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Berorientasi Pelayanan Akuntabel Kompeten
Harmonis Loyal Adaptif Kolaboratif

NEUTRON IMAGING

Neutron Vision:

A New Window Into Enhanced Oil Recovery



Fahrurrozi A
Instrument / Beamline Scientist
Neutron Imaging and Artificial Intelligence
fahr006@brin.go.id

BRIN
UNIVERSITAS TRISAKTI

American Physical Society
UKRI Science and Technology Facilities Council

Physics Matters Colloquium: July 30th 2026

My Research

TEAM

BRIN

Abu K R, Iwan S, Fahrurrozi A, Bharoto, A Ramadhani, Sulistioso GS



UNIVERSITAS TRISAKTI

Rini S, M Furqon, Fajri M, M Taufiq



Science and Technology Facilities Council

Ranggi S



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Why Oil is Very Important?

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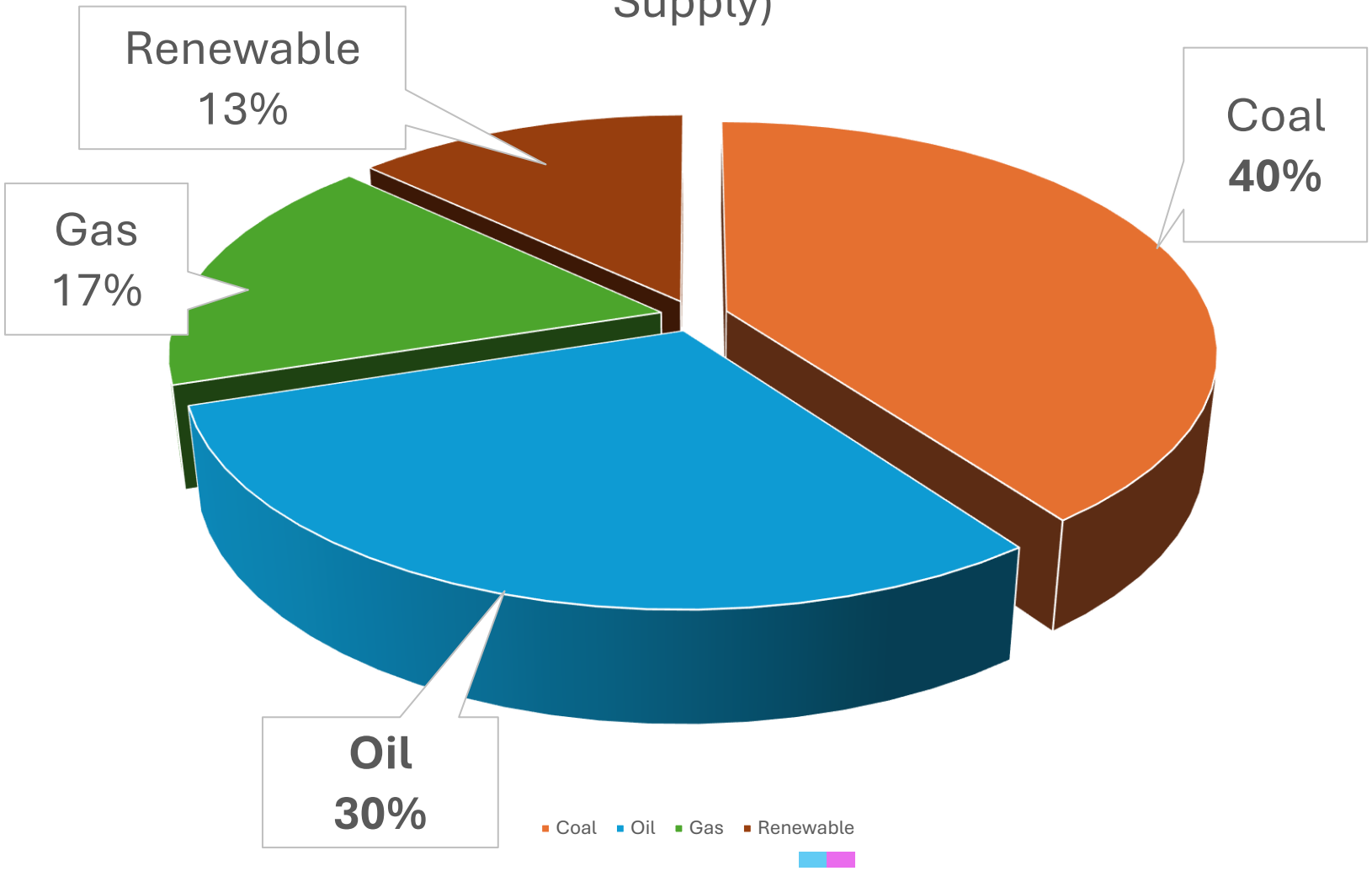
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- ✓ **61%** Transportation
- ✓ **21%** Non-Energy Petrochemicals and Manufacturing
- ✓ **7%** Industrial Manufacturing
- ✓ **1%** Power and Electricity



