



## **Formation Damage Apparatus**

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# 1. Introduction

## 1.1. System Overview

The Core Flood System enables to perform (i) liquid permeability measurement, (ii) unsteady state 2-phase relative permeability, (iii) EOR processes such as water flooding, gas flooding and (iv) formation damage tests.

Tests can be conducted using reservoir or outcrop core material at specified temperatures and pressures. Confining pressure can be up to 690 bar or 10,000 psi maximum. Temperature can be up to 150 °C or 302 °F maximum. The pore pressure is measured at inlet and outlet ports of the core sample by using low pressure transducers. Pressure taps are used to monitor the pressure along the core thanks to pressure transducers. Likewise, the confining pressure is measured with an analogue gauge. All wetted components are of Stainless Steel 316L. The system includes oven, pumps, vacuum pump, mud pump, valves, core holder, accumulators, back pressure regulator, transducers and data logger which are mounted on specific chassis. Operation of the system is controlled through a computer. Data logger and some basic calculations are performed through the software in the computer. The software operates under the Microsoft Windows operating system for multitasking capability. This gives the user maximum versatility in performing tests. Each of the key components is discussed in later sections of this manual.



## 1.2. Injection Pump

Pump is capable of constant flow operation over wide pressure range. The pumps design incorporates motor driven pistons, pressure measurement to comply with most application requirements. Fluid delivery is

possible at constant rate or constant pressure. The pump has a flow rate range adjustable from 0.001 to 100 ml/min by increment of 0.001 ml. The maximum pressure rating is 690 bar or 10,000 psi. The pump is controlled from its own front panel.

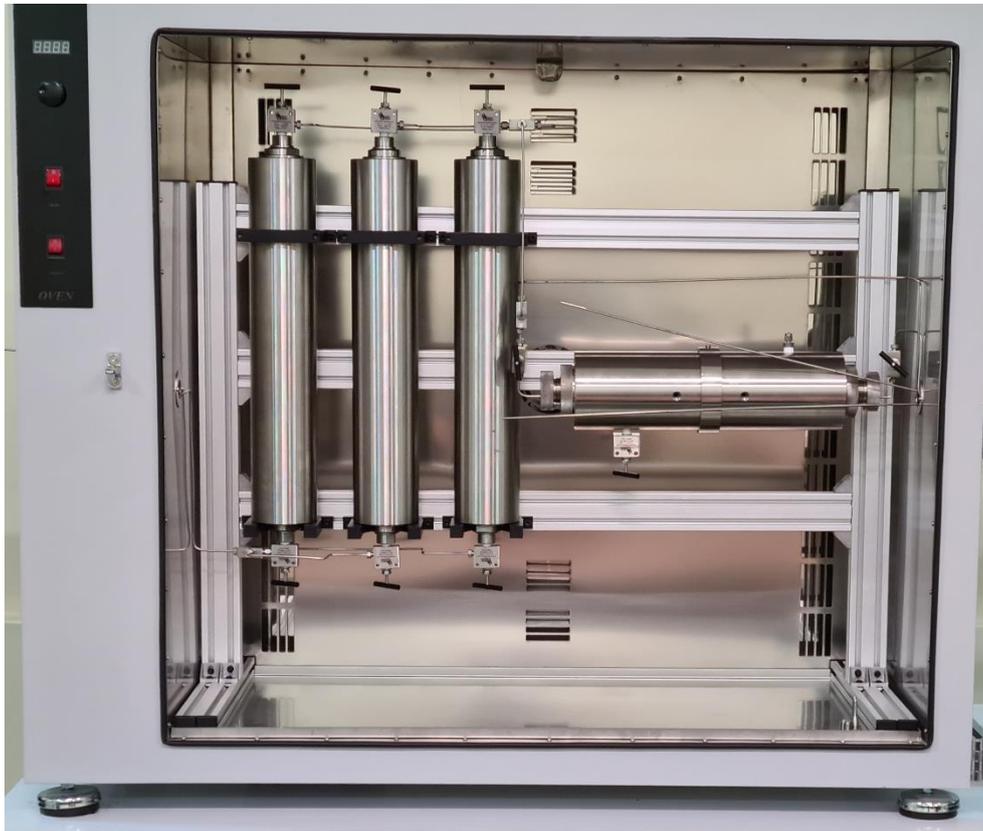


### 1.3. Mud Pump

The mud pump placed in the oven allows for mud fluid flowing across the face of the core sample. The pump includes a chamber with two gears rotating together. The chamber of the pump has a capacity of 100 ml. The pump automatically circulates the mud fluid in a closed-system (loop) comprising three valves and a 3/8 in tubing coil in order to increase the heated mud volume. The pump has a flow rate range adjustable from 100 to 6,000 ml/min. The maximum pressure rating is 400 bar or 5,801.5 psi.

