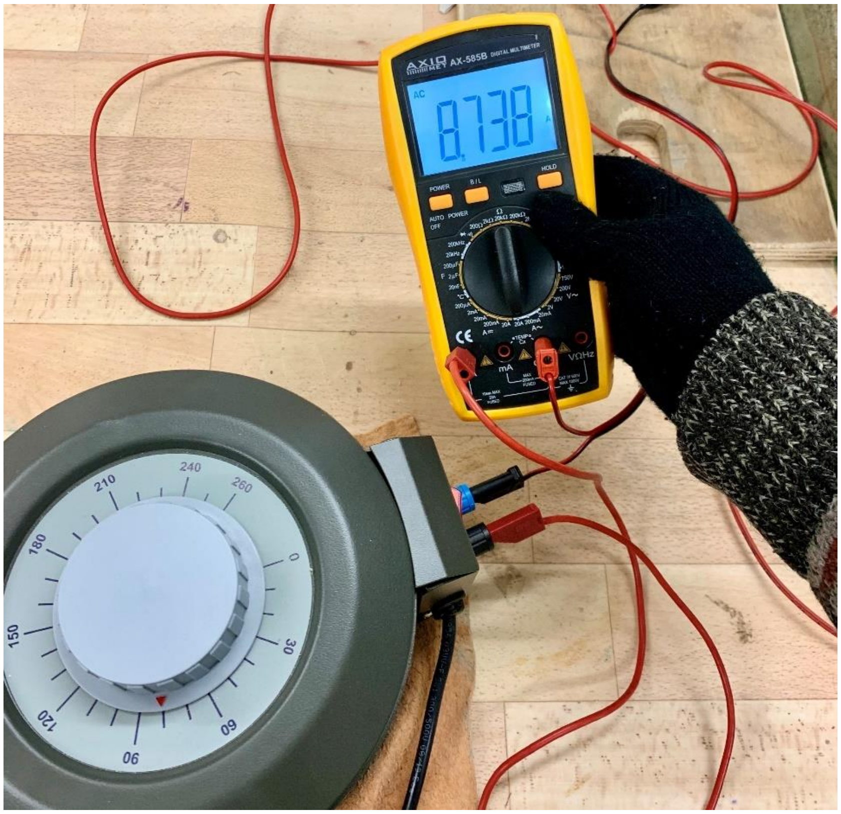


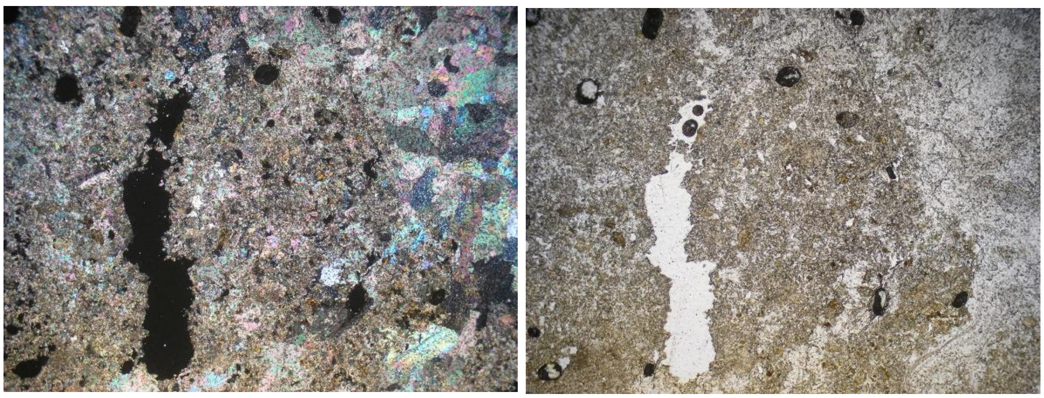

*Figure (36) is showing Both of auto transmitter with the multimeter. Approximately (80) V is applied to the model during the electrostimulation. For the force of (80) V, (8.7) A of electrical current are generated. For (20) min the electrostimulation is continued by that value.*

# 3 Results

## 3.1 Thin section samples under the microscope:

Thin section observations under microscope:

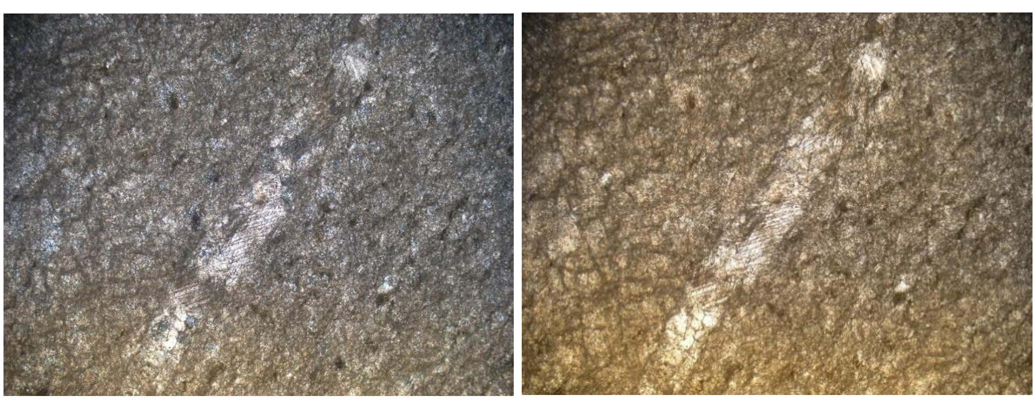
Rock (A) is a carbonate. The sample has high and Interconnected porosity as shown in the fig (37), the pores are black in the XPL regime even if it is rotated under microscope and no interference color at the PPL regime.



*a* *b*

*Figure (37) the thin section of rock (A) under microscope. (a) is XPL and (b) is PPL.*

Rock C is carbonate as well. The sample has bad porosity with tiny carbonate vein. As shown in the figure (38).



