DOSFIAC 2017

Shahid Bahonar University of Kerman

Effect of ultrasonic waves on improved oil recovery and asphaltene precipitation and deposition: an experimental visual study

Ali Mohebbi

Professor of Chemical Engineering

5th Digital Oilfield Summit Forum & International Academic Conference

Qingdao, 15-18 October, 2017

In the Name of God

Outline

Overview

Materials & Methods

Results & Discussion

Conclusions & suggestions

Introduction

- Primary recovery
  - Natural flow
  - Secondary recovery
    - Water flooding
    - Tertiary recovery
      - Thermal methods
      - Non thermal methods
        - Chemical
        - Miscible & Immiscible gas injection
      - Electrical EOR
        - Ultrasonic waves
        - Microwaves EOR
    - Hydrocarbon gases injection
  - Artificial lift

- The idea use of seismic waves for oil recovery back to 1950.
- When increased oil production was observed due to earthquake.
- Work and research on ultrasonic waves in the late 18th century and early 19th century was carried out.
- The peak of activity returns to the 1970 and 1980 in the United States and the Soviet Union.
- China is the third country, following the United States and Russia has made a great progress in this technique.

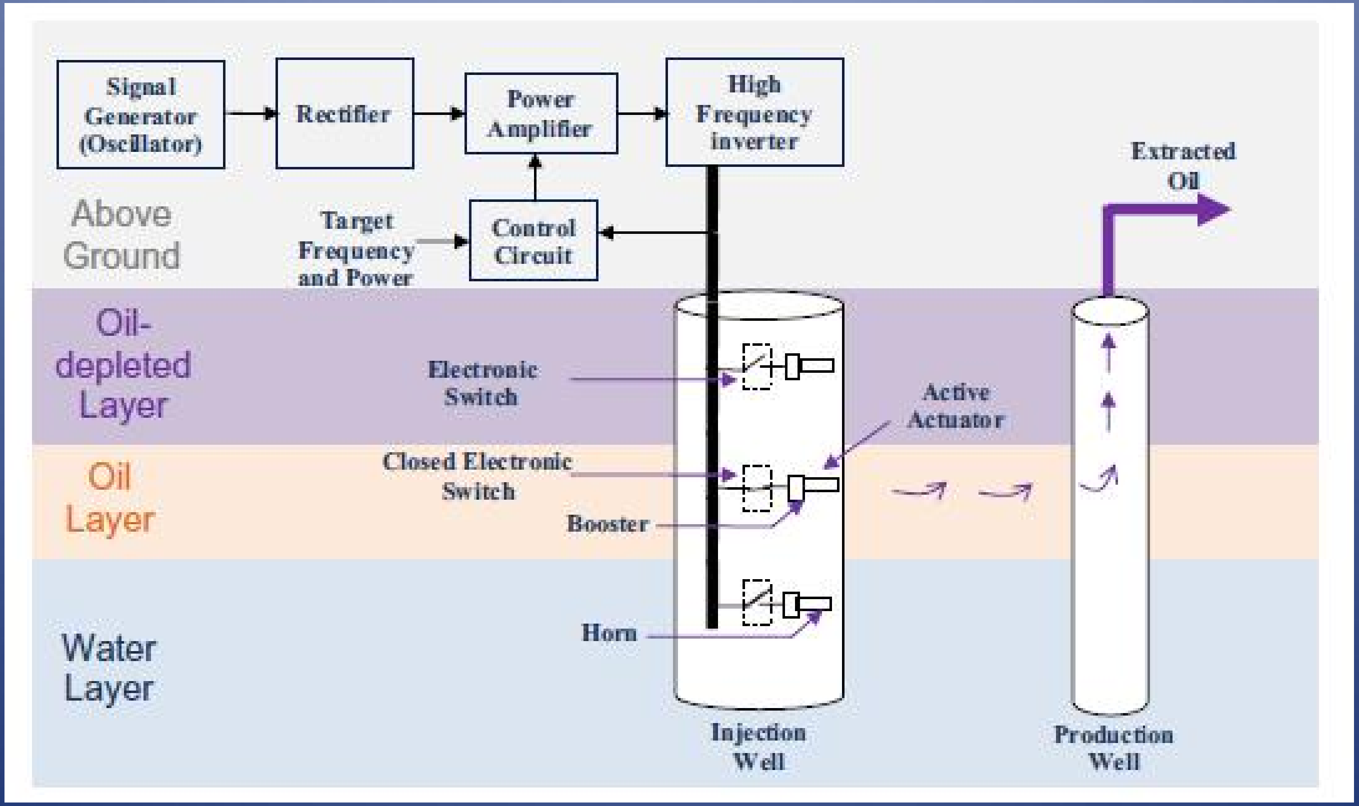
- Sound waves ⟶ Mechanical waves

➢ Frequency lower than 20Hz ⟶ Infrasound

➢ Between 20 Hz to 20 kHz ⟶ Sound

➢ Upper than 20 kHz ⟶ Ultrasound

- Ultrasonic-based EOR model (field scale):



- Advantages of ultrasound to the conventional oil recovery methods:
  - There is no need for chemical stimulation
  - It can be used while the initial recovery is in progress
  - It can be employed to remove the filter cake
  - Suitable for reservoirs with high water saturation or depleted reservoirs (residual oil saturation)
  - Suitable for the reservoir having heavy oil lying behind water

- Limitations:
  - Ultrasonic applications are limited to the near wellbore area due to the high attenuation through rock or fluids
  - According to Biot's theory, the attenuation length of utrasound at 20 kHz ranges from 2 to 10 cm.
  - Most research in recent years has shifted to low energy, low frequency waves
  - Dispersion of low frequency waves within porous media forms high frequency harmonics (ultrasonic noise)
  - Size of ultrasonic vibrator is limited by the diameter of injection well
  - Not suitable for unconsolidated formations with compressive strength of less than 150 psi
  - Not suitable with a slurry mixture of sand and water

- Mechanisms of ultrasonics waves:
  - Peristaltic transport due to mechanical deformation of the pore walls
  - Reduction of capillary forces due to the destruction of surface films
  - Coalescence of oil drops due to the Bjerknes forces
  - Excitation of capillary trapped oil drops
  - Forces generated by cavitating bubbles
  - Increase in relative permeability of phases
  - Reduction of surface tension, density and viscosity as a consequence of heating by ultrasonic radiation
  - Increase in rock permeability and porosity due to deformation of pores

- The experiments were conducted:

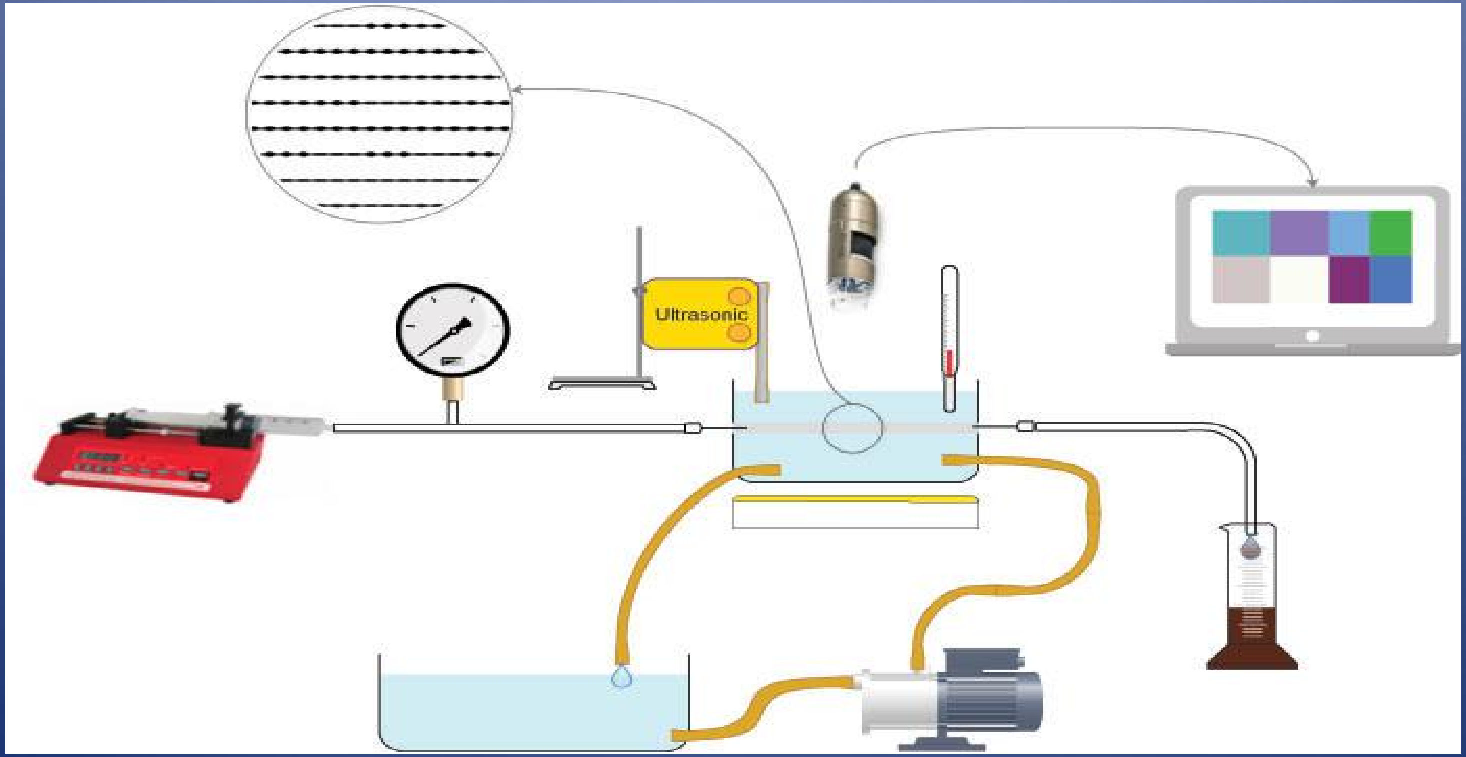
  - Fingering phenomenon
  - Removing asphaltene deposition
  - Oil recovery

Materials & Methods

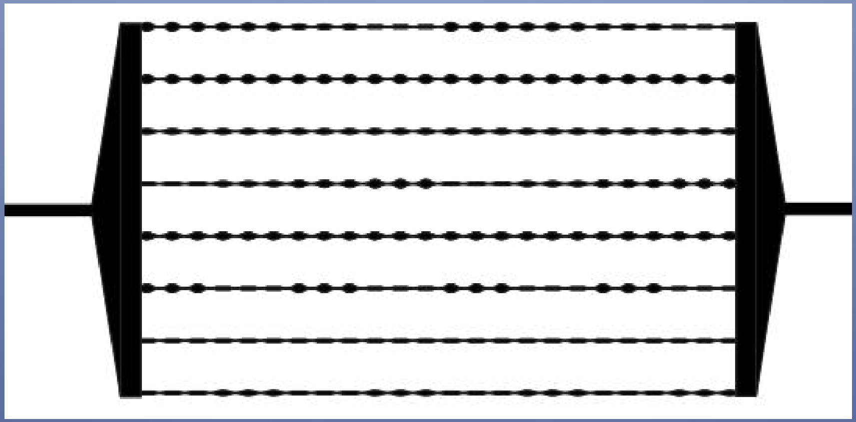
- Physical properties of the crude oil at lab conditions:

Temprature: 30 ˚C	Oil #1	Oil #2
Density (gr/mL)	0.90	0.87
Viscosity (c.p.)	88.22	9.57
IFT with distilled water (mN/m)	31.85	26

- Experimental set-up:

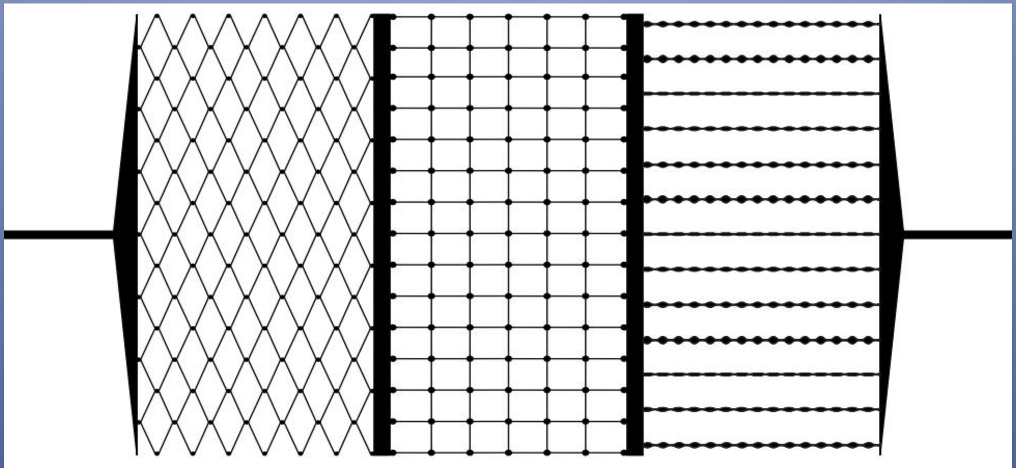


Micro-model:



Porosity (%)	Permeability (D)	Average diameter of pores (mm)	Depth of pores (mm)
18.48	0.327	0.3	0.06

Micro-model:



Pattern No.	Porosity (%)	Average diameter of pores (mm)	Depth of pores (mm)
1	8.65	0.2	0.08
2	8.37	0.2	0.08
3	11.64	0.3	0.08

- Experiment of fingering phenomenon:
  - Hele-Shaw model

    These experiments were conducted with oils #1 and 2
  - Procedure:
    1. Hele-shaw model was saturated with distilled water
    2. Injecting oil
    3. Flooding by distilled water

- Experiment on removing asphaltene deposition:

Oil that we used in these experiments:

✓ Oil #1 (a sample from one of the Iranian oil fields)

✓ Synthetic oil (contains toluene, n-heptane and asphaltene from the crude oil)

Composition of connate water:

	gr/100 cc
NaCl	10.512
$MgCl_2$	0.286
$CaCl_2$	4.209
TDS (ppm)	150064

Brine flooding was used with a solution of 100000 ppm $MgCl_2$

- Experiment on removing asphaltene deposition:

➢ Procedure:

1. Micro-model was saturated with formation water
2. Injecting oil
3. Flooding by n-pentane to precipitate asphaltene
4. Flooding by $MgCl_2$ solution under ultrasonic vawes

- Experiments on oil recovery:
  - These experiments were conducted in two different micro-models.
  - Experiments were carried out with oils #1 and #2
  - Procedure:
    1. Micro-model was saturated with distilled water
    2. Injecting oil
    3. Flooding by coloured water under ultrasonic waves

- Fingering phenomenon (Oil #1):
  - Flow rate = 10 mL/hr

Results & Discussion

The fluid movement in all pictures is from left to right.