### 1.4. Accumulators

The accumulators supplied as part of the system allow you to maintain the test fluids at reservoir condition during experiment. Accumulators are basically cylinders equipped with two end plugs and one floating piston, which separates the cylinder by a driving chamber and a test chamber. The driving chamber contains the driving fluids (deionized water or hydraulic oil) while the test chamber contains the test fluids. The standard capacity of the cylinders is 1 liter. Accumulators have a maximum rating of 690 bar or 10,000 psi and 150 °C or 302 °F.



### 1.5. Core Holder

The core holder is used for placing the core into it and perform the experiment. The core sample is held within a rubber sleeve by confining pressure. The confining pressure simulates reservoir overburden pressure. An inlet and outlet distributor plug allows fluids and gases to be injected through the core sample. All internal volumes are kept to a minimum so that accurate flow data can be determined. A unique feature of the core holder is that the core holder does not need to be completely disassembled to remove the core sample. Particularly, the sleeve remains in place when removing the core sample. By releasing the confining pressure and unscrewing the end plug, the core sample can be easily removed without exposing it to the confining fluid. This allows the core sample to be easily installed or removed. The core holder was designed to accept core length from 5 to 15 cm using the built-in adjustment and diameter of 38.1 mm (1.5 in). Core holders have a maximum rating of 690 bar or 10,000 psi. The temperature rating is 150 °C or 302 °F.



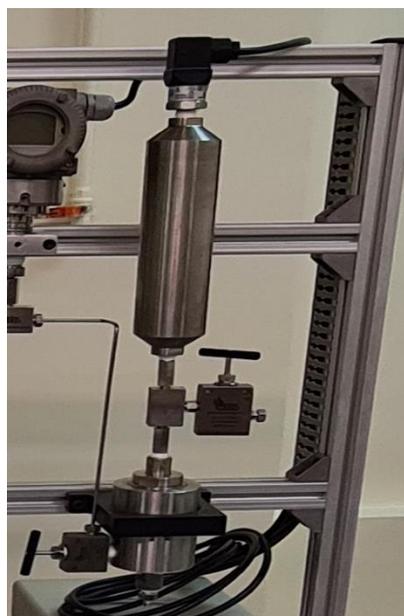
## 1.6. Heating System

The measurements can be conducted at representative reservoir temperatures using an oven (air bath), which heats the core holder, accumulators and core sample. Take care to not adjust it above 150 °C or 302 °F, the maximum rating of the core holder and the system.



## 1.7. Back Pressure Regulator

The BPR consists of two chambers separated by a piston with a needle connected to it on the lower side. The upper chamber receives the gas and water pressure and the lower chamber receives the process pressure. The BPR acts as a comparator. When the upper pressure is higher than the process pressure, the needle seals off the pressure and maintains the pressure. Inversely, when the process pressure exceeds the upper pressure, the needle opens up and the excess process fluid flows out. A hydraulic hand pump allows to control the upper pressure via a buffering cylinder. The BPR has a maximum rating of 690 bar or 10,000 psi.



## 1.8. Pressure Transducers

The pressure transducers supplied as part of the system are Rosemount pressure transducers. The standard full-scale range is 690 bar or 10,000 psi. As a standard configuration, one monitors the inlet pore pressure of the core, one monitors the outlet pore pressure of the core, and two monitors the pore pressures along the core.



## 1.9. Electrical Connections

Electric voltage required for all system is:

220-230 VAC, 50 Hz, 4.6 kW.

Power is distributed as follows:

The oven is 220-230 VAC, 50 Hz, 4.0 kW

The injection pump is 220-230 VAC, 50 Hz, 0.6 kW

The monitor(s), computer(s) and other accessories can be plugged on standard 220-230 VAC, 50 Hz sockets.

It is **highly** recommended to plug the all system into a surge suppressor (UPS).

## 2. System Capabilities

### 2.1. Overall System

Max. Conf. Press.	690 bar (10,000 psi)
Max. Pore Press.	690 bar (10,000 psi)
Temp. Range	room temperature to 150 °C (302 °F) maximum
Multiple Fluids	up to 3 different fluids
Wetted Material	316 Stainless Steel
Electrical	220-230 VAC, 50 Hz, 4,600 W

**Warning:** power should be disconnected before attempting to repair or work on any electrical components as electrical shock could occur.

## 2.2. Main Oven

Max. Temp.	150 °C (302 °F)
Resolution	1°C
Dimensions	100 cm W × 60 cm D × 90 cm H
Weight	approx. 100 kg
Electrical	220-230 VAC, 50 Hz, 4,000 W

The oven is used to heat the core holder and associated parts. With the oven, full access to the core holder and valves is provided. An air fan and heater is used to heat the system. A thermocouple and digital temperature controller are used to control oven temperature.