*a* *b*

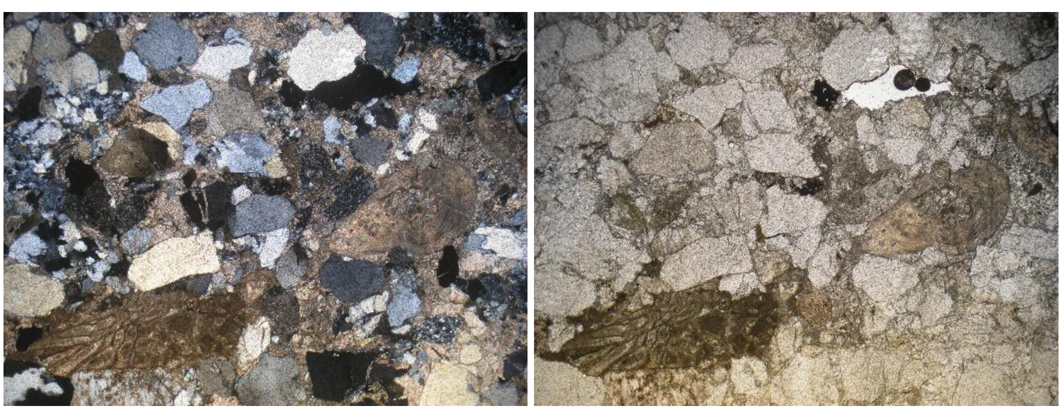
*Fig (38) the thin section of rock C under microscope. (a) is XPL and (b) is PPL.*

The rock sample (D) is sandstone. It has Quartz + plagioclase acid. Glauconite is green color in both o XPL and PPL regimes. Also, the sample is containing muscovite in purple color at XPL regime, and it has black biotite mice. Generally, Porosity is low. From the sample, quartz is white in the XPL regime and colorless at the PPL regime, as shown at follows fig (39).

*a* *b*

*Fig (39) the thin section of rock (D) under microscope. (a) is XPL and (b) is PPL.*

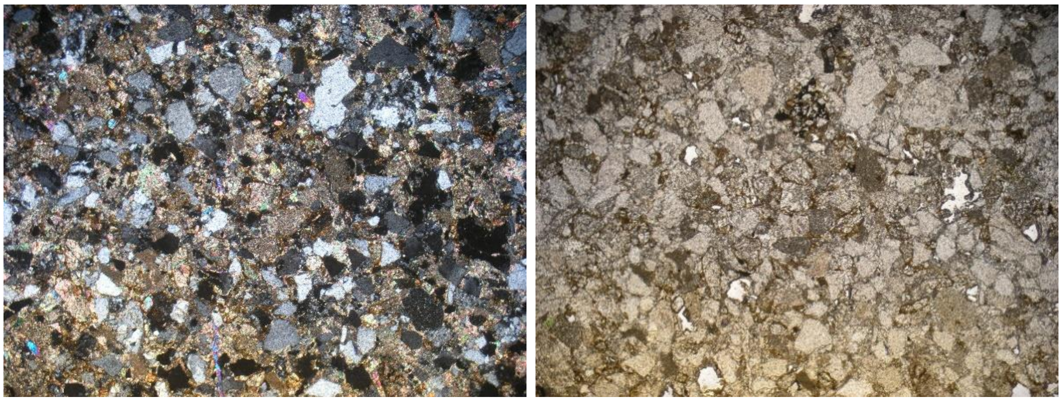
Rock E is Siliciclastic sediment. It has Coarse grains which is equal to (1mm), but the average grain size is medium which is equal to 0.8mm. Fossils are moss animal, age is Cretaceous. The pore in PPL has low refraction index as shown in fig (40) and in XPL is dark. Pore has irregular shape; size is less than (1mm)



*a* *b*

*Fig (40) the thin section of rock (E) which is siliciclastic, under microscope. (a) is XPL (b) is PPL.*

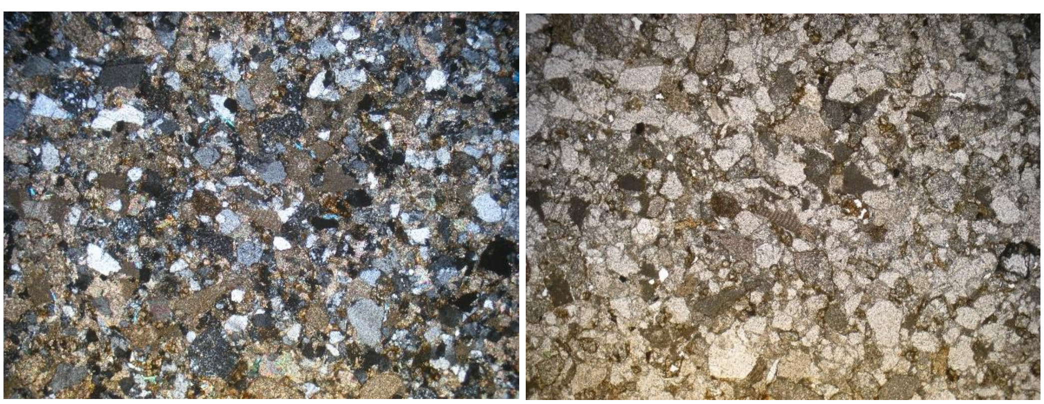
The rock (F) which is sandstone, it has medium Grains and carbonation cement as well as Quartz, K-feldspar, microcline (k-feldspar) system is like net from the sample. Pores are intergranular, size of pores are equal to 0.1mm and the average grain size of the sample is 0.4mm which is medium, as shown in the fig (41).



*a* *b*

*Fig (41) the thin section of rock (F) which is sandstone, under microscope. (b) is XPL and (b) is PPL.*

The sample (G) is sandstone rock. It has large and coarse grains with long distance between grains. Porifera fossil can be observed. There are various minerals, like: Opaque mineral. Glauconite with white mica + muscovite, as shown in the fig (42). The sample has low porosity and permeability.



*a* *b*

*Fig (42) the thin section of rock (G) which is sandstone, under microscope. (a) is XPL and (b) is PPL.*

In that case, the sandstone grains are the most proper one to be the main reservoir layer for the model, due to their permeability and porosity. Otherwise, other sample of rock grains for instance clay, can be mixed with the reservoir layer in some specific places to make heterogeneity.

## 3.2 Circulation of the EOR model:

### 3.2.1 Before Electrostimulation:

First test: The produced (out-take) flow rate through the production well = (0) L/min. The circulation failed. So, the water didn't come out through the production well. With accumulation with high amount of water flow and pressure inside the reservoir model, the middle part of the sealed layer (clay) above the sand cracked and leakage happened, as shown in the fig (43). The water came out through the cracks to the surface.