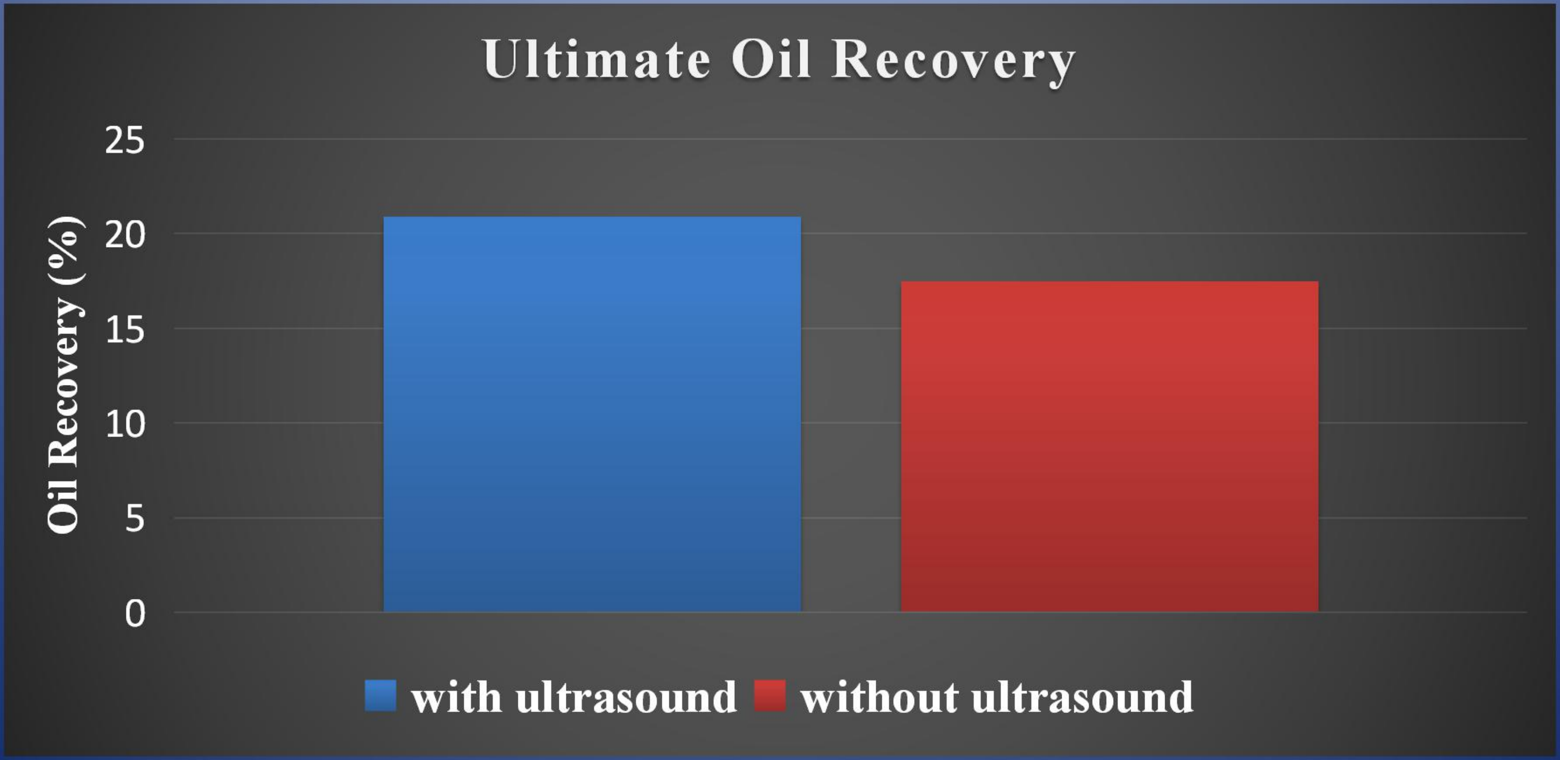
Time					100 s

Without ultrasound

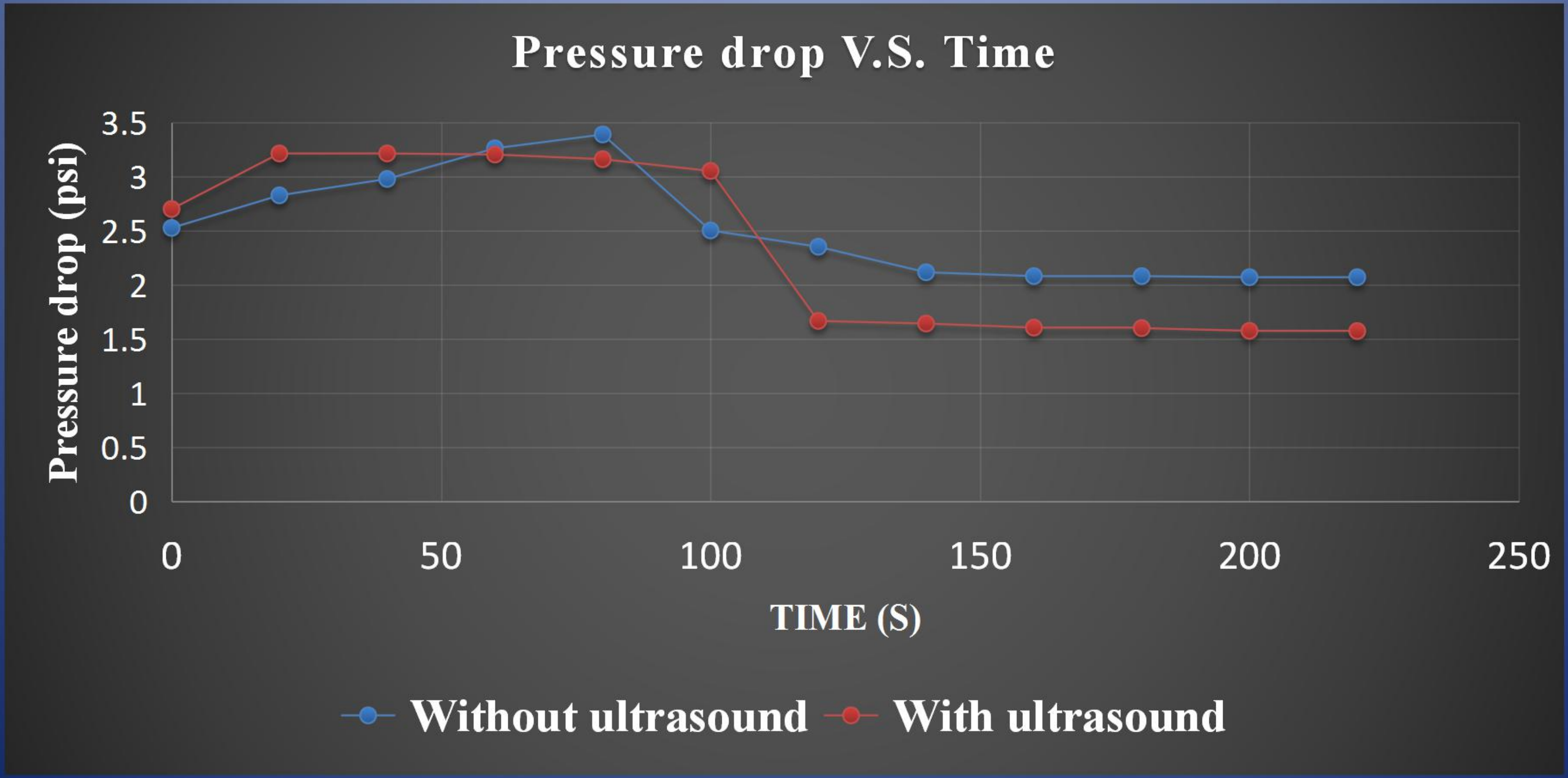
Time	20 s	40 s	60 s	80 s	100 s

With ultrasound

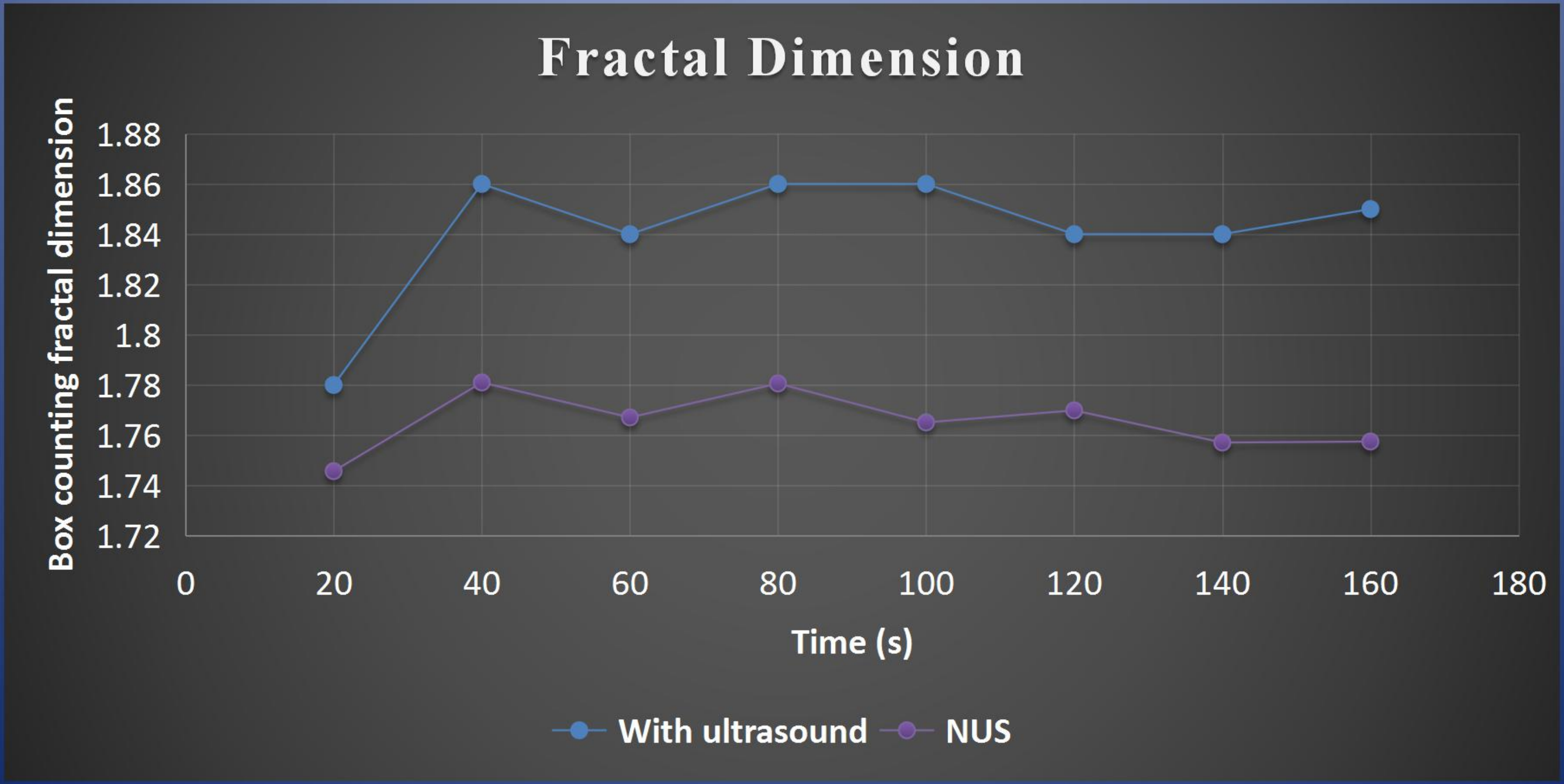
- Fingering phenomenon (Oil #1):



- Fingering phenomenon (Oil #1):



- Fingering phenomenon (Oil #1):



- Fingering phenomenon (Oil #2):
  - Flow rate= 10 mL/hr.