## 2.3. Injection pumps

Delivery Mode	Constant-Flow or Constant-Pressure
Max. Pressure	690 bar (10,000 psi)
Flow range	0.001 to 100 ml/min (increment by 0.001 ml)
Wetted Material	Stainless Steel 316
Dimension	54 cm W × 64 cm D × 180 cm H
Weight	200 kg
Electrical	220-230 VAC, 50 Hz, 600 W

The Injection System consists of two automatic pumps equipped with a fill/drain system. This is placed on a moveable trolley to provide easy access for maintenance. Use the constant flow mode of the pump to continuously inject the driving fluid through the accumulators.

Note that the pump is injecting deionized water through the accumulators. A supply reservoir is included in the pump.

The procedure used for filling and draining the driving fluid from the accumulators is discussed in the operating procedure section of this manual.

The basic control functions of the injection pump are operated manually (from the panel interface user).

## 2.4. Manual Pump

### 2.4.1. Pump for BPR

The BPR Pressurizing System consists of a hand pump equipped with a tank of inert gas. Note that the use of inert gas is **compulsory** in order to have a smooth and precise pressure regulation of the BPR. The best regulation is achieved with the use of water and gas. If the pressure of inert gas is not enough for the

experiment condition, use the hand pump to increase the pressure. The hand pump is bolted on the right side of the main oven's frame. The basic control functions of the pump are operated manually by using your hand to wheel the pump handle.

Max. Press. Rating	420 bar (6,100 psi)
Capacity	120 ml

## 2.5. Core Holder

The core holder is designed for easy assembly, disassembly, core sample installation and cleaning. The core lengths are fully adjustable per the specifications.

Core Diameter	38.1 mm (1.5 in)
Core Length	5 to 15 cm
Max. Confining P.	690 bar (10,000 psi)
Max. Temperature	150°C (302 °F)
Wetted Material	316 Stainless Steel
Sleeve Material	fluorocarbon rubber (Viton ®)
Overall Length	70 cm
Weight	40 kg

## 2.6. Accumulators

Max. Pressure	690 bar (10,000 psi)
Max. Temp.	150 °C (302 °F)
Wetted Material	Stainless Steel 316
Outer Diameter	98 mm
Inner Diameter	60 mm
Overall Length	650 mm
Weight	25 kg

## 2.7. Back Pressure Regulator

Wetted Material	Stainless Steel 316
Flowing Lines	1/8 in outer diameter
Pressure Rating	690 bar (10,000 psi)
Temp. Rating	150 °C (302 °F)
Dimension	7 cm OD x 14 cm H
Weight	4 kg

## 2.8. Instrumentation

### 2.8.1. Pressure Transducers

The pressure transducers supplied as part of the system are gauge-pressure transducers with an accuracy of +/- 0.075% of full scale. The maximum full-scale range is 690 bar at room temperature.

Pressure Range	-1 – 690 bar (-14.7 – 10,000 psi)
Accuracy	0.075 % of Full Scale
Electrical	24 VDC

## 2.9. Piping and Valves

### 2.9.1. Flow Lines

The system provides flow lines as normally required for the performance of the system.

Wetted Material	Stainless Steel 316,
Flowing Lines	1/8 in outer diameter
Fittings	BBS and VEE-LOK type
High Pressure Rating	10,000 psi for 1/8 in
Temp. Rating	150 °C (302 °F)

The high-pressure tubing utilized in the pore wetted portion of this system is manufactured from Stainless steel 316. The OD is 1/8 in (3.18 mm). The maximum pressure rating is 690 bar or 10,000 psi at 150 °C.

### 2.9.2. Hand Valves

The system provides hand valves as normally required for the performance of the system. These valves are manufactured by BBS. The wetted material of construction is Stainless steel 316. The maximum pressure rating is 690 bar at 150 °C.

Wetted Material	Stainless Steel 316
Flowing Lines	1/8 in outer diameter
Fittings	BBS and VEE-LOK
Pressure Rating	690 bar (10,000 psi)
Temp. Rating	150 °C (302 °F)

## 3. Installation

### 3.1. Utility and Floor Space Requirements

#### 3.1.1. Utility Requirements:

Oven	220-230 VAC, 50 Hz, 4000 W
Injection Pump (BSP500)	220-230 VAC, 50 Hz, 600 W

#### 3.1.2. Room Requirements:

Main Frame	400 cm W × 100 cm D × 200 cm H / 400 kg
Injection Pump	54 cm W × 64 cm D × 180 cm H / 200 kg
Suggested Floor Space	5.00 x 6.00 meters

### 3.2. Location of the Equipment

The core flooding setup should be placed in a low traffic area away from any frequently traveled doors that may allow inadvertent tampering with the apparatus during a test procedure. The equipment should be located in an area with sufficient power utilities.

There should be sufficient area around the equipment to allow the operator access to all sides of the instrument at any time without restriction (usually a 30 square meters' area will suffice for the instrument).

A sample and equipment preparation area with a tabletop should also be available in the immediate vicinity. This tabletop area will be utilized to load the sample into the core holder sleeve and also to clean components and tubing between test procedures.

The setup should be utilized in a clean and dry area that offers temperature control to within +/- 2 °C.