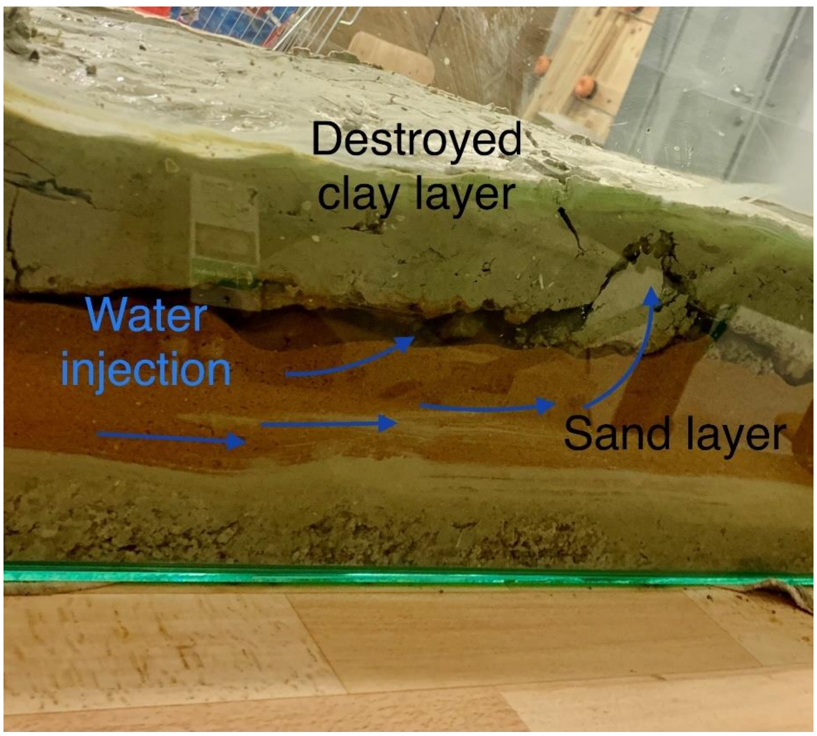
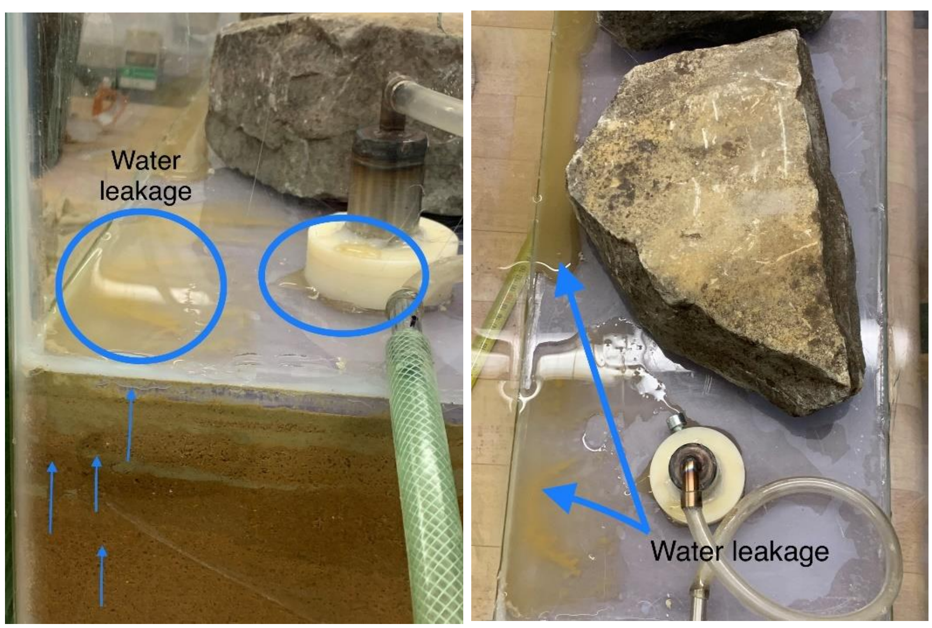



*Figure (43) is showing the failed circulation due to breaking the sealed clay layer above the sand layer. The water is leaked through the big crack to the surface (outside of the model).*

Second test: The produced (out-take) flow rate through the production well = (0) L/min. The circulation failed. Again, leakage happened. The pressure was not able to push the water from the reservoir to the surface through the (1) m tall production well. The reservoir surface was more effected by the pressure. In the result, water leaked through the channels.

Third test: The produced (out-take) flow rate through the production well = (0.5) ml/4min. The out-take flowrate in 4 minutes was (0.5) ml. The produced flowrate was unpredicted low. The reservoir pressure was built-up and the glass model from the sides was expanded. In the result, water was able to migrate to the surface through the edges between the layer and the glass.

Fourth test: The produced (out-take) flow rate through the production well = (0) ml/min. The pressure affected the glass model and the glass bulged from the sides as shown in the fig (30). The water is leaked from sides of both of clay layer and polycarbonate layer to the surface instead of the production well, as shown in the figures number (44).




a b

*Figures number (44) in both a and b, water leakage from the sand reservoir layer to the surface through the silicone which used for the purpose of closing spaces between the polycarbonate and the glass model.*

Fifth test: The produced (out-take) flow rate through the production well = (0) ml/min. The sand layer is saturated by water, as the front can be seen in Figure number (30). After 10 minutes the front closed to the production well and water infiltrated the gravel as shown in the figures (30). The water is raised inside the production well until a specific level. After that, the intake pressure is increased. finally, the water leaked in the injection well area, between the polycarbonate and the injection well. Also, the water found some channels between the plastic (polycarbonate) and the injection well with the glass model, and the silicone was destroyed, as shown in fig (45).


*Figure (45) the water leaking through the spaces between the injection well and the polycarbonate which blocked by silicone, but it is opened by salt water with high pressure.*

Sixth test: The produced (out-take) flow rate through the production well = (2) L/min. The sand layer is saturated, and the front is moved from the injection to the production well, as can be seen in fig (46). After (15) minutes, the front reached the production well area, it infiltrated into the gravel. Finally, water is produced through the production well. The produced water flow is dropped into the bucket. The out-take flow rate was measured as (2)

L/min, as can be seen in fig (47). There were noted factors that became a reason for the successful circulation: The first factor was the grain size of the reservoir sand layer. The second factor was the length of the production well. The third factor was the thickness of the sealed clay layer above the sand layer. (10) cm was the thickness of clay which was enough to prevent leakage for that design. The fourth factor was the gravel which applied to the perforated zone of the production well. Fifths factor is the way of injecting the water through the pump. The flow rate and the pressure must be applied slightly high. In the case of low intake flow rate and low pressure, the injected water or the front was gone towards the production well inside the reservoir layer, through the channels, gently!