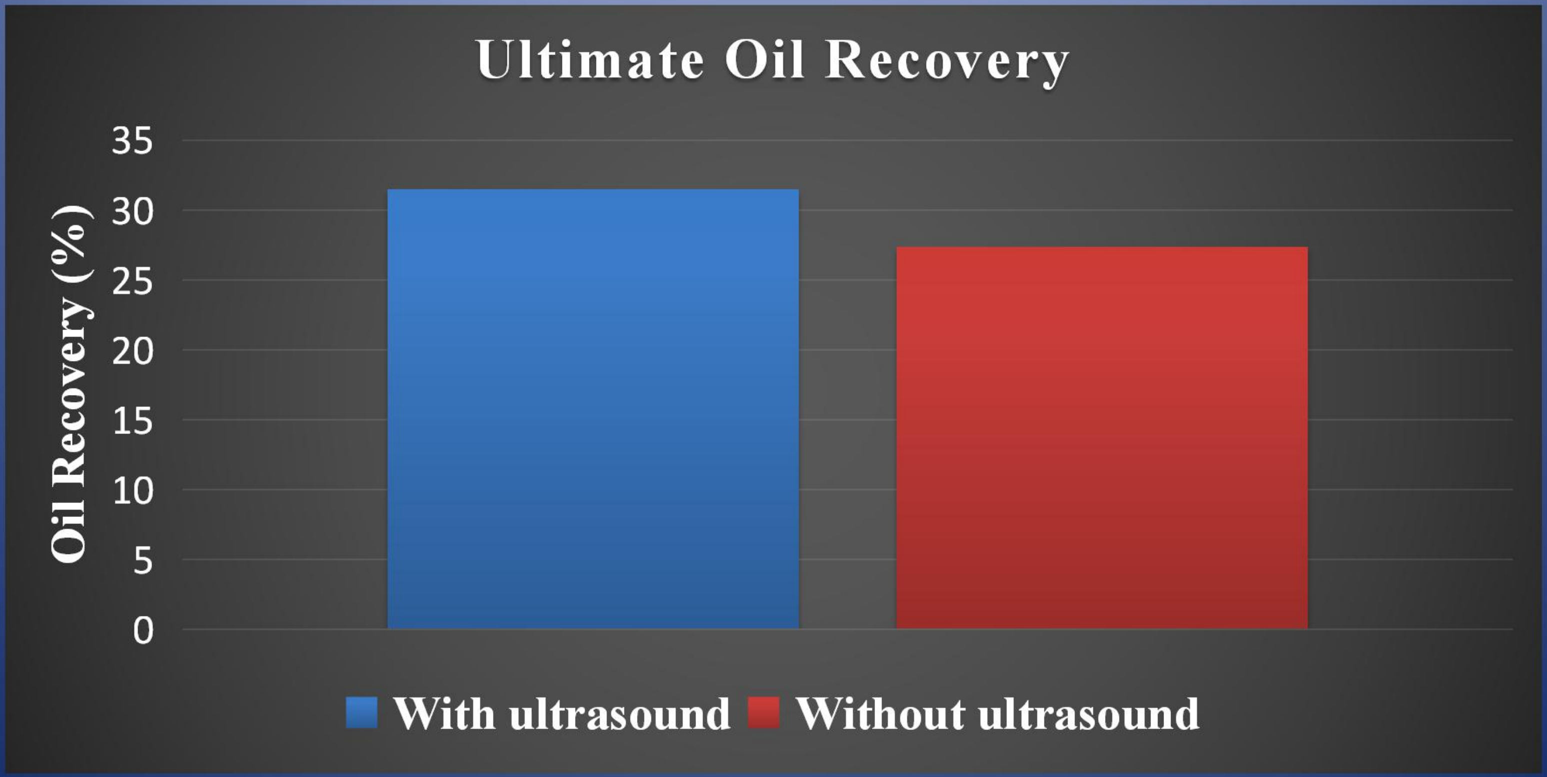
Time	30 s	60 s	90 s	120 s	150 s

Without ultrasound

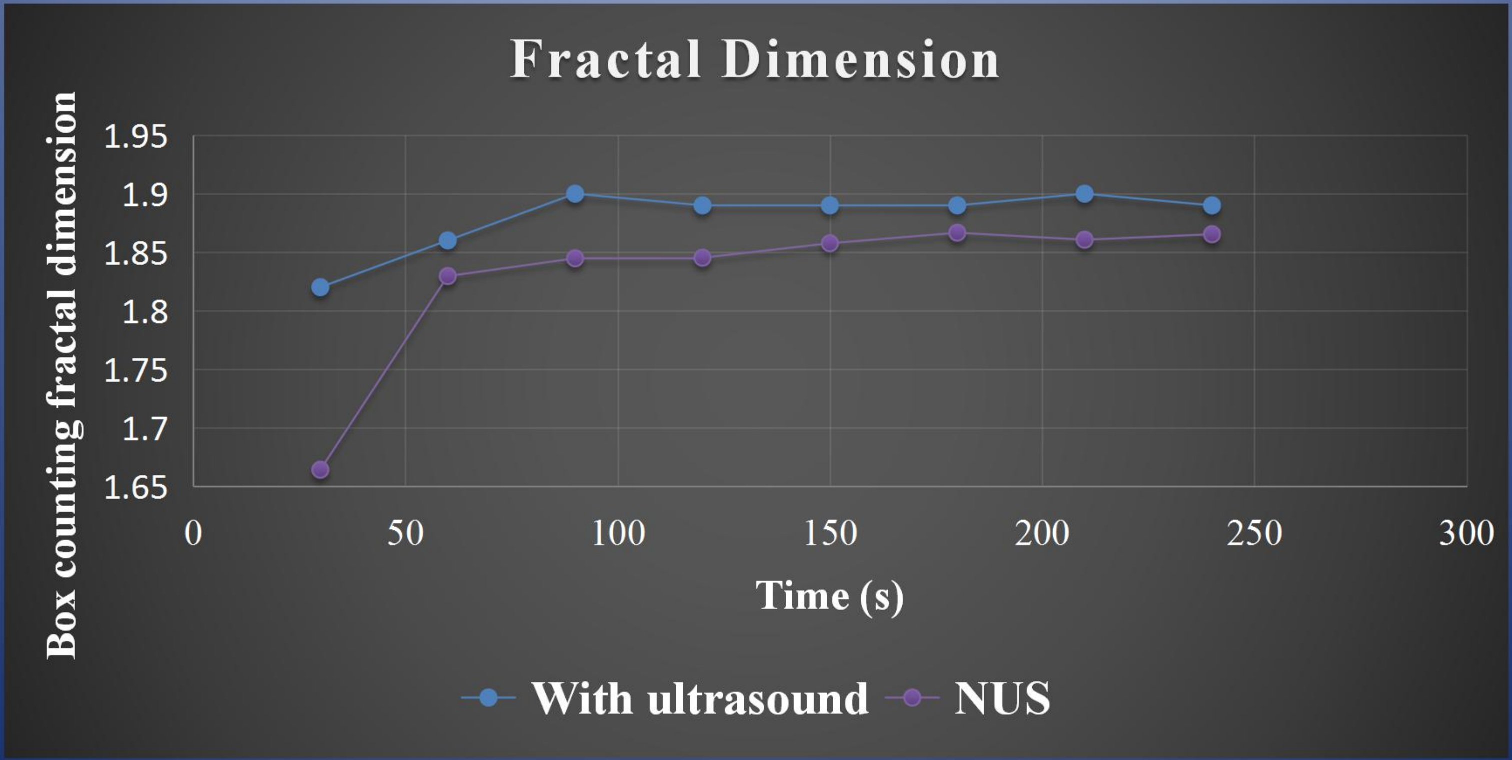
Time	30 s	60 s	90 s	120 s	150 s

With ultrasound

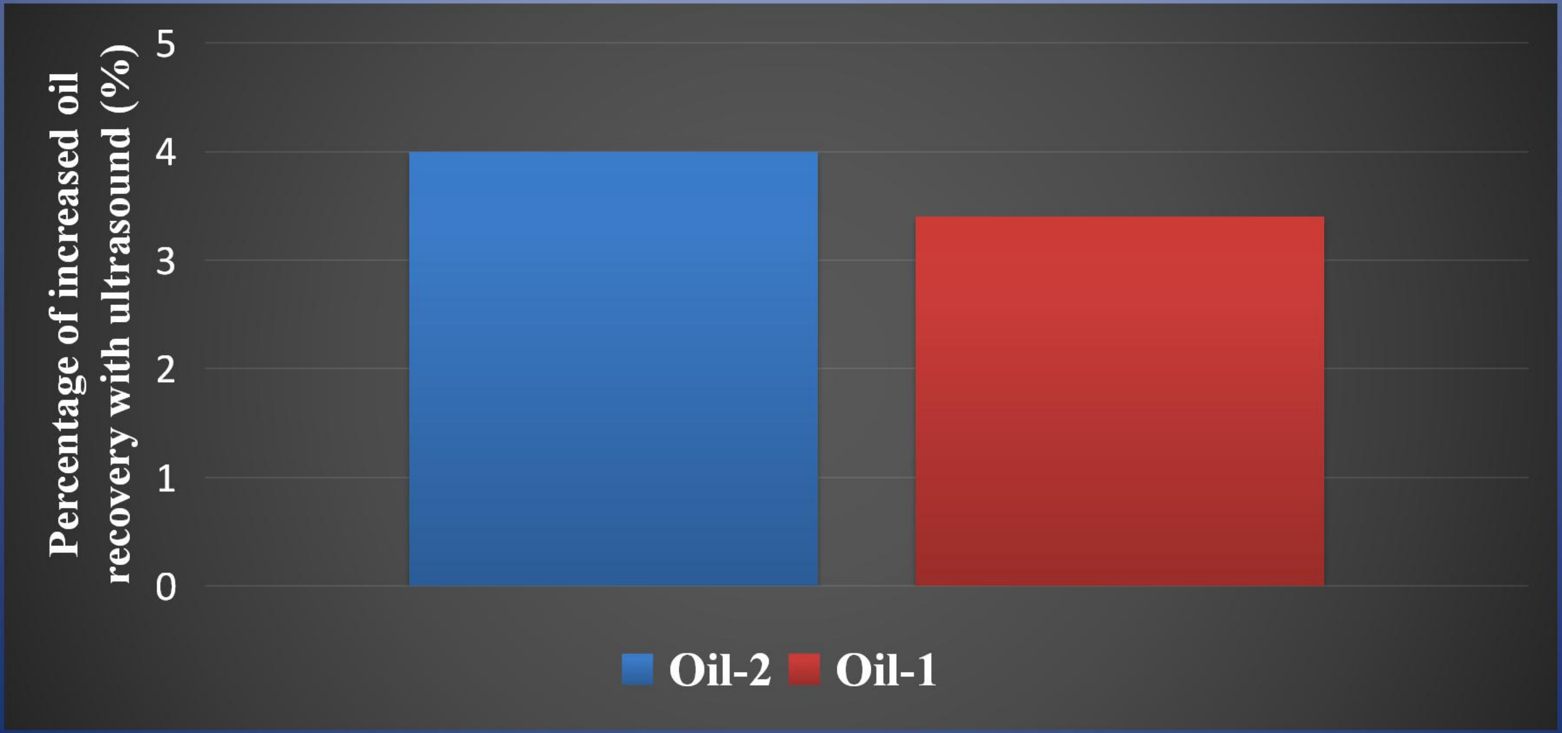
- Fingering phenomenon (Oil #2):



- Fingering phenomenon (Oil #2):



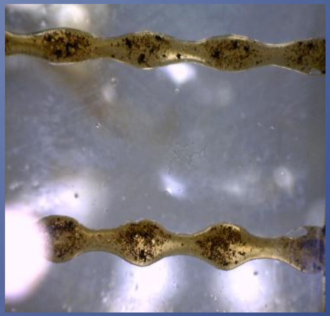
- Fingering phenomenon:



- Removing asphaltene deposition (synthetic oil):

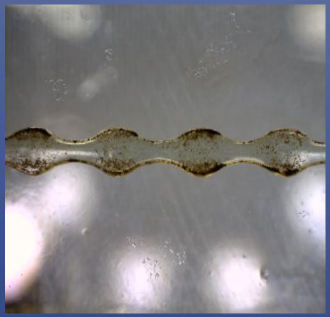
End of flooding by n-pentane

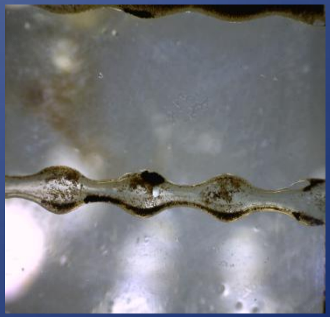




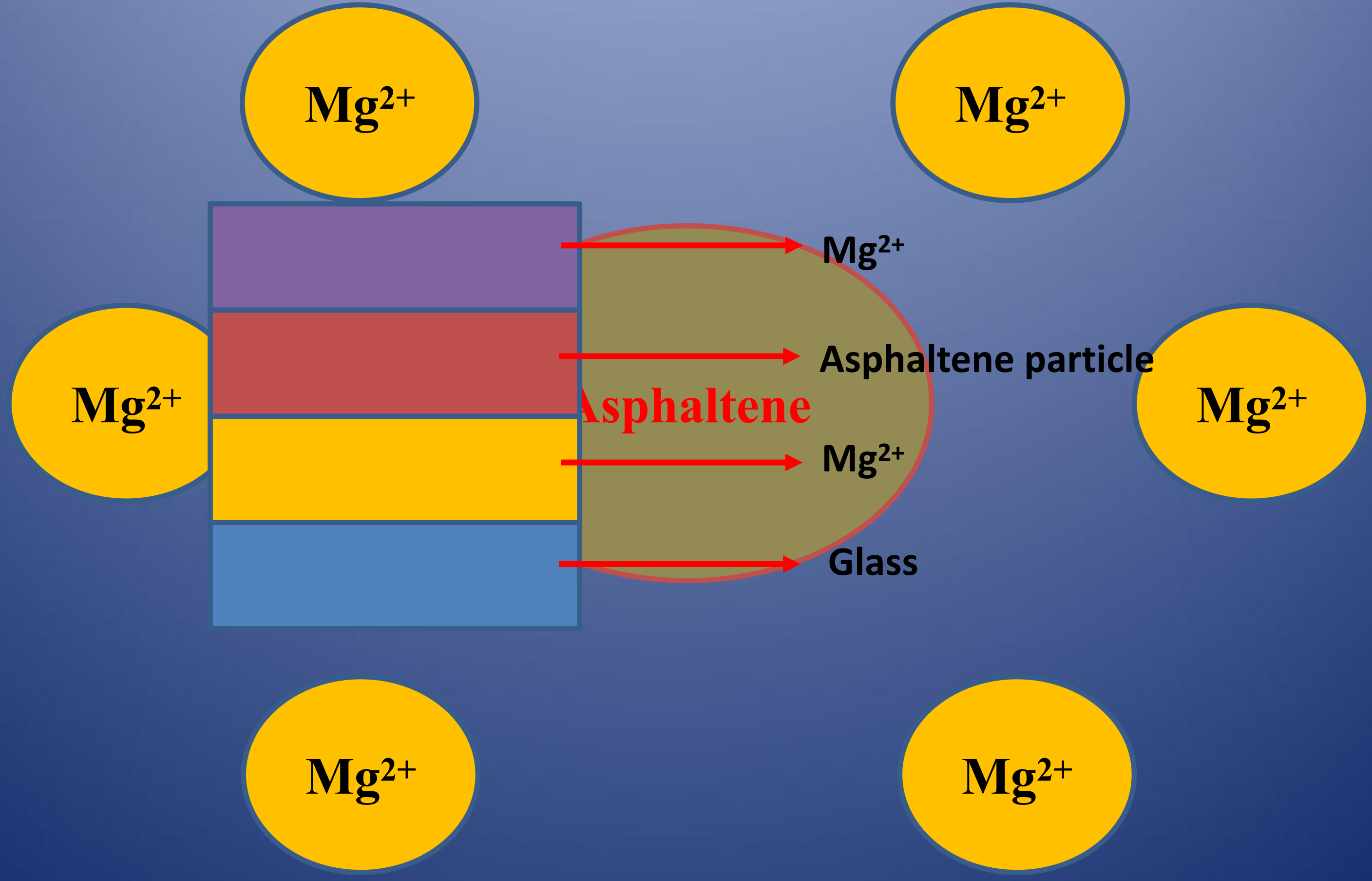
End of flooding by brine

Without ultrasound



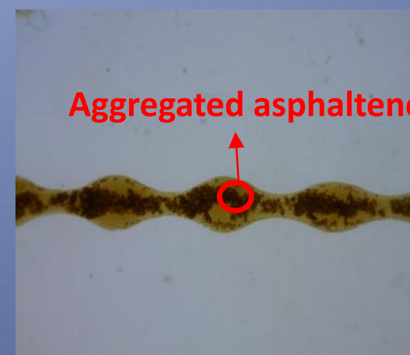


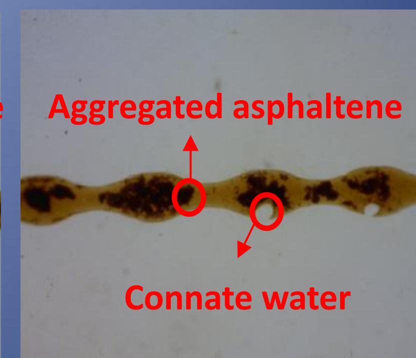
Mechanism of asphaltene deposition:



- Removing asphaltene deposition (synthetic oil):

End of flooding by n-pentane





End of flooding by brine

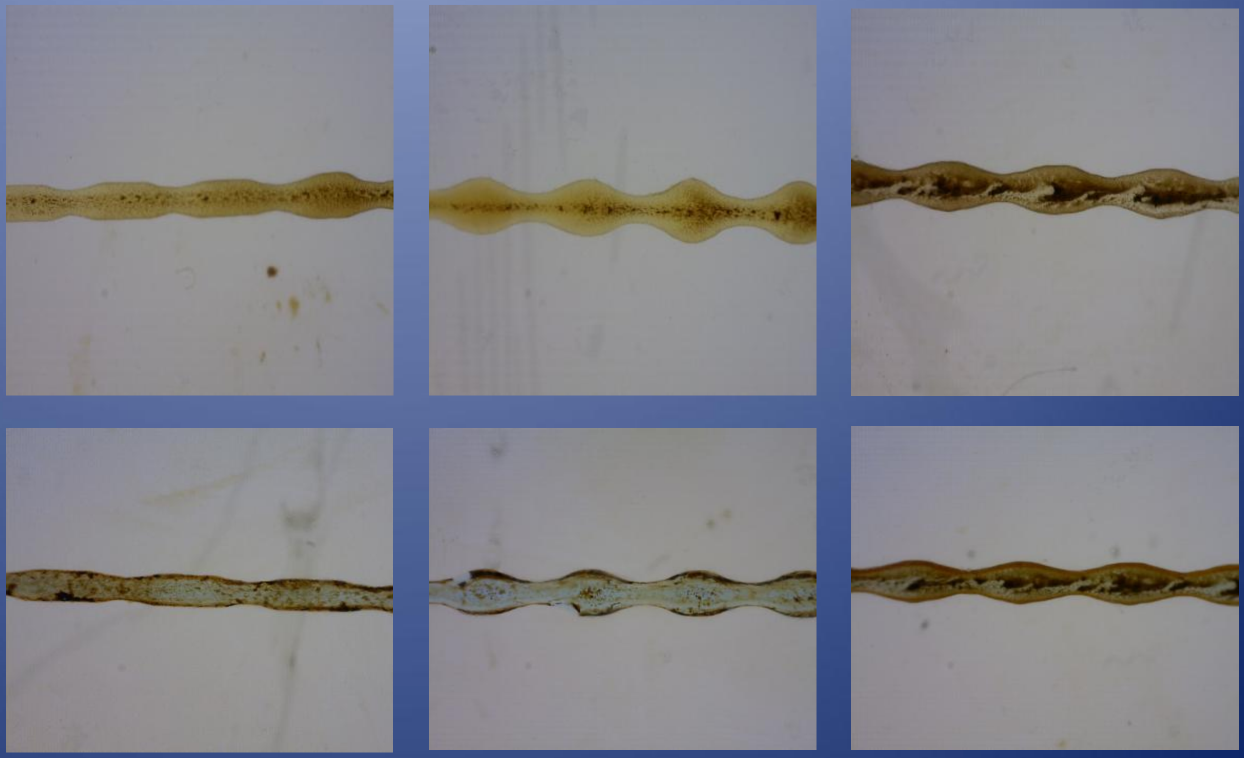
With ultrasound

- Removing asphaltene deposition (Oil #1):

End of n-pentane flooding

End of brine flooding

Without ultrasound

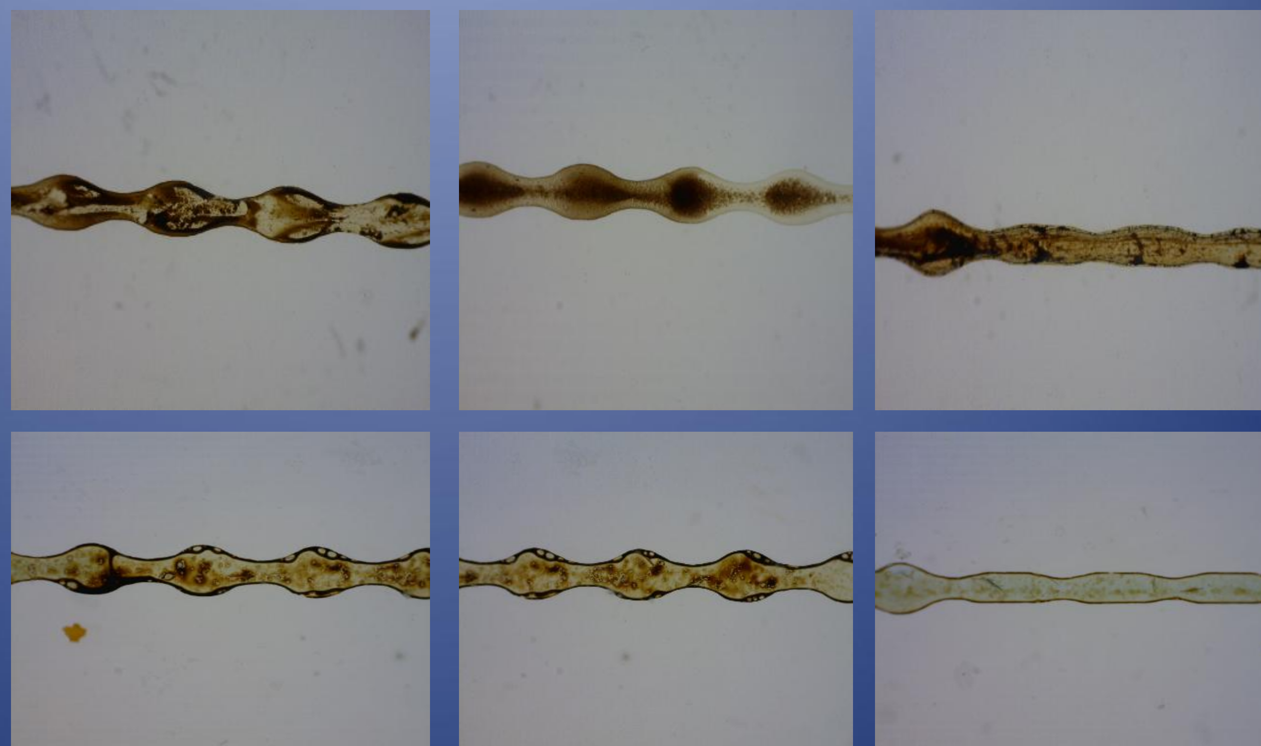


- Removing asphaltene deposition (Oil #1):