### 3.3. Installing the System Components

#### 3.3.1. Core Holder:

There is a frame installed on the core holder. In order to mount the core holder to its place, hold it firmly and pick it up and place it inside the oven. Then, reconnect the plumbing to the core holder. It is necessary to mention that tubing nuts should be tight smoothly. Over tightening of nuts leads to damage to the nuts and threads.

#### 3.3.2. Accumulators:

To install the accumulators into the oven, first pick them up and place them on the embedded plates. Then use the brackets to surround the transfer vessels and tight them to hold the accumulators firm in their plates. There are 3 frames embedded in the oven. Each of the accumulators can be placed to its own frame in the oven.

At the end, reconnect the plumbing to the transfer vessels. It is necessary to mention that tubing nuts should be tight smoothly. Over tightening of nuts leads to damage to the nuts and threads.

### 3.3.3. BPR:

Tight the BPR on its support located in the main oven and reconnect the plumbing. Be sure to tighten the tubing nuts snugly (do not over tighten).

## 3.4. Turning the System ON

The power cables for the oven and the pumps are separated from each other. The oven is powered by its own cable and requires a 220-230VAC, 4.0kW circuit. Do not connect these cables to electrical power until all parts of the system have been installed and checked for proper connections.

Make sure that all switches are set to OFF before plugging the cables into proper socket.

When the power is connected, simply flip the power switches ON to power the pressure transducers and other electrical instruments.

## 4. Preparation for a Test

### 4.1. Preparing the Core Sample

All core samples should be precision right cylinders with end faces parallel to within +/-0.2mm. The following descriptions should help you determine the best procedure to use.

### 4.2. System Preparation

**Warning:** the best procedure for removing and filling the system will result in the fewest fittings being removed each time. The reason for this is the system to remain completely leak free. The fewer times a fitting is removed and replaced, the longer the fitting will remain leak free. The procedure stated below offers a recommended procedure. However, there are several ways to accomplish the same end result. The end result is to have all pressure transducer tubing and downstream tubing up to the backpressure regulator completely liquid filled with no air cavities when connecting to the core sample.

The system must first be prepared. System preparation requires cleaning out existing fluid, washing and drying liquid saturated parts and reassembly. Inspect and replace all seals by new seals if needed.

If the pumps have already been filled with the correct liquid(s), then it may not be necessary to refill these systems before the start of a test.

#### 4.2.1. Rebuild the Core Holder

1. Inspect all O-Rings and replace it if the O-Rings are obviously worn, torn or are brittle. Replace all O-Rings that have been exposed to elevated temperatures (greater than 120°C) for more than 24 hours.
2. Inspect the sleeve and replace if it is obviously cracked and/or deformed. Install the sleeve inside the core holder.
3. Slide the sealing glands into the sleeve. Put the lever and the distributor into the sleeve and tight the cap such that the lever sits on the sealing gland.

4. Place the core sample into the sleeve, and make sure there is no gap between the core and distributor. Measure the remaining length in the sleeve. Then, choose appropriate number of spacers which is connected to another distributor to fill the free space in the sleeve and keep them tight in their place.
5. Screw the other cap to tight the core and other belongings in their place. Do not over tighten the cap that may cause damage to the thread.

#### 4.2.2. Rebuild the Accumulators

1. Clean the sealing plug stems, piston and the body with solvents and/or methanol and then blow air through it to remove any residual fluid and dirt.
2. Inspect all O-Rings and replace it if the O-Rings are obviously worn, torn or are brittle. Replace all O-Rings that have been exposed to elevated temperatures (greater than 120°C) for more than 24 hours.
3. Use vacuum grease on the O-Rings of piston, and then insert the piston into the body slightly.
4. Fill the end side with deionized water and close the end cap.
5. Fill the upper side with desired fluid. Close the upper cap and place the accumulators inside the oven on their places.

#### 4.2.3. Rebuild the BPR

1. Clean the sealing plug, the piston and the body with proper solvents then blow air through it to remove any residual fluid and dirt. Particularly, be sure that the inlet and outlet holes of the body are clean.
2. Inspect all O-Rings and replace it if the O-Rings are obviously worn, torn or are brittle. Replace all O-Rings that have been exposed to elevated temperatures (greater than 120°C) for more than 24 hours.
3. Use a needle-nose pliers to screw the needle to its place on the piston. Do not over tighten the needle.
3. Put the O-Ring on the piston and use vacuum grease and then mount the needle piston inside the body of BPR.
4. Insert the sealing plug into the body.
5. Put the BPR to its place on the oven and connect the plunging.

#### 4.2.4. Refill the Confining Pump

It is recommended to use deionized water to load the confining chamber of the core holder. Whenever the pump cylinder is empty, open the valve which is connected to the supply reservoir, and wheel the hand pump.