*Figure (46) the last design of the EOR lab model which the sand reservoir layer is saturated with water from the injection to the production well. The hose as can be seen is connected with the production well. The water produces and goes to the water tank.*

*Figure (47) the bucket which the produced flow rate is measured manually. The hose which connected the production well with the water tank, took out from the water tank and put into the bucket, time is set-up, the flow rate was (2) L/min.*

The main flow path inside the reservoir is found by ink injection (tracer). The sand layer is 100% saturated with water as done in the previous test. In that test, the main channel or the main flow path is found which fluid goes through, from the injection well to the production. The ink is injected as a (tracer). After (2) minutes, the coarse gravel around the injection was well saturated with the ink as shown in fig (48). Then, the ink moved to the production well slightly from the higher permeable channels. Finally, after (20) min, the ink reached the perforated zones of the production well. The whole permeable channel appeared from the injection well to the production as shown in fig (49). Grain sizes of the sand layer start from (0.5-1) mm. The blue color which is shown in the permeable sand layer from fig (49), has the highest permeability from the sand layer.

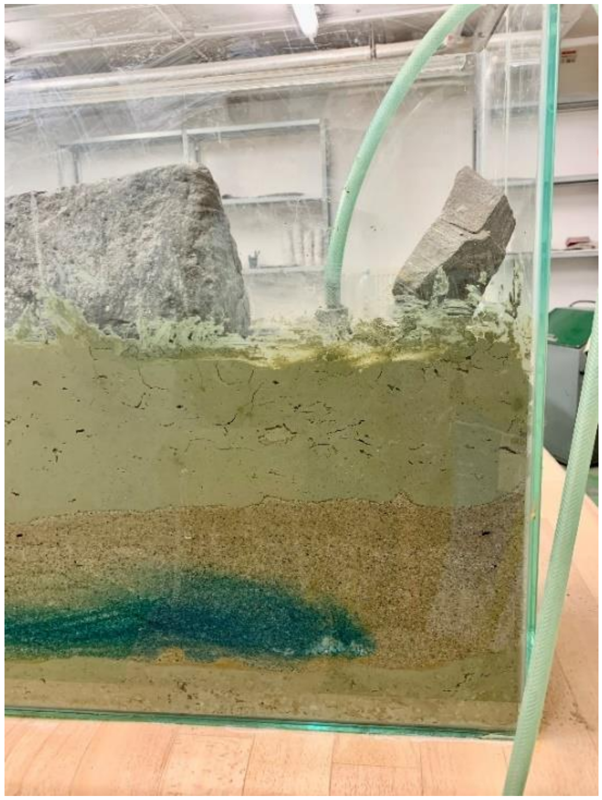


*Figure (48) is presenting that, the blue ink is injected to the EOR model through the injection well. Coarse gravels around the injection well are fulfilled with the ink then the ink swept water towards the production well through high permeable zones.*

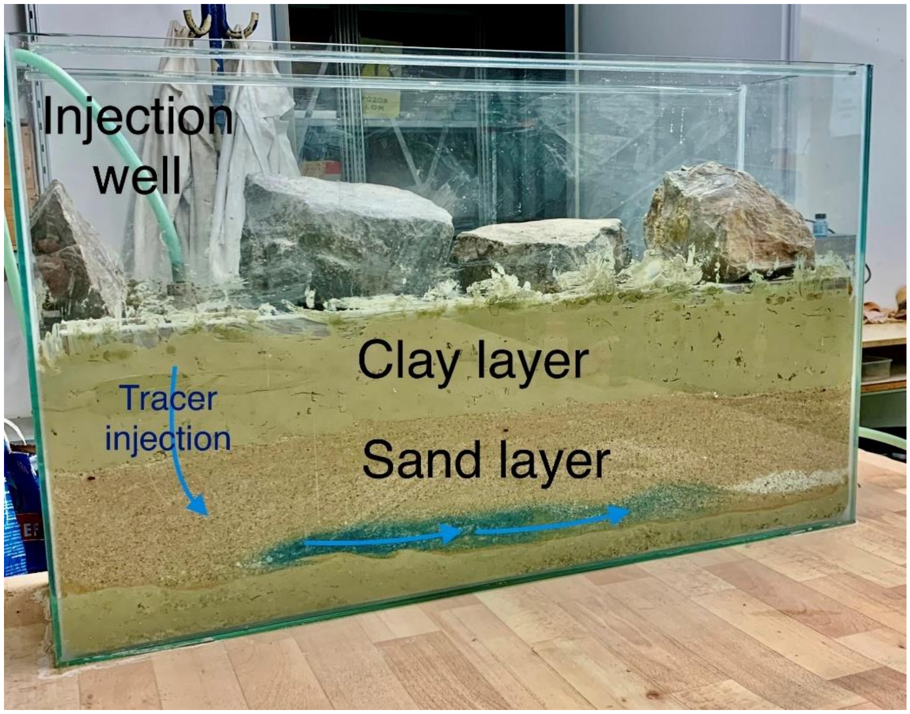



*Figure (49) the highest permeable layer which ink went through from the injection well to the production well inside the reservoir sand layer.*

### 3.2.2 Electrostimulation by Direct Current:

The resistance of the layer between both wells was measured as 500 ohms.

Test seven: (101.4) Volts of direct current (DC) from the electric power supply to the model with (5.2) A were not able to affect (50) g of clay and improve near wellbore damage in (80) min.

Volt x Amperes = Wat

= 101.4 x 5.2 = 527.28 W

(527.28) W by direct current (DC) can't improve damages caused by (50) g of clay.

The flow rate in the first minutes was measured as (2) L/min.

The produced flow rate after (80) min, was measured as (2.4) L/min because the weight above the sand reservoir layer decreased.

For test number seven, the out-take flow rate is measured manually (the out-take flow hose, which is interlinked with the production well, is taken out from the water tank; it is put into the bucket, and time is set up. Then, measured) as (2) L/min. After that, in the first (20) minutes, (24) volts are applied to the model. The flow rate is measured again manually as (2) L/min, which was the same manner as before. Next, the number of volts increased to (101.4) and amperes were (5.2). After (80) minutes of circulation, the flow rate increased from (2) L/min to (2.4) L/min. Finally, the reason for the increased flow rate is checked and evaluated. The cause of increasing the produced flow rate was not by improving near wellbore damage by direct currents. The reason was the constant pressure from the pump, which was able to rise the sealed clay layer for a few millimeters above the reservoir layer, this is the cause for decreasing weight on the sand grains and make the possible environment for injected water to improve proper permeability to migrate through it.

### 3.2.3 Electrostimulation by Alternating Current:

Distance between electrodes = (80) cm.

For the test number eight, as shown in the table (1), at first, (5) V is applied from the auto transmitter to the model with (0.9) A, for (20) min. The flow rate is measured as (0) ml/min.