End of n-pentane flooding

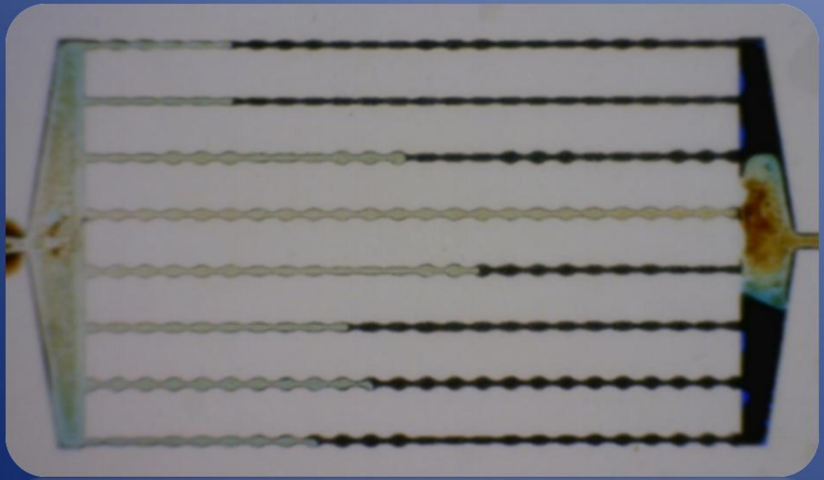
End of brine flooding

With ultrasound

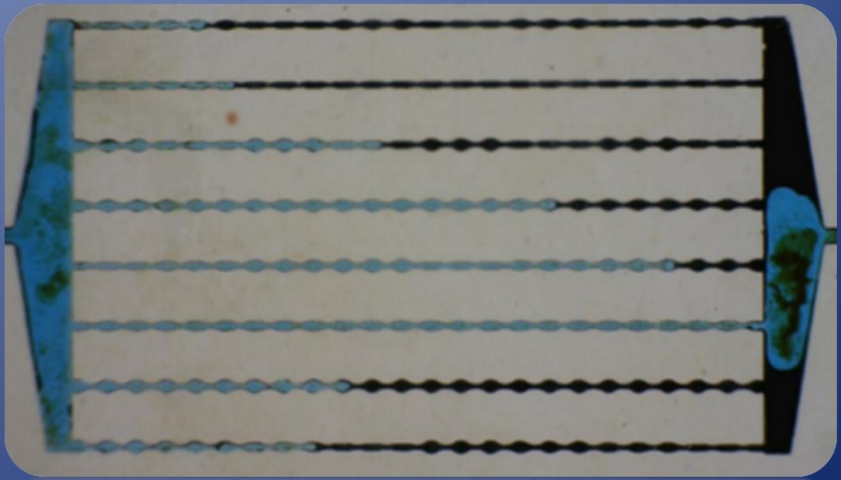


- Results of oil recovery (Oil #1):
  - Flow rate = 0.03 mL/h

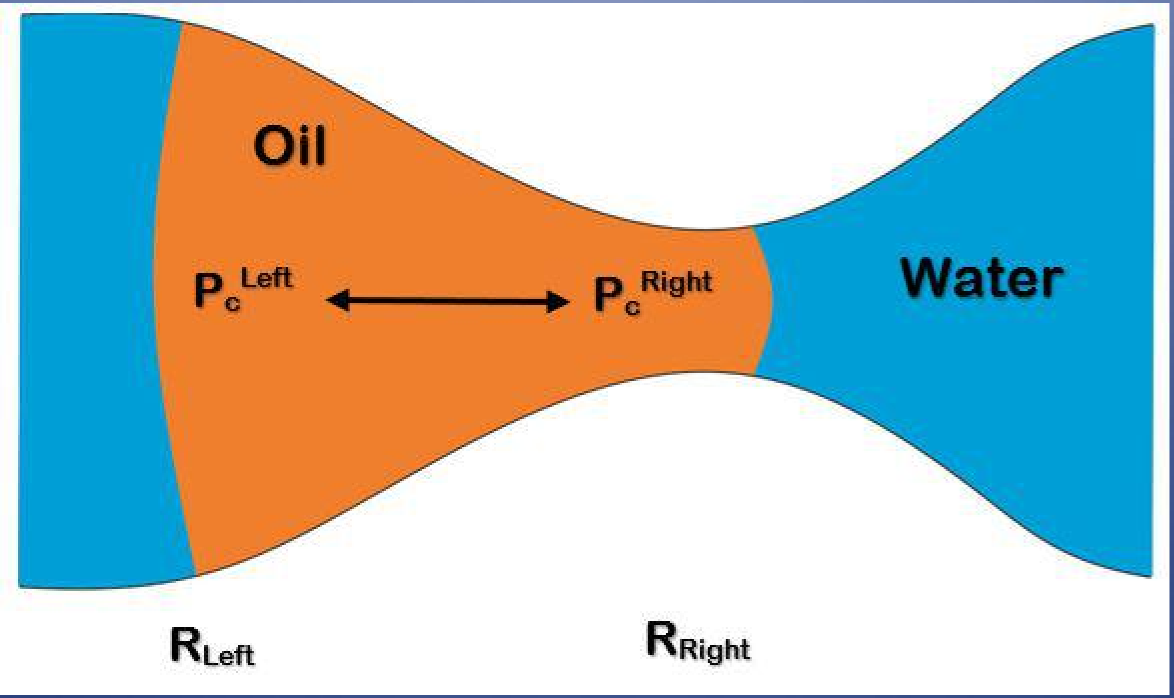
Without ultrasound



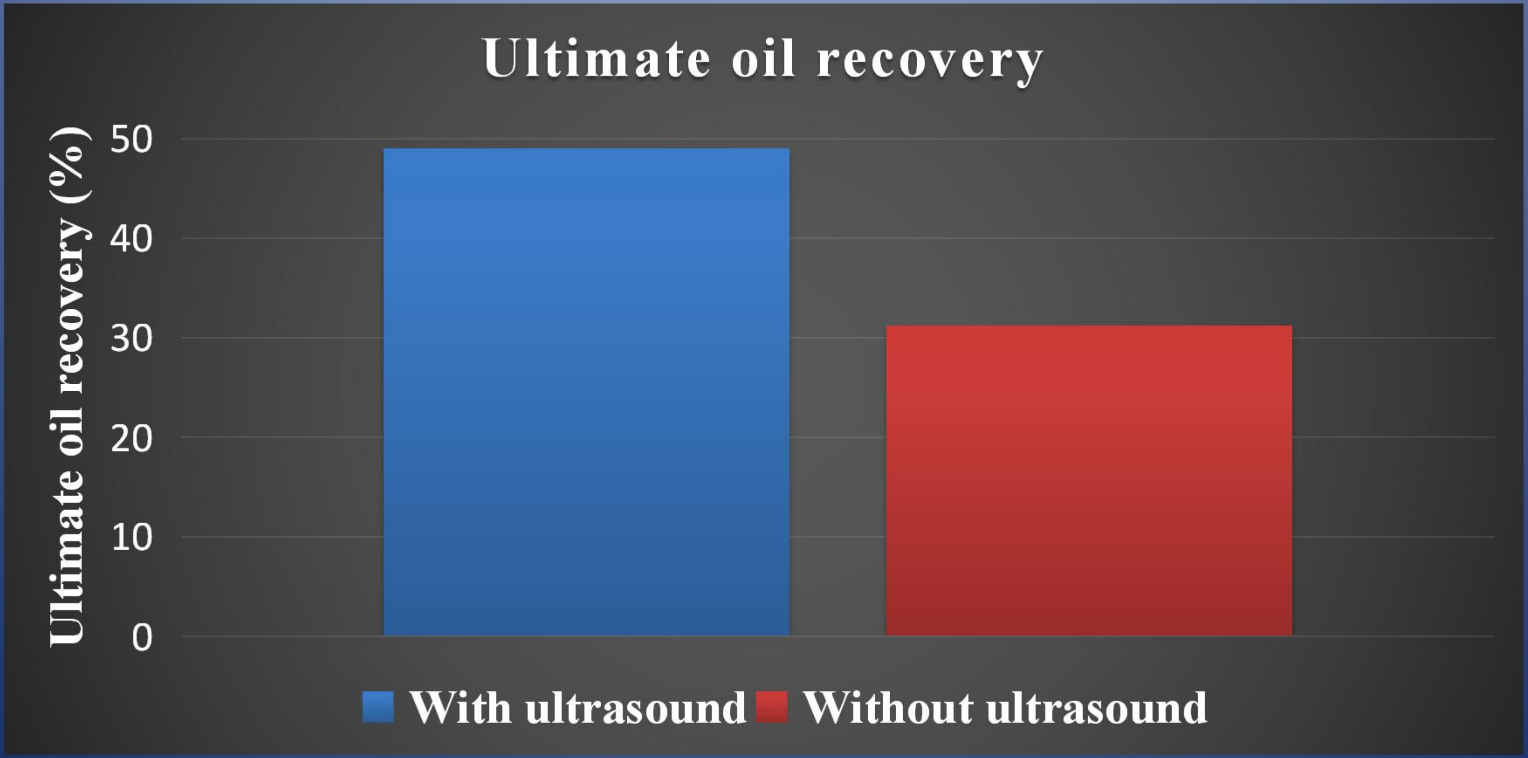
With ultrasound



- Oil droplet trapped in a throat:

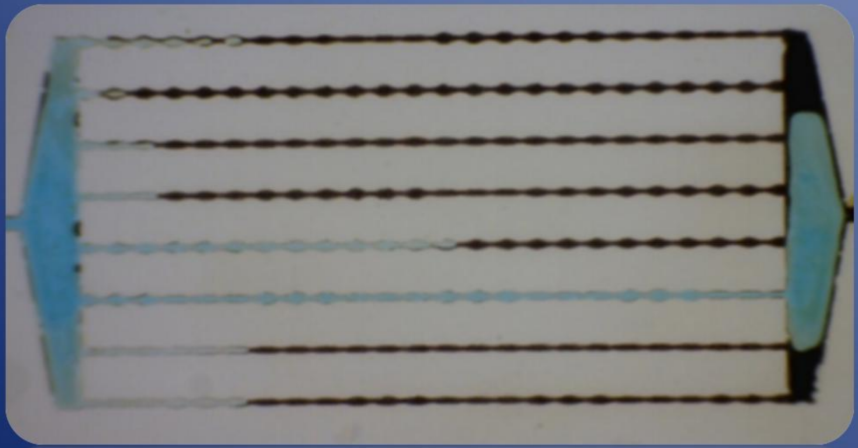


- Oil #1(oil recovery enhancement: 17.87 %)