**Warning: IF A NEW LIQUID IS TO BE USED IN THE UPCOMING TEST, CLEAN THE PUMPS SUPPLY RESERVOIR, TUBING AND CYLINDERS FIRST!! It is extremely important that the pump reservoir is clean prior to filling them.**

#### 4.2.5. Clean all Upstream and Downstream Tubing

Flow solvents and/or methanol through all flow tubing and valves to clean any unwanted oil and/or brine from the tubing and valves then, dry it with air. It will also avoid any blockage in the piping than could occur with crude oil for example.

#### 4.2.6. Measure the dead volumes

For dead volumes measurement, the standard procedure is:

1. Flush the line to be measured with compressed air.
2. Connect the line to the injection pump.
3. Run the pump at low flow rate (less than 1 cc/min).
4. Stop the pump when the first drop is flowing out of the line.
5. Read the volume on the pump monitor.

## 5. Test Procedures

The operation of the system is briefly discussed below. Detailed procedures should be determined by the user depending on their specific needs and desires. If live or recombined fluids are to be used, special procedures must be followed after loading the core sample into the system. Special equipment is also required to charge the system with live fluids at the required pressures.

**Caution: THE OPERATOR SHOULD BECOME FAMILIAR WITH THE ENTIRE SYSTEM TO OPERATE THE EQUIPMENT SAFELY AND EFFECTIVELY.**

**High-pressure Caution: HANDLE PRESSURIZED COMPONENTS SAFELY AND CAREFULLY TO AVOID INJURY TO PERSONNEL AND TO AVOID DAMAGING EQUIPMENT.**

### 5.1. Are you ready for the upcoming test?

Use the following list to ensure all information and system parameters are ready for the upcoming test procedure.

1. Know the sample dimensions (will the sample fit in the core holder?).
2. Have at least 500cc (1 liter is recommended) of the liquid to flow through the sample during the test procedure.
3. Know the flowing liquid viscosity (cp) at ambient and test temperatures.
4. Know the flowing liquid density (g/cc) at ambient temperature.
5. Know the pore pressure (psi) required for the test procedure.
6. Know the desired flow rate (cc/min) to use during the test procedure.
7. Sample Pore Volume (cc).
8. Sample Bulk Volume (cc).
9. Know the liquid content (cc or % pore space) in the sample pore space.
10. Initial flowing liquid saturation (%) of pore space.
11. If two liquids are present, know the initial liquid saturation (%) of pore space.
12. Saturated weight of sample (g).
13. Ensure that the confining pressure supply reservoir is full.
14. Ensure that the injection pumps supply reservoir is full.

15. Ensure that there is enough gas pressure for the BPR.
16. Ensure that all upstream and downstream flow lines are clean and dry.
17. Ensure that the BPR has been rebuilt and is ready for service.
18. Ensure that the accumulators are cleaned and filled with the correct liquid (if used).
19. Ensure the core holder is cleaned, rebuilt and ready to perform a test.
20. Ensure that all pressure transducers are zeroed and calibrated.
21. Store the core sample under the last fluid flowed through the sample until it is ready to load into the confining sleeve.

## 5.2. System Preparation

Use the following list to ensure all information and system parameters are ready for the upcoming test procedure.

### 5.2.1. Load the Core Sample

1. First, disconnect all tubing connections from the core holder if any. You may slowly pull the core holder and its support to have easy access to the core holder.
2. Measure the sample weight before loading and record the value. Be sure to wipe excess liquid off the surface of the sample without wiping liquid out of the pores on the surface of the rock before weighing it.  
**Note:** normally a core sample is pre-prepared in a separate system before it is loaded into the core holder.
3. Remove the caps from the body by unscrewing them, and pull the lever and attached spacers from the core holder. Then, push the rod along with the core sample in the sleeve to recover the core sample.
4. For inserting the core sample into the core holder follow the procedure discussed before.
5. Push the core holder support back to its original position and reconnect all plumbing to the core holder.  
**Warning:** avoid any gap between the core and the end piece. The gap could occur if the floating end piece is not pushed in all the way or if the core sample has not square end faces. Upon pressurizing, a gap will cause the sleeve to extrude and rupture.
6. Connect the confining pressure tubing to the confining port.
7. The sample is now loaded into the core holder body and locked in place.

### 5.2.2. Apply Confining Pressure

1. Check the liquid level in the pump reservoir. Add additional liquid as required to fill it. Check the connections to the core holder to make sure that all connections are tight. Only pressurize the core holder if a core sample is properly installed.
2. Remove the plug located on the top of the core holder. This will allow the air to be purged from the core holder.
3. Run the confining pump until some hydraulic fluid flows out of the core holder.
4. Put back the plug located on the top of the core holder and tight it correctly. Wheel the pump to pressurize to 500-800 psi at first.

5. If the pressure needs to be decreased, open slowly the valve connected to the supply reservoir or turn the hand wheel backward. The hydraulic fluid will go back in the hand pump reservoir and the pressure will decrease.