(30) V is applied for (20) min. The current is measured by the multimeter, which the current was (2.6) A. Oil drops appeared with water. After that, the in-take pressure is increased by the regulator and the out-take flowrate is changed from drops to thin liquid flow.

Electrostimulation is applied for (20) min with the force of (60) V and electric current is measured by the multimeter as (5.5) A. From that test, the electrical power is (330) W because the Electrical Force (V) multiplied by Electrical Current (A) is equal to the Electrical Power which is measuring by Wat. By applying of (330) W the produced flowrate (water and oil) is increased and measured as (3) ml/min.

As shown in the diagram (1) with increasing the electrical power, the flow rate is increased which is a sign for improving near wellbore damage by clay. Alternating current is behaving to increase the damaged permeability by clay.

Finally, the circulation is stopped, and the electrostimulation is applied for other (20) min with the force of (80) V and electric current is measured by the multimeter as (8.4-8.8) A. The produced flowrate is increased and measured approximately as (5) ml/min, but the produced flow rate was only water.

From the diagram (2) is shown that how the applied electrical power (W) is increased with the increasing both of electrical force (V) and current (A).

*Table (1) is showing the AC Electrostimulation tests with electrical force and current power that affecting the flow rate and near wellbore damage. By increasing the electrical power flow rate is increased which is a sign for improving near wellbore damage.*

| AC Electrostimulation tests | Electric force in (V) | Electric Current in (A) | Electric power in (Wat) | Time in (min) | Flow Rate in (ml/min) |
|---|---|---|---|---|---|
| 1 | 5 | 0.9 | 4.5 | 20 | 0 |
| 2 | 30 | 2.6 | 78 | 20 | 0.5 |
| 3 | 60 | 5.5 | 330 | 20 | 3 |
| 4 | 80 | 8.7 | 696 | 20 | 5 |

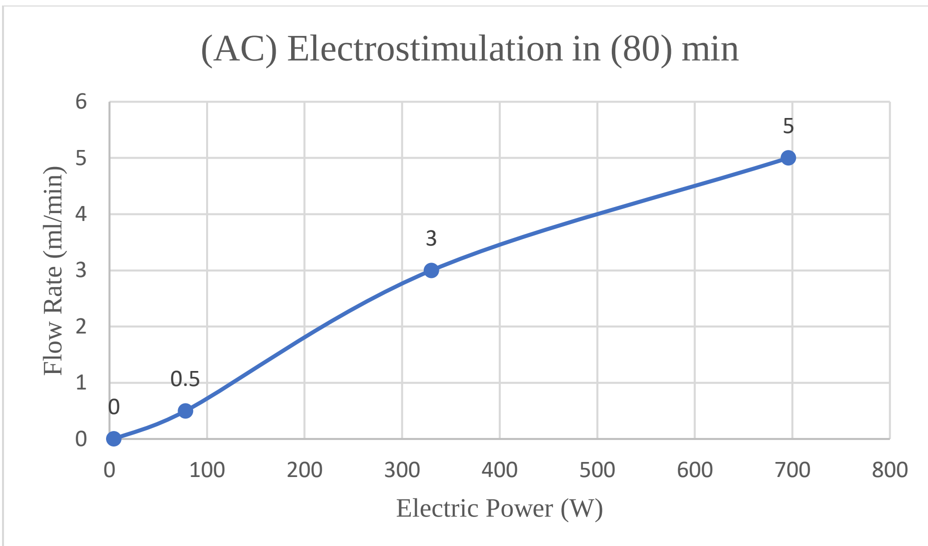



*Diagram (1) shows the flow rate of the EOR laboratory model is increased by increasing the Electrical Power (wat). Which the wat is multiplication between the number of volts and amperes. By applying (700) W the flow rate is increased for (5) ml/min.*

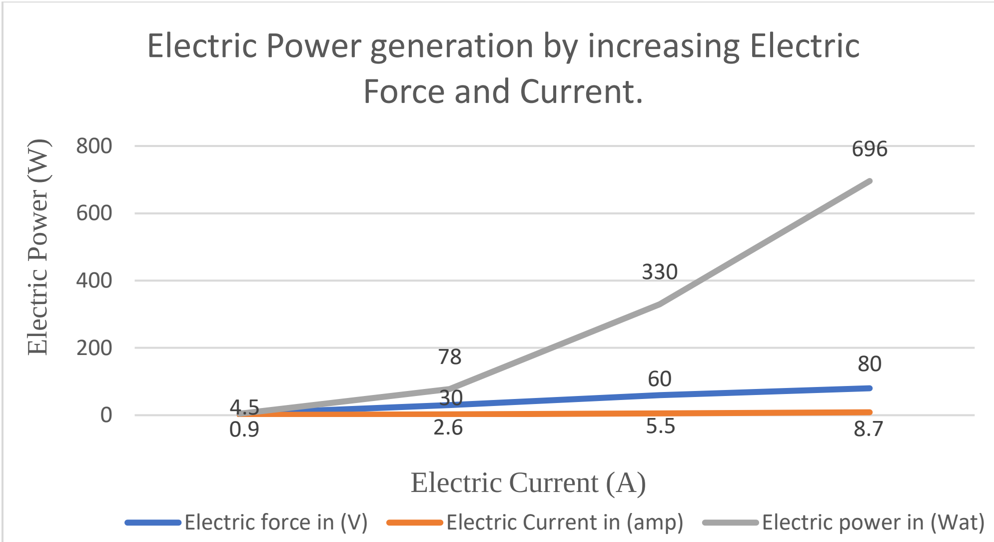



*Diagram (2) is showing the amount of electrical current, force and power in each test of the four tests. the electrical power and current are increased by increasing the electrical force. For instance, in the second test the amount of electrical force is (30) V, then by multimeter the electric current is measured as (2.6) A. by multiplying the electrical force with current the result is electrical power measured as (78) W.*

# 4 Discussions

## 4.1 Thin section samples:

The target of taking samples and creating thin sections with core plugs is to prove scientifically that, which kind of rock grains and soil rocks, are the most appropriate to be the reservoir layer for the model. Properties like porosity, grain size distribution, type of minerals, and type of rocks are observed and identified from the samples. Two of them are carbonate rocks. To make sure that these are carbonates, hydrochloric acid was used and dropped on them because it dissolves the carbonate rock (Mumallah, 1991).

Rock (A and D), as mentioned in the result section, are carbonates because they have sparite and micrite. In sample (A), the rock contains little matrix which is sparite. Also, the rock contains micrite, which rock has carbonate mud, by Folk. Also, Dunham is calling it pack-stone and grain-stone. In sample (C), the rock contains carbonate mud which is micrite.