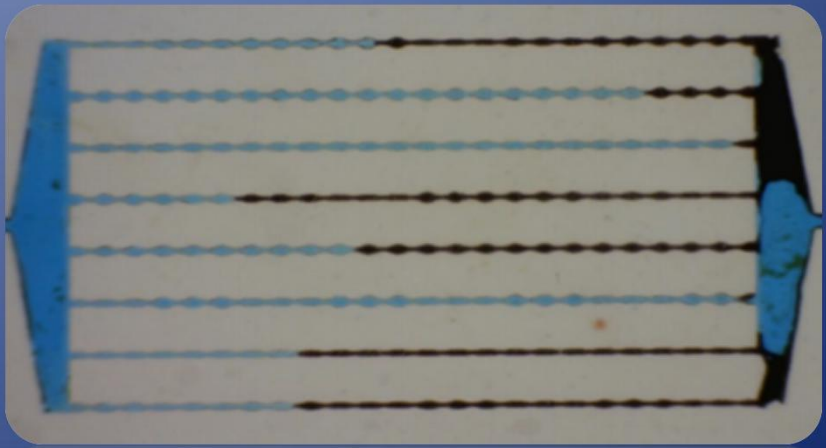


- Results of oil recovery (Oil #2):
  - Flow rate = 0.03 mL/h

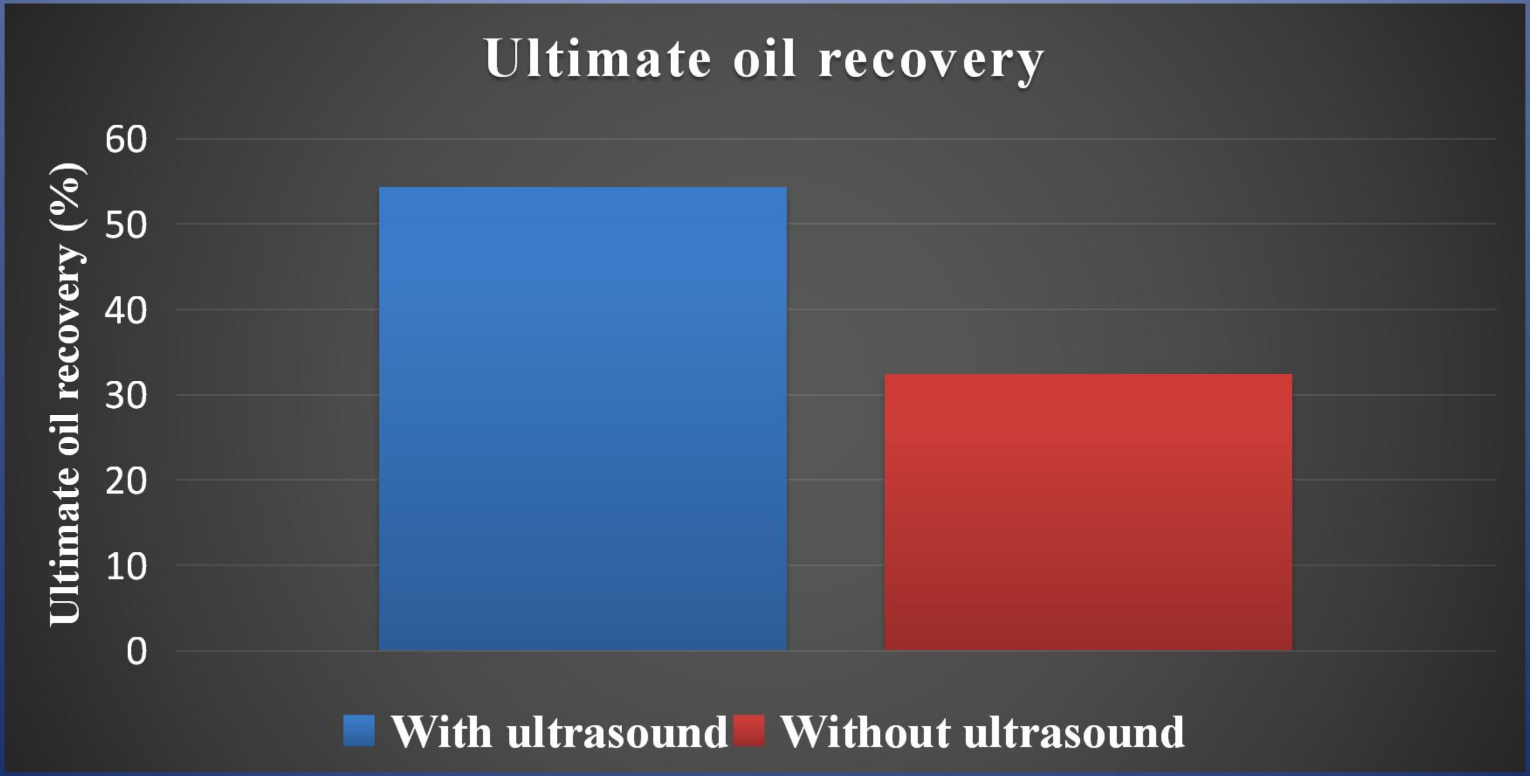
Without ultrasound



With ultrasound

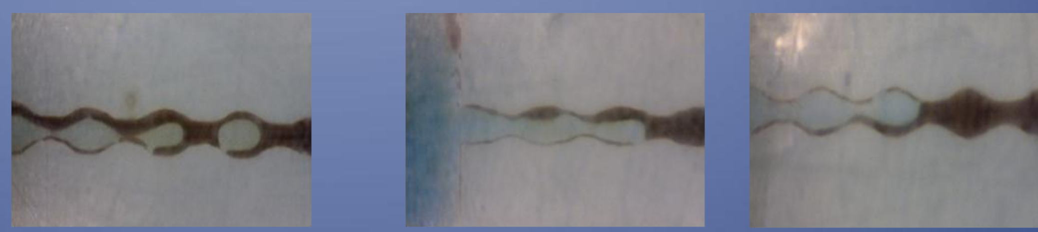


- Oil #2 (oil recovery enhancement:20.9 %)

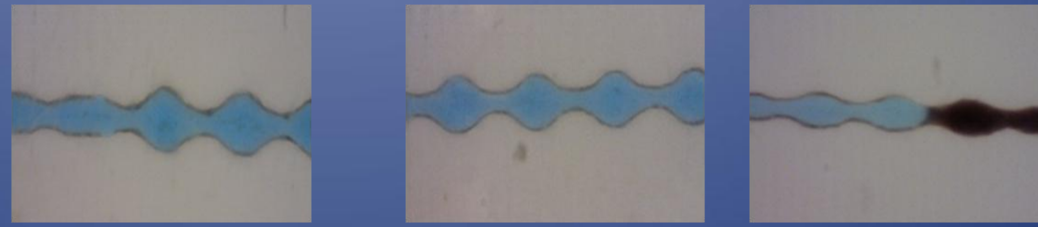


- Microscopic pictures at the end of distilled water flooding for oil #2:
- *(a) without ultrasonic waves*
- *(b) with ultrasonic waves*

(a)

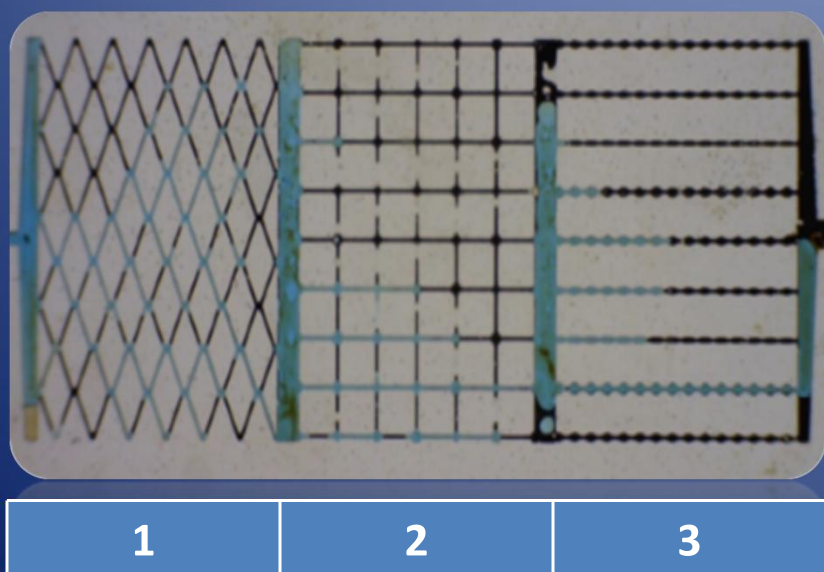


(b)

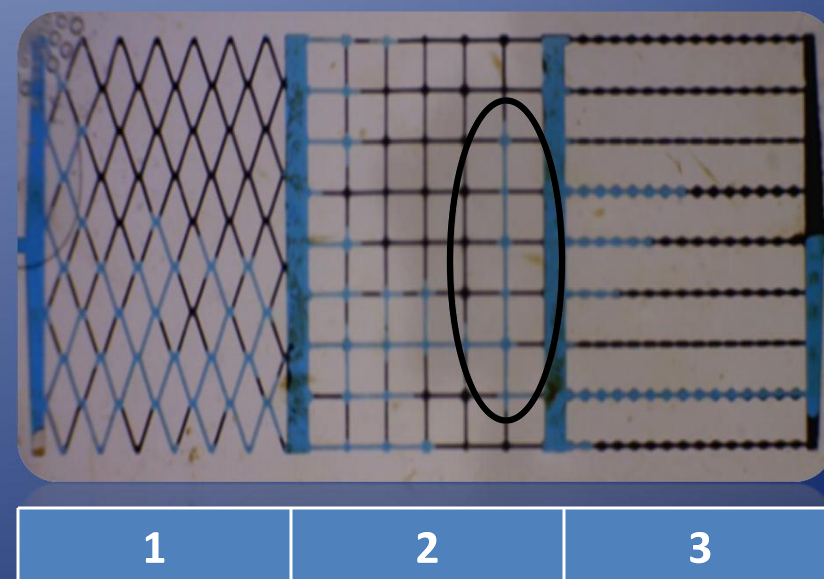


- End of distilled waterflooding for oil #1
  - Flow rate = 0.03 mL/h

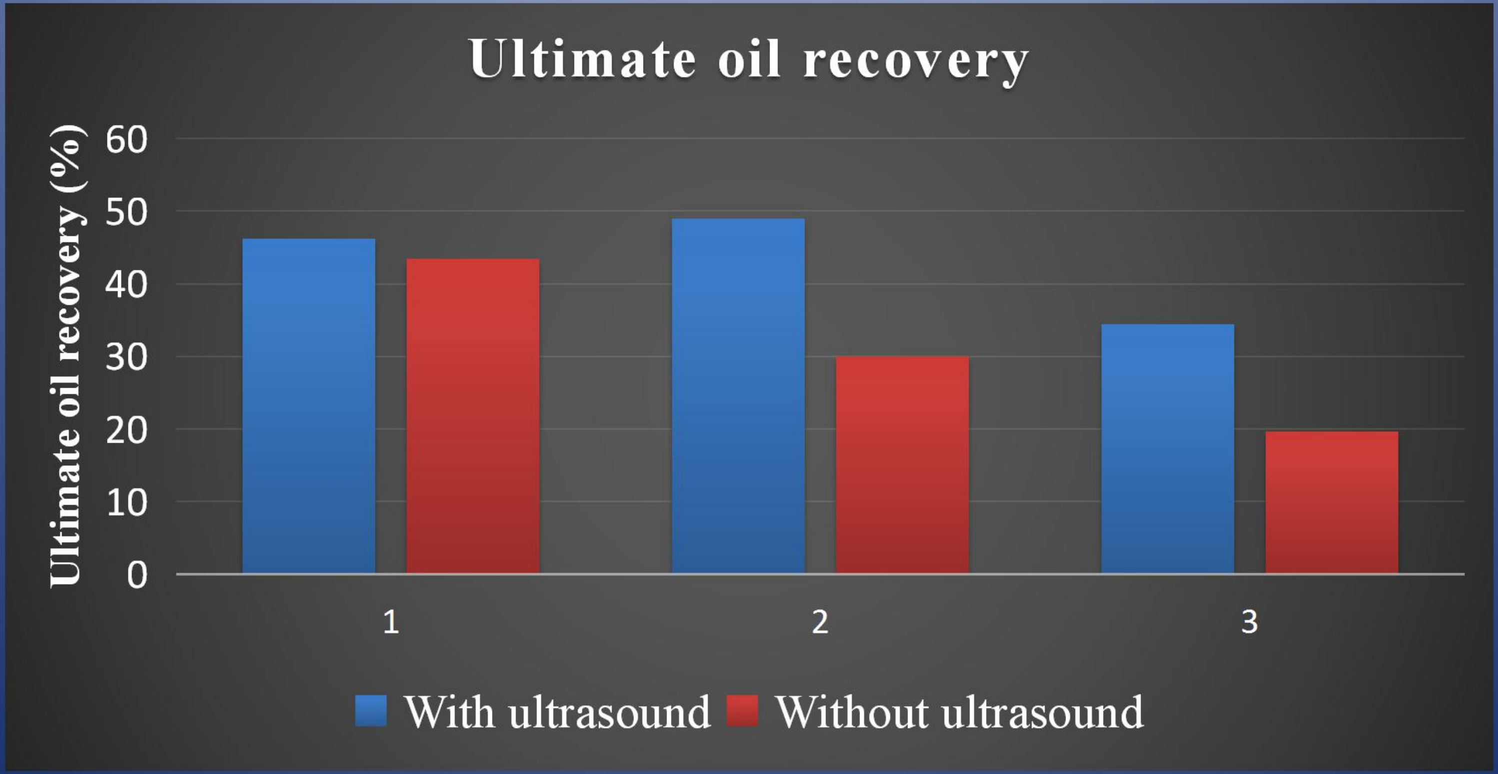
Without ultrasound



With ultrasound

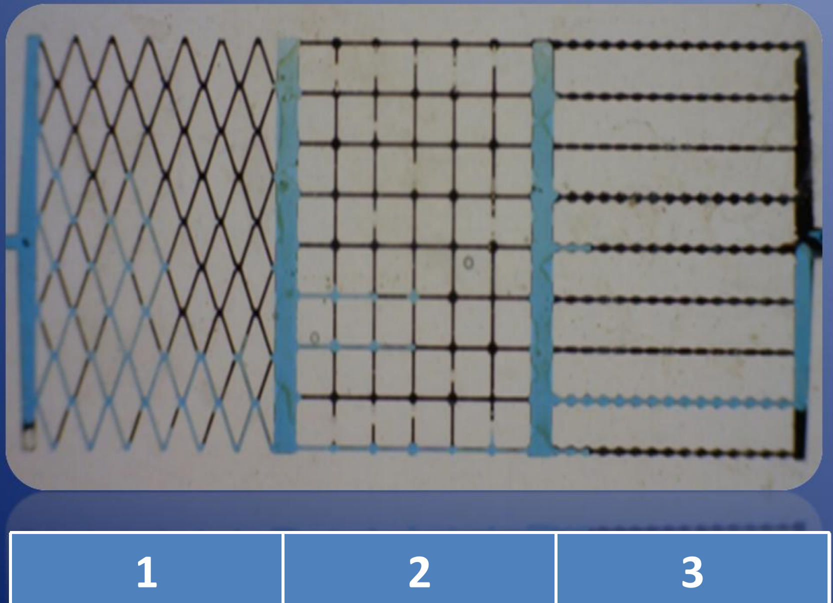


- Results of oil recovery (Oil #1):