6. If the pressure needs to be increased, close the vent valve, open the isolation valve and wheel the hand pump.

**Warning:** if core holder temperature is increased during or after setting the confining pressure, the core holder confining pressure will increase, due to thermal expansion of the fluid. You must carefully monitor this pressure as the core holder heats. Be sure that the pump is not full to ensure pressure regulation.

### 5.2.3. Fill the Accumulators

You may fill the accumulators by removing the top end closer and pour directly the fluid (brine or other fluids with no pressure) into it. As discussed before the lower side of the piston is filled with deionized water. After pouring the fluid into the accumulator, open the valve on the cap and easily place the top cap and tight it. Once you are tightening the cap the excess fluid will be removed from the valve.

If you want to fill the accumulators with live oil or a gas, use the following procedure:

1. Connect the lower valve to the automatic pump.
2. Use the pump to move the piston to its higher possible position inside the accumulator and pressurize the lower chamber to desired pressure 100 psi less than the live oil or gas.
3. Set the automatic pump in constant pressure mode while you are injecting live oil or the gas into the upper chamber.
4. Connect the cell containing live oil or the gas cylinder to the higher cap.
5. Start to inject the live oil or the gas with constant rate to fill the upper chamber.

### 5.2.4. Saturate the Tubing and Accumulators

Accumulators must be filled with process fluids (see above).

1. Open the refilling valve of the accumulators and run the injection pump to purge the process chamber of the accumulators. It is recommended to purge the accumulators one by one. Inject 50 ml minimum into each accumulator.

2. Purge the tubing all the way between accumulators and the core holder inlet(s).

**Warning:** the core sample must be loaded into the core holder and the initial confining of at least 500 psi must be placed on the core holder prior to vacuum filling any tubing that connects to the core sample pore system.

**Warning:** always purge the process chambers of the accumulators by running the injection pump. If the accumulators are not correctly purged, you may inject air into the system.

### 5.2.5. Raising the Temperature

Upon filling the system and fixing any leaks, the operator should close the oven door. Upon doing so the follow steps should be followed:

1. Make certain the power is connected, and turn the oven ON with the power switch.
2. Set the temperature to the temperature to be used in the upcoming test. The temperature controller may display the actual temperature or the set point. To confirm and set the temperature, press button.
3. Allow the temperature in the oven to rise to the set condition.

**Warning:** during temperature increasing, continuously monitoring the confining pressure and pore pressure of the system, even if pressures are automatically controlled. If the confining pressure ever becomes less than the pore pressure, the core end piece could be expelled from the core sleeve and the confining fluid could contaminate the core sample. This would require starting the test over again with another sample.

4. Allow the temperature in the core holder to rise to the preset oven temperature (within 2 degrees). This may take a few hours.

5. When the core holder temperature is stable, wait an additional hour or more before going to the next step.

**Note:** as the oven heats up, the liquid and gas in the system will expand. This expanded volume in the pore system will exit from the BPR at the set point pressure. This is normal but inspect for leaks frequently!!

**Remember:** the temperature stability will always take a few hours, depending on the temperature set point. Even if pressures are automatically controlled, it is highly recommended to watch the system during temperature increasing or decreasing. Never start raising the temperature when leaving the system without watching.

**DO NOT FORGET: TEMPERATURE IS STABLE ONLY WHEN THE PRESSURE IS STABLE.**

#### 5.2.6. Pressurize the Pore Circuitry

The injection pump will be used to create pressure in the pore system. Determine what liquid is the flowing liquid in the core sample and use the pump and accumulator system with that fluid in it. Open the appropriate valves to connect the correct flow system to the core sample.

The following procedure is described assuming the core sample is 100% saturated with brine:

1. Upon raising the confining pressure on the core sample to 500-800 psi, insuring that there are no leaks, vacuum filling and connecting the flow tubing, effluent tubing and pressure ports to the core holder the pore system can be pressurized.
2. Nitrogen cylinder being connected, pressurize the BPR by opening slowly its valve. If higher pressure is required, stroke the hand pump until the desired pressure is reached.
3. Pressurize the system pressure and overburden pressure step by step (each step increases the pressure 100 psi) to reach the desired pressure. Overburden pressure is always 500-800 psi higher than system pressure.
4. If the pressure needs to be decreased, open the vent valve, open slowly the isolation valve. The oil will go back in the hand pump reservoir and the pressure will decrease.
5. Check for leaks in the system and fix any found. Upon fixing all leaks the system is ready to apply heat.

**Warning:** it is imperative that the confining pressure is always maintained 500-800 psi above the pore pressure. Failure to do this could result in failure and core sample contamination.