Dunham is calling it mudstone or wackestone. Due to sparite and micrite, the rock sample or the rock layer gets heterogeneity (Kirstein et al., 2016).

The rock sample (D) is sandstone because minerals like Glauconite and quartz can be seen plus plagioclase acid. Glauconite appeared from the sample which is green in color in both XPL and PPL regimes, under a microscope (Amouric, 1985). Glauconite is common in sandstones. The porosity of the sample is low because calcite cement is everywhere & there are muddy matrices around quartz. The calcite cement and muddy matrices are decreasing permeability in some cases to zero (Xiong, Azmy, and Blamey, 2016). Sample (G) is sandstone as well because it contains minerals like Opaque, Glauconite with white mica + muscovite. The sample has low porosity and permeability, because of the cement porifera fossils (Al-Dabbas, Al-Jassim, and Al-Jumaily, 2009).

## 4.2 Circulation and improve near wellbore damage:

For the first test, to make permeable and impermeable parallel layers onto each other such as rock layers of the formation, the bottom face of the model is sealed by clay particles mixed with water, because the clay minerals are impermeable (Shikinaka et al., 2019). The medium grain sands are put into the model in the case of making 40% porosity because the average porosity of sand was observed toward being 37.7%, 42.3%, as well as 46.3% for compacted, natural (in situ), and loose packing environments, correspondingly, across a range of sorting coefficients and grain sizes, based on the analysis of published data (Curry et al., 2004). The design is chosen because the medium grain sand layer has high porosity and permeability same as high permeable scales in the reservoir layers. The model is created as a cubic shape by the glass to inside appearance especially fronts during injection operations. The perforated zone of the production well is set up inside the sand layer because, in the oil field, the production tube inside the drilled well is perforating at the reservoir level which has a high number of hydrocarbons with high permeability to make a flow path from the reservoir to the wellbore (McLeod, 1983). Then, the injection holes from the wells are set up into the sand layer. After that, the upper part is sealed by the clay particles mixed with water to cover the permeable sand layer with an impermeable layer and act as a cap rock, the same as an oil reservoir, which has a cap rock above. The cap rock is covering the reservoir and reservoir pressure is in its condition due to the non-permeable cap rock (Li et al., 2006). The flow rate of the pump is 18 L/min because the amount is possible for the size of the model. Also, the flow rate can be decreased and increased by the regulator. During the circulation, when the water is injected into the reservoir (sand layer), the water pushed the air inside the sand pores to the perforation zone of the production well. Then, to the surface through the well. After that, to the water tank through the hose. Bubbles in the water tank which connected with the production well by the hose, were a good sign because it proves that the circulation is closed and layers above even under the sand layer, are sealed. Having a closed circulation system is necessary to keep the pressure in a reservoir manner because if the pressure builds up inside the reservoir or is increased by injecting EOR methods, the only predicted way to get free to go out, is the production well. The injected water reached the perforated zone, the perforated holes were filled with sand particles. But scientifically this cannot be a challenge because the sand is permeable even if perforated holes fulfill with sand grains. So, the water didn't come out through the production well. With the accumulation of a high amount of water and pressure inside the reservoir model, the middle part of the sealed layer (clay) above the sand, cracked and leakage happened. The water came out through the cracks to the surface and the reason for the failure is the pressure affected the surface area of the reservoir and leakage happened. The scientific reason is the height of the production well, which is (1)m tall, and due to the following equation (Pressure = Force/Area), with a lower area, the pressure will be higher. But from the prepared model, the area of the reservoir surface is (2000) cm2 because the length is (100) cm, and the width is (20) cm. There was an unbalanced principle between the height of the production well and the surface area of the reservoir. The head of the production well was (70-75) cm higher than the level of the surface area of the reservoir. As the result, the pressure was not able to push the water from the reservoir to the surface through the (1)m tall production well. The injected pressure is increased, but the reservoir surface was more affected by the pressure, and it cracked. As the result, water leaked through the channels. Increasing the weight of the reservoir area can solve the problem but increasing too much weight, is a challenge because the model is made of glass. Otherwise, in the oil reservoir, cap rock or seal rock is behaving to avoid any challenges made by high pressure inside the reservoir (Li et al., 2006). But this is the lab model, new designs are required.

For the second test, the thickness of the sealed clay layer of the upper part is increased by more than (12) cm, due to increasing the thickness to be stronger for preventing water leakage. Then, wood is fitted to the model and placed above the clay layer on the surface area and four rock samples are placed above the wood to spread weight along the layer, equally. After that, circulation started, and the pressure of the pump increased more than in the first test. The pressure was higher than the intake water flow rate that's why the pressure of the reservoir model built up. The pressure affected the surface area of the reservoir and the glass model as well. Again, leakage happened between the phase layer and the glass because of the same issue as before which is the length of the well.

For the third test, the thickness of the permeable sand layer is increased due to making a more permeable reservoir layer, and the length of the production well is reduced from (100) cm to (30) cm due to solving the previous challenge. The head of the production well was (40) cm higher than the bottom of the model as shown in fig (11) because the bottom part of the (30) cm well was set up inside the sand layer and under it is the clay layer. Failure tests of the model gave knowledge that to have pressure effects on the water to produce through the production well, there are two options: One is reducing the height of the production well, or the second option is reducing the area of the reservoir to have a shorter surface because as mentioned before, there should be a balanced manner between the surface area of the layer and the length of the well. Otherwise, the pressure is more effective on the reservoir surface instead of pushing water through the tall production well, due to the following law: (Pressure = Force / Area). The first option has proceeded in which the length of the production well is shortened, and the small hole is drilled from the glass model at the same level as the head of the production well, to fit the hose from the production well to the outside of the model at the same height level. Also, the wooden compacted layer is fitted to the model and placed above the polycarbonate layer to make more support, and prevent leakage and cracking of the clay layer below. After that, four samples of the non-light rocks are placed above the wood layer, to make more weight on the formation layers. The circulation started, and the pump pushed the water to the model. The sand layer is saturated with the water and the first water drop has appeared from the production well. The produced flow rate was unpredicted low. The reason was the in-take flow rate from the pump to the model was low because the pressure from the pump was higher than the flow rate. The reservoir pressure was built-up and the glass model from the sides bulged that's why the liquid was able to migrate to the surface through the edges.