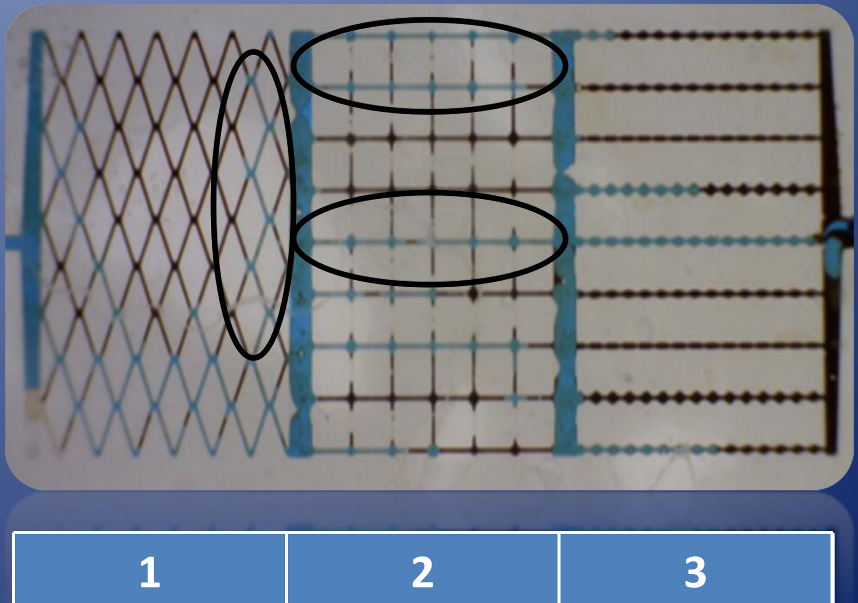


- End of distilled waterflooding for oil #2
  - Flow rate = 0.03 mL/h

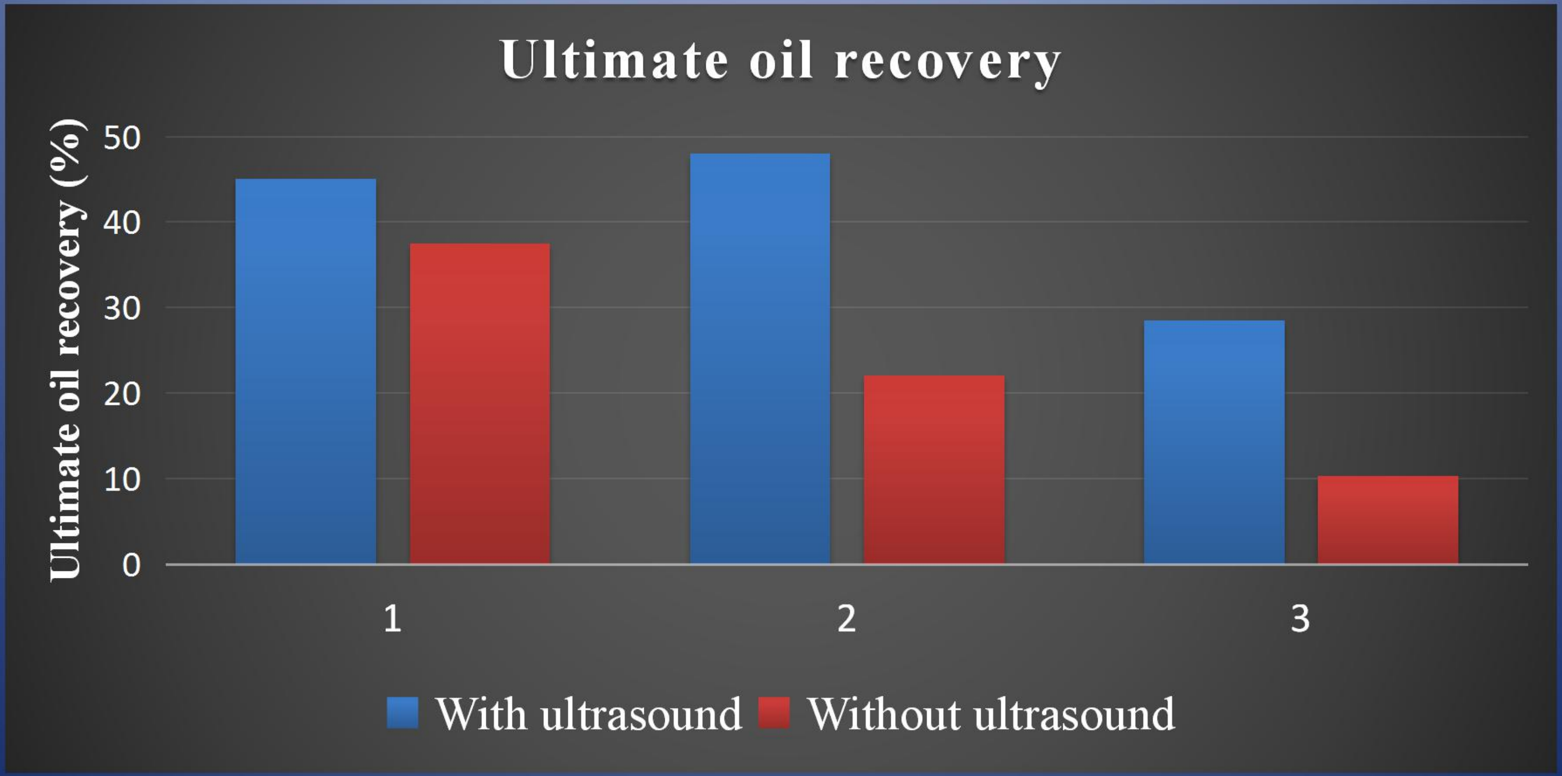
Without ultrasound



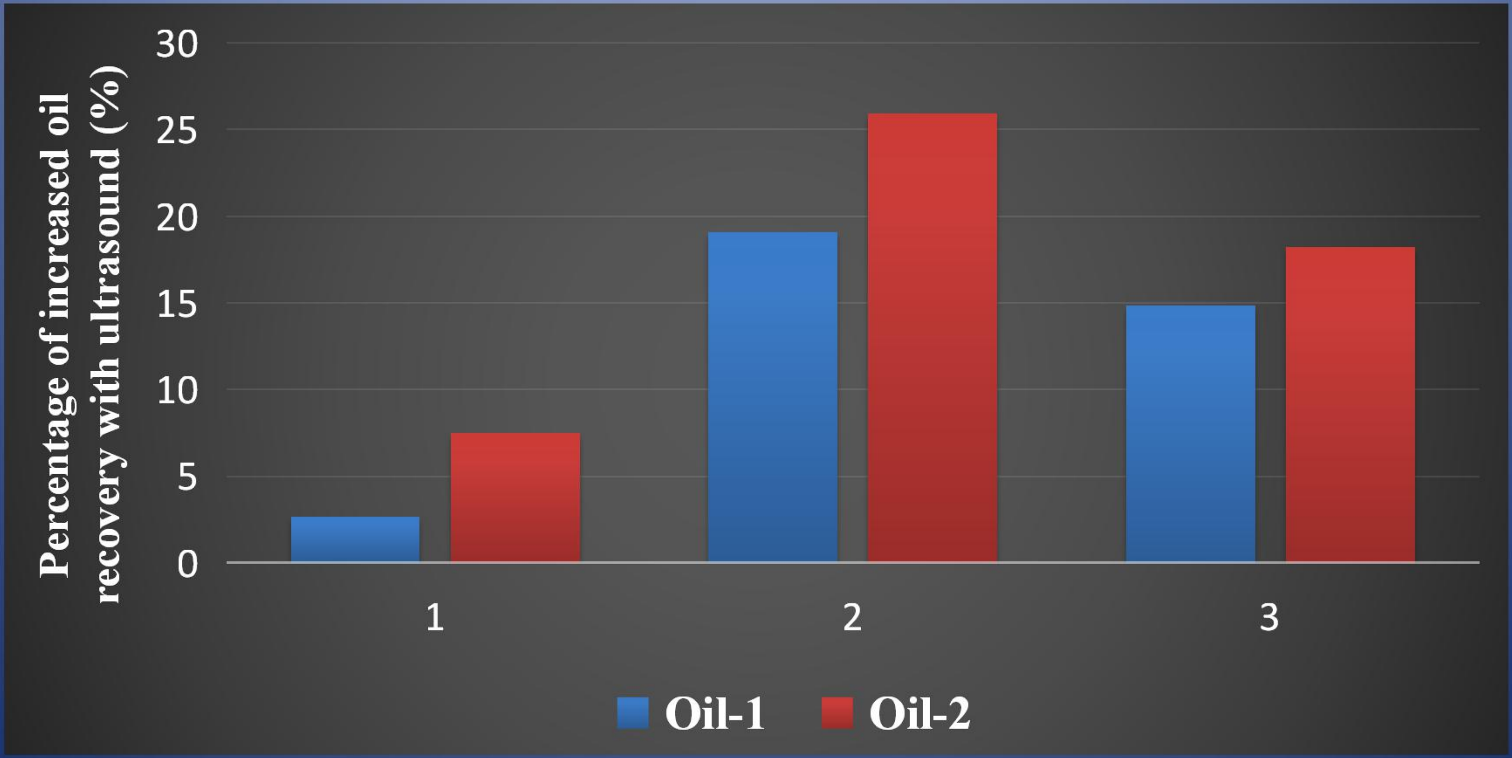
With ultrasound



- Results of oil recovery (Oil #2):



- Comparison of enhanced oil recovery under ultrasonic waves in different micro-model's patterns for oils 1 and 2



Conclusions & Suggestions

Conclusions:

- Ultrasound waves caused reducing fingering phenomenon
- The use of ultrasound caused increasing the efficiency of oil recovery
- The use of ultrasound can be used for removing and preventing asphaltene precipitation and deposition
- The vibration could shake the porous medium walls which caused to form an emulsion on the pore walls.

Conclusions:

- Ultrasonic waves caused decreasing of the oil thickness on pore walls and increasing the effective pore diameter by the mechanism of oil layering
- By propagating ultrasound oil percolation paths increased.
- Effect of ultrasound is greater in the oil type with lower viscosity.
- In order to use these waves, the type of oil and geometry of flow should be considered.

Suggestions:

- Modelling experiments to find the optimum parameters for using this type of waves
- Investigation the effect of using ultrasound on enhanced oil recovery along with other conventional methods
- Conducting experiments under temperature and pressure of oil reservoir
- Studying the effects of ultrasound on live oil

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Thank you for your attention