### 5.3. Performing a Test

#### 5.3.1. Typical porosity measurement:

There are several ways to measure the porosity. One of the best and most accurate ways is as below:

1. Weigh the dry core sample.
2. Insert the core sample into a transfer vessel, then close the cap of the transfer vessel.
3. Connect the vacuum pump to the transfer vessel. Then give the system 2 hour for complete air removal.
4. Connect the transfer vessel to the brine supply. By opening the valve between them, the brine will fill the transfer vessel and pore volume.
5. Open the transfer vessel lid and pour some brine into it such that the transfer vessel is fully filled.
6. Close the lid again and connect the other side of the transfer vessel to the pump and give the system 2000 psi for 12 hours to ensure that porous medium of the core is fully filled with brine.
7. Remove the core and weigh it.
8. The difference between dry and wet weight is the brine weight inside the pores.
9. Use the equation below to calculate the porosity.

$$\phi = \frac{m}{\frac{\pi \rho D^2 h}{4}}$$

Where, m is the weight of brine in the core,  $\rho$  is the density of brine, D is the core diameter and h is the core length.

#### 5.3.2. Typical Water Permeability Procedure

This procedure assumes that the sample has been saturated with brine outside of the system before the core sample is loaded into the system.

1. Use the pump to inject the brine into the core holder.
2. Set several Flow rates based on the following equation.

$$\frac{\mu q L}{A \phi} \geq 1$$

Where;  $\mu$  is viscosity based on cp, q is flow rate in cc/min, L is length of the core in cm, A is cross sectional of core sample in  $\text{cm}^2$ , and  $\phi$  is porosity.

3. Calculate the differential pressure along the core at different flow rates.

**Note that: wait until the pressure along the core is stabilized and record it, then change the flow rate to another one.**

4. Plot the q vs.  $\Delta P$  and obtain the slope.
5. Calculate the permeability with the following equation.

$$K = \frac{\text{Slope} \times \mu L}{4.083 A}$$

Where;  $\mu$  is the viscosity in cp,  $L$  is the core length in cm,  $A$  is the cross sectional of the core in  $\text{cm}^2$  and  $K$  is permeability in darcy.

### 5.3.3. Typical Oil Flood Procedure

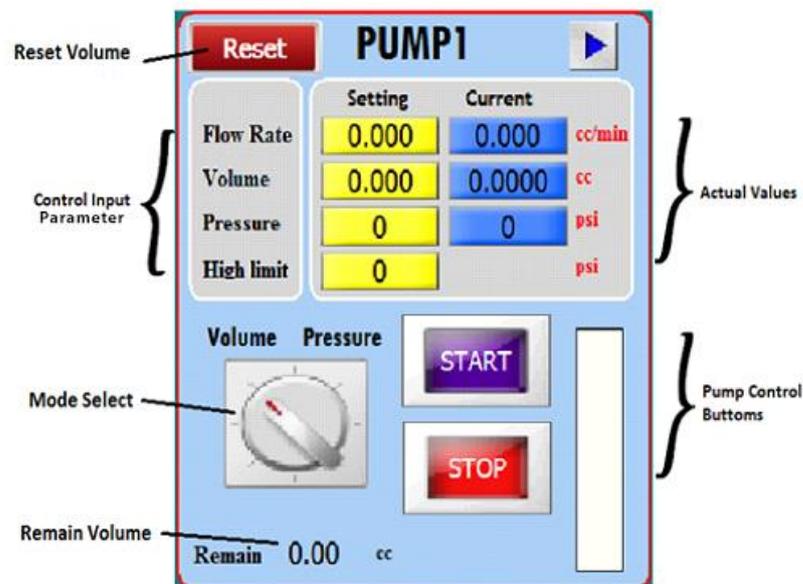
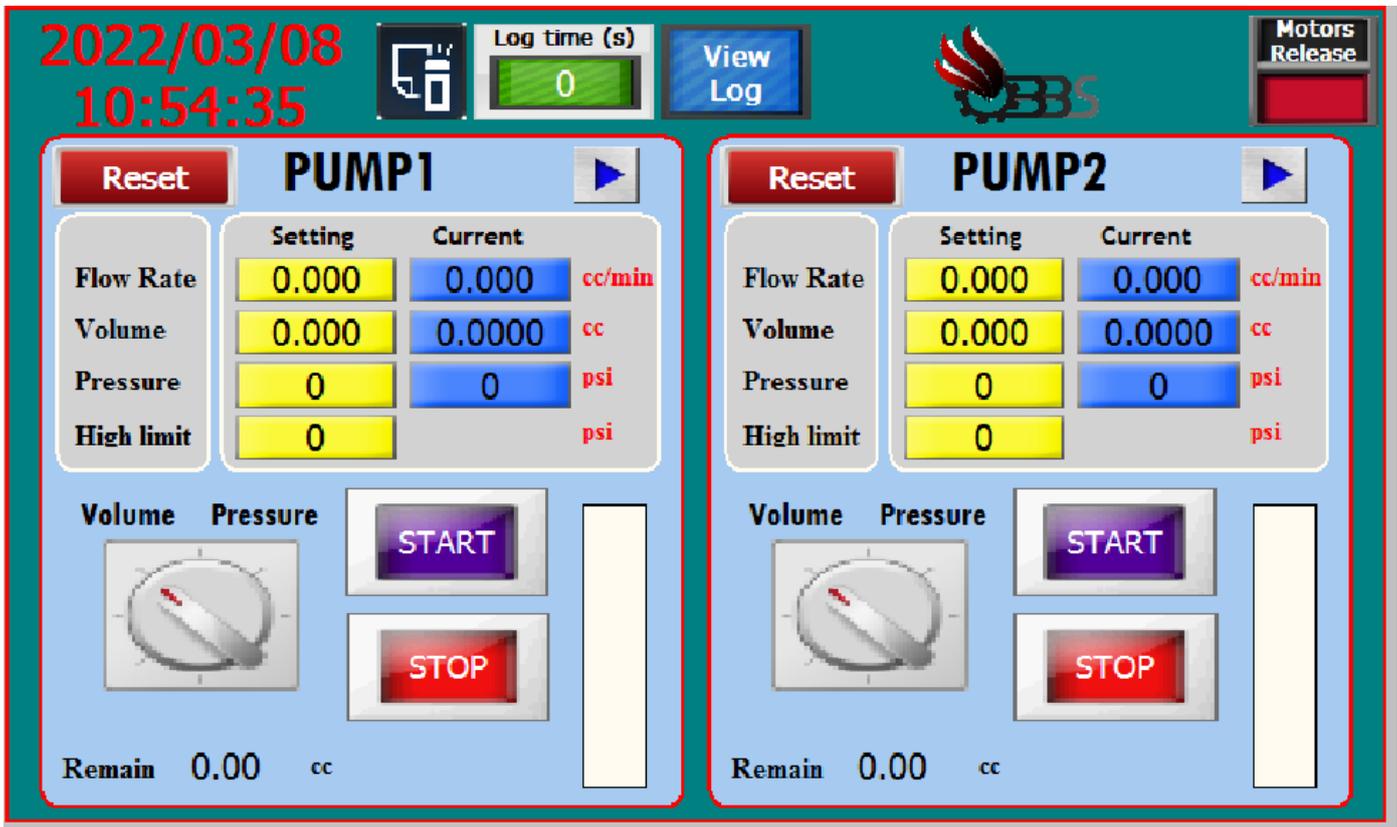
Set the **Flow rate** based on the data measured during the brine permeability determination. The final oil permeability measured at residual brine saturation will help determine the rate to perform the water flood. After the oil flood procedure has ended, it is standard procedure to flow enough oil through the core to determine the oil permeability. The basic things to remember are to choose an appropriate flow rate based on the rock and fluid properties. Set the other parameters based on the general information in the previous section.