For the fourth test, the length of the production well is decreased more, as shown in fig (15), to have the pressure effects on the water level be raised and pushed to the surface through the production well, as explained in the third test. The coarse gravels are placed around both injection and production wells in the perforation zone to infiltrate more water. As shown in fig (14). Only polycarbonate (plastic) is placed along the surface area and between the thick permeable sand layer and the polycarbonate was a thin clay layer to make a uniform and good interlink between the polycarbonate face and the reservoir face. Four rock samples are placed above the polycarbonate, due to make weight on the model to avoid the effect of pressure upon the sealed polycarbonate. The water is injected, and the layer is saturated. When the water reached the production well, the pressure built up inside the reservoir model. The water is raised inside the production well but till a specific height. The pressure affected the glass model and the glass bulged again from the sides as shown in fig (29).

Because the previous medium grain sand layer was compacted too much, for test five, a new sand layer is used which has a variety of grain sizes as a real reservoir. The edges (spaces between the polycarbonate and the glass model) are sealed by the silicone due to act as a cap rock to prevent any leakages. Two long parallel irons are horizontally placed above the polycarbonate, and four rock samples are placed above the irons to distribute the weight along the whole of the surface, to avoid any failures by pressure build up inside. The water is injected slightly, and the pressure of the pump is not much increased. The water is raised inside the production well until a specific level. After that, the intake pressure increased to push the water to the surface through the production well. finally, the water leaked in the injection well area between the polycarbonate and the injection well.

For the sixth test, the new sand grains which were a mixture of various grain sizes are sieved to separate and get the grain size between (0.5-1) mm for the reservoir layer, because the sand grain sizes of the previous test were (0-1) mm, which the very fine rains were the cause to plug the permeability of the reservoir layer. The design of the model is reupdated by reducing the size of the production well too (8) cm and the production well is applied horizontally. The perforated holes from the production well are redesigned. The glass is drilled in the lower height to interlink the wellhead to the outside of the model as presented in fig (45). After that, a thick layer of clay is applied to the upper part of the formation to seal it. Then, rock samples are applied and placed above the clay layer to make the weight of the model to avoid any challenges by pressure build-up inside the reservoir. The saltwater is slightly injected into the reservoir model through the injection well. the sand layer is saturated, and the front is moved from the injects to the production well as can be seen in the picture. After that, the front reached the production well area, it infiltrated the gravel. Finally, water is produced through the production well. The produced flow rate is linked to the water tank by the hose and water circulation is successfully prepared for the EOR model. There were noted factors that became a reason for the successful circulation. The first factor was the grain size of the reservoir sand layer because the injected water was able to find channels and reach the production well with less intake pressure made by the pump, for the model. The second factor was the length of the production well because the water is produced by lower pressure applied by the pump. Otherwise, of the higher length of the production well, the pressure building up inside the reservoir was the cause of leakage by breaking the sealed clay layer in the upper part instead of pushing water to the surface through the production well. The third factor was the thickness of the sealed clay layer above the sand layer. 10 cm was the thickness of the clay which was enough to prevent leakage for that design. Otherwise, in previous designs in which the production well was taller, a higher amount of clay is applied to increase the thickness of the sealed layer, and polycarbonate with wood are added as well but still, water leaked, as explained in previous tests clearly. The fourth factor was the gravel which was applied to the perforated zone of the production well for more water infiltration. Fifths factor is the way of injecting the water through the pump. The flow rate and the pressure must be applied slightly high. Because in previous tests, the high amount of pressure was the reason for water leaking near the injection well. The accumulating of water with a high amount of pressure is the reason for water moving upward and affecting the upper sealed layer and breaking it. In the case of low intake flow rate and low pressure, the injected water or the front is going towards the production well inside the reservoir layer through the channels gently. After successful circulation, the sand layer is 100% saturated with water. In that test, the main channel or the main flow path is found which fluid goes through, from the injection well to the production. For that purpose, ink is injected as a tracer, to show the most permeable channel as shown in fig (32). At first, (50) g of blue ink is mixed with (20) L of water. After that, the pump is turned on, the ink is slightly injected into the reservoir model with low pressure and low intake flow rate to avoid pressure buildup and leakages near the injection well. The whole permeable channel appeared from the injection well to the production by the blue ink. The purpose of identifying the main flow path is a properly treatment with it and prepare the plans for Electrostimulation. The plan is, to apply the clay to the main flow path to decrease the permeability. After that, testing of Electrostimulation and showing how the electric improves damage increases permeability and its behavior in tertiary recovery.

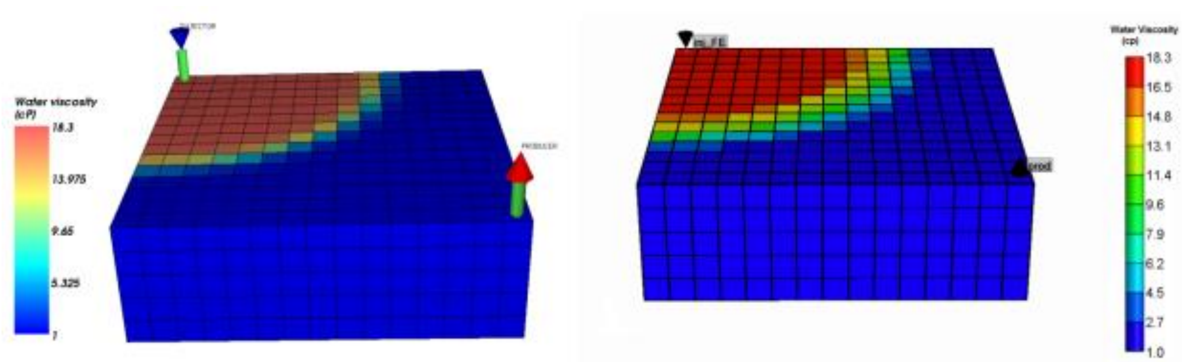
### 4.2.1 Electrostimulation by Direct Current:

From the project, the electrostimulation EOR has been researched to find out its behavior and effect on increasing oil recovery. For test seven, clay is added to the sand layer especially to the coarse gravels near the perforated zone of the production well for the same level where the ink (tracers) showed the highest permeability, in the sixth test, to decrease the permeability and make damage. The amount of added clay to the gravel near the wellbore was (50) g. After that, the electric supply is used to apply a direct current of electricity (DC). A wire is interlinked with the injection well and another with the production well. Both wells acted as electrodes to send direct currents from one to another. The electric power supply had a limited number of volts to send for the sand layer due to the resistance of the layer which is measured as (500) ohms. The resistance is decreased by adding more salt to the injected water. Then, the maximum number of volts and amperes became higher. Finally, the circulation is started. The out-take flow rate is measured manually (the out-take flow hose, which is interlinked with the production well, is taken out from the water tank; it is put into the bucket, and time is set up. After that, the regulator is set up stably to make constant pressure from the pump to the reservoir. The flow rate is measured again manually as (2) L/min, which was the same manner as before. Next, the number of volts is increased to (101.4) and amperes were (5.2) to be more effective on the clay, which is the cause of decreased permeability, in near production well. After (80) minutes of circulation, the flow rate increased. Finally, the reason for the increased flow rate is checked and evaluated. The cause of increasing the produced flow rate was not by improving near wellbore damage by direct currents. The reason was the constant pressure from the pump, which was able to rise the sealed clay layer for a few millimeters above the reservoir layer, this is the cause for decreasing weight on the sand grains and make the possible environment for injected water to improve proper permeability to migrate through it.