**Warning:** it is important to remember to isolate the crude oil accumulator if live crude oil is used. Closing the accumulator valves promptly after the test will help ensure that the live oil pressure will remain above the bubble point of the oil enabling the remaining volume of oil to be used in any forthcoming tests.

### 5.4. How to work with pumps:

1. Before any tests, fill the supply reservoir with deionized water.
2. For turning ON/OFF the pump, easily flip the switch on the pump's box and make sure that emergency button is inactive.
3. Before any injections, air removal should be performed. To do this, close the valve to supply reservoir, and pressurize the pump to 1000 psi. Then, slowly open the valve to supply reservoir to let the compressed air leaves the pump's cylinder. Do this procedure several times to ensure there is no more air in the pump's cylinder.
4. To fill the cylinder with deionized water, close the valve that is connected to the coreflooding system and open the valve connected to the supply reservoir. Choose the volume mode and enter a negative number in volume section in order to make the suction mode active and run the pumps.
5. The pumps can inject the hydraulic fluid in constant rate and constant pressure mode.
6. To inject deionized water to any system, open the valve that is connected to the coreflooding system and close the valve connected to the supply reservoir. Then, enter a positive number in the volume section in order to make the injection mode active and run the pump.

The below screenshot shows the interface of the user panel. To do the suction or injection, enter a negative/positive number in volume section. Values should be entered in the yellow boxes, and run the pumps. You can give a limit to the volume of suction/injection by entering a number in the setting volume. High limit shows the pressure you cannot exceed more than that, and the number of this box can be changed by the user. To reset the value of blue boxes to zero, press and hold the reset button for a few seconds. For log data to the internal memory input log period time in second and press Logging bottom. Data logged in internal memory and user can see and move data by pressing view bottom.



When using the pumps pay attention to following warnings and notes.

1. Do not touch the advanced electronic instruments and high precision gear box at any conditions at all.
2. Make sure that the room is equipped with appropriate air conditioner to provide a dry air in the laboratory.
3. Be careful not to pour any fluids on the electronically instruments.

4. Your electrical plug should be equipped with appropriate earth connection to avoid any electrical shocks and measurement error.
5. Whenever you saw the stop alarm appeared on the screen, there should be a problem with the system. First check emergency button to ensure it is inactive. Otherwise stop the working with the pumps and check the whole system for failures.