### 4.2.2 Electrostimulation by Alternating Current:

Saltwater is a good conductor of electricity (Cox, Culkin, and Riley, 1967). Also, to look after that how much the effect of seawater is in the process, for the test eight 20 litters of water are put into the water tank with 600g of NaCl to insert the brine with the salinity of seawater because the typical range of ocean salinity is (33–37) g/L (NWS JetStream – Sea Water, 2023). For test eight, the salt water is injected into the sandy reservoir layer in the EOR laboratory model to decrease the resistance of the layer between both electrodes and push the oil inside. The layer didn't 100% saturate with water because the water was not able to push the heavy oil and produce it through the production well. The water injection is stopped, and electrostimulation is started by applying AC to the model. It was not possible to test circulation and electrostimulation together at one time, because of two main reasons, first during water circulation, the electric current will transfer in the opposite direction which is from the electrodes to the water tank instead of the reservoir layer. Because the electric transfers in the easier way. The second reason is the trip of the circuit breakers in the laboratory which by primary tests on the AC electrostimulation, the circuit breakers got off by applying both circulation and the electrostimulation together. Otherwise, applying both tests together would be more required. At first, (5) V is applied from the auto transmitter to the model, for (20) min, to know the effect of the low electric force on the clay which damaged the permeability. After that, water circulation is started. Again, water was not able to produce the heavy oil and near the wellbore, the damage was not improved. Then, the circulation is stopped, and electrostimulation is started with approximately (30) V for (20) min. The current is measured by the multimeter, and the current was (2.6) amps for (30) V of electric force, as shown in fig (34). Next, the electrostimulation is stopped, and the circulation is started. The saltwater is injected into the model and after 5 minutes, noticed that liquid is produced in drops which is a sign of theta the (30) V of the electrical current can improve the damage made by clay. From the out-take flow rate, oil drops appeared with water. After that, the intake pressure is increased by the regulator and the out-take flow rate is changed from drops to thin liquid flow. Then, the circulation is stopped, and the electrostimulation is applied for (20) min with the force of (60) V and the electric current is measured by the multimeter as (5.5) amps as shown in fig (35). Then, the electrostimulation is stopped, and the circulation is started. The produced flow rate (water and oil) is increased and measured as (3) ml/min because the permeability is increased. The permeability could not be measured because the EOR lab model was not as advanced as necessary and the pressure gauge didn't set-up, up for both injection and production well. If the difference of the pressure between intake to out-take wells and the viscosity of the fluid are estimated or measured, then the permeability can be measured by the Darcy law ($Q = K\ A\ (\Delta P) / \mu\ L$). Finally, the circulation is stopped, and the electrostimulation is applied for another (20) min with the force of (80) V and the electric current is measured by the multimeter as (8.4 - 8.8) amps as shown in fig (36). Then, the electrostimulation is stopped, and the circulation is started. The produced flow rate is increased and measured approximately as (5) ml/min, which means the permeability is increased but the produced flow rate was only water, because of the water breakthrough. Water breaks through when the mobility ratio of the fluid is not favorable especially when the viscosity of the displaced fluid is lower than the viscosity of the displacing fluid, the injected fluid (displaced) goes through the displacing fluid (residual oil) and makes channels without sweeping the oil effectively.

From the methodology, a result of some parameters has been found and calculated. Such as flow rate, ampere, volt, watt, grain size particles, and membrane of salt water…etc. By preparing a more advanced model with measurements in the future, more parameters can be calculated, such as pressure, bubble point, the permeability of the reservoir rock layers, contact angle, skin effect, and oil viscosity…etc. By calculating such data, a software model can be used and run for the EOR model. if required data is installed to the CMG software for example, it can show the simulation and how the electric current with water is playing inside the reservoir and water move from the injection to the production well. An example of EOR by CMG and UTCHEM model is shown in fig (50).




a b

*Figure (50) the EOR model is running by different software, (a) is UTCHEM and (b) is CMG. Required data installed to software and the software shows the injected method from the injection well to the production well (Goudarzi, Delshad and Sepehrnoori, 2013).*

# 5 Conclusions:

The damaged permeability by clay is being improved and increased via electrical EOR. However, it depends on how it is used. The decreased permeability by clay was unaffected by the DC electrostimulation for the designed EOR model. In contrast, AC impacted and enhanced the clay-damaged permeability near the wellbore by strong electrical force, where the distance between the two electrodes was (80) cm. As the distance between the electrodes is reduced, the result could change as the short-range current alterations. The lab model as a reservoir, which is less complex than a natural reservoir, studies have been conducted using earth and rocks. More research is needed to determine the actual method of EEOR application for oil reservoirs.

In the laboratory model, the simulation is not a real reservoir, it is just a sample simulation of porous media where I decrease permeability to almost zero, by adding clay particles. This never happens in a real reservoir because the sand particles are cemented in the sandstone. Sand migration particles towards the production well was a challenge that improved by adding more weight to the reservoir.

My preliminary investigation of this thesis is how the electrical current would affect the permeability of the layer and decrease it.

It has been partly investigated and we had some positive results to make a real simulation and the sandstone would be used in the laboratory. It would be required more advanced equipment installation and a complete redesign of the setup for precise measurements. In the future we are planning to collaborate with the faculty of electrical engineering at the university of western Bohemia, to design such a setup. it would be required to invest several million CZK to design such an experiment. Only an electrical transformer would cost 1 million CZK.

It has been estimated that we need to run two years of experiments to get a computer simulation to investigate the potential of this technology. The plan would be to use firstly sandstone rock for the reservoir and later carbonate. The technology has the potential to the improvement of oil recovery, a decrease of water-cut and potentially cleaning of geothermal wells. I am planning to investigate this in my master's and Ph.D. degrees.

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