Estimate Energy Consumption Breakdown (Primary Supply)



https://business-indonesia.org/energy_overview

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Life Cycle of Oil and Gas Field



EXPLORATION ▶ DEVELOPMENT ▶ EARLY PRODUCTION ▶ FULL PRODUCTION ▶ RECLAMATION

Fig 1. Life Cycle of Oil and Gas Field

Reclamation



“EOR”

40-50% Extract
More oil if Possible



Enhanced oil recovery (EOR)

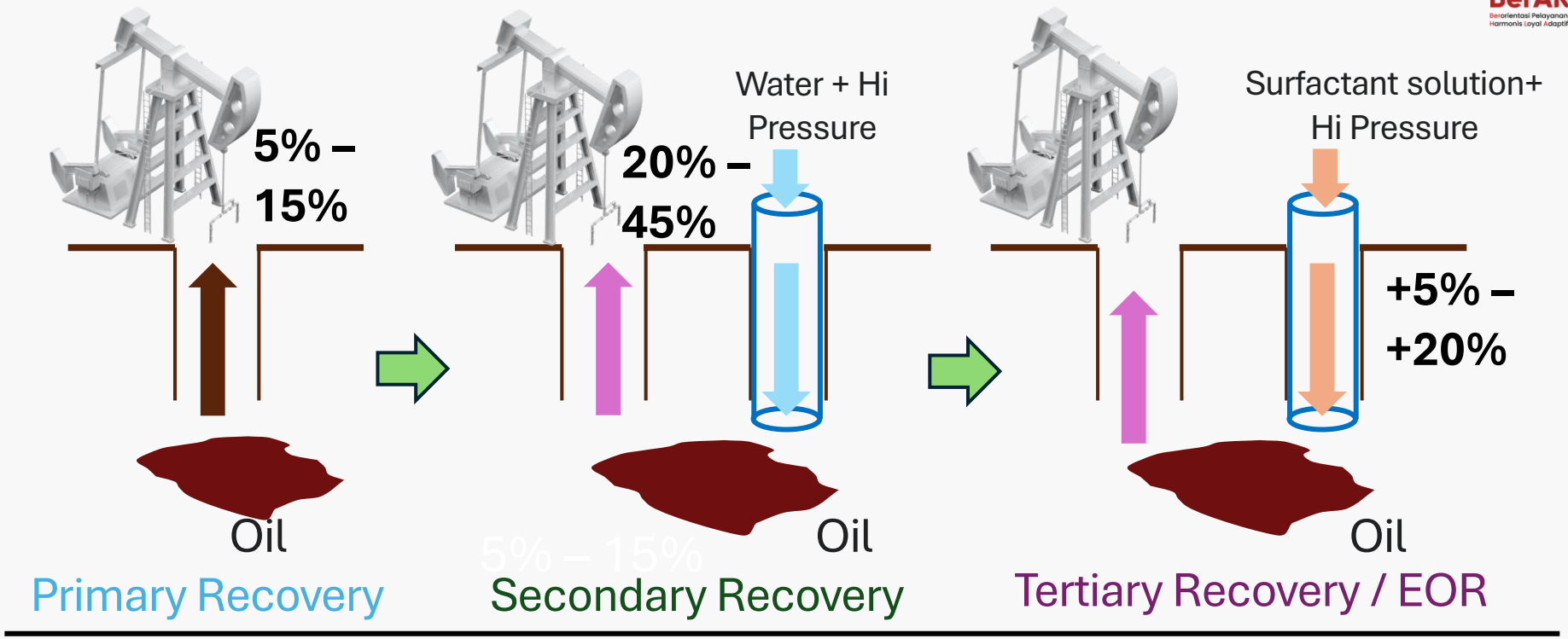


Fig 2. Primary, Secondary, and Tertiary Recovery (EOR) techniques

Primary + Secondary + EOR = 40% – 60%+

- ✓ Enhanced oil recovery (**EOR**), also called **tertiary recovery**, is the extraction of crude oil from an oil field that cannot be extracted otherwise.
- ✓ It works by altering the **chemical composition** of the oil itself to make it easier to extract.



Background

No surfactant can maximize (100%) of oil production from the field.

We Propose **Neutron Imaging Technique** → Performance of Surfactant (EOR)

Could Neutron Imaging see the **performance of surfactants** non-destructively → for both quality and quantity.



Neutron CT

Instrument Parameters

- ✓ Neutron source: RSG-GAS reactor beam port S2
- ✓ Neutron flux at sample position: 10^6 to 10^7 n.cm^{-2} sec^{-1}
- ✓ Beam size at sample position: 30 cm (diameter)
- ✓ Collimator L/D ratio: 87
- ✓ Cadmium ratio: 6.4
- ✓ Neutron/Gamma ratio : >10^5 n/cm^2/mR
- ✓ Radiography techniques: Gd converter and X-ray film, Li_6-ZnS scintillator screen, CCD-based electronic imaging system, CMOS Camera.
- ✓ Resolution: 150-200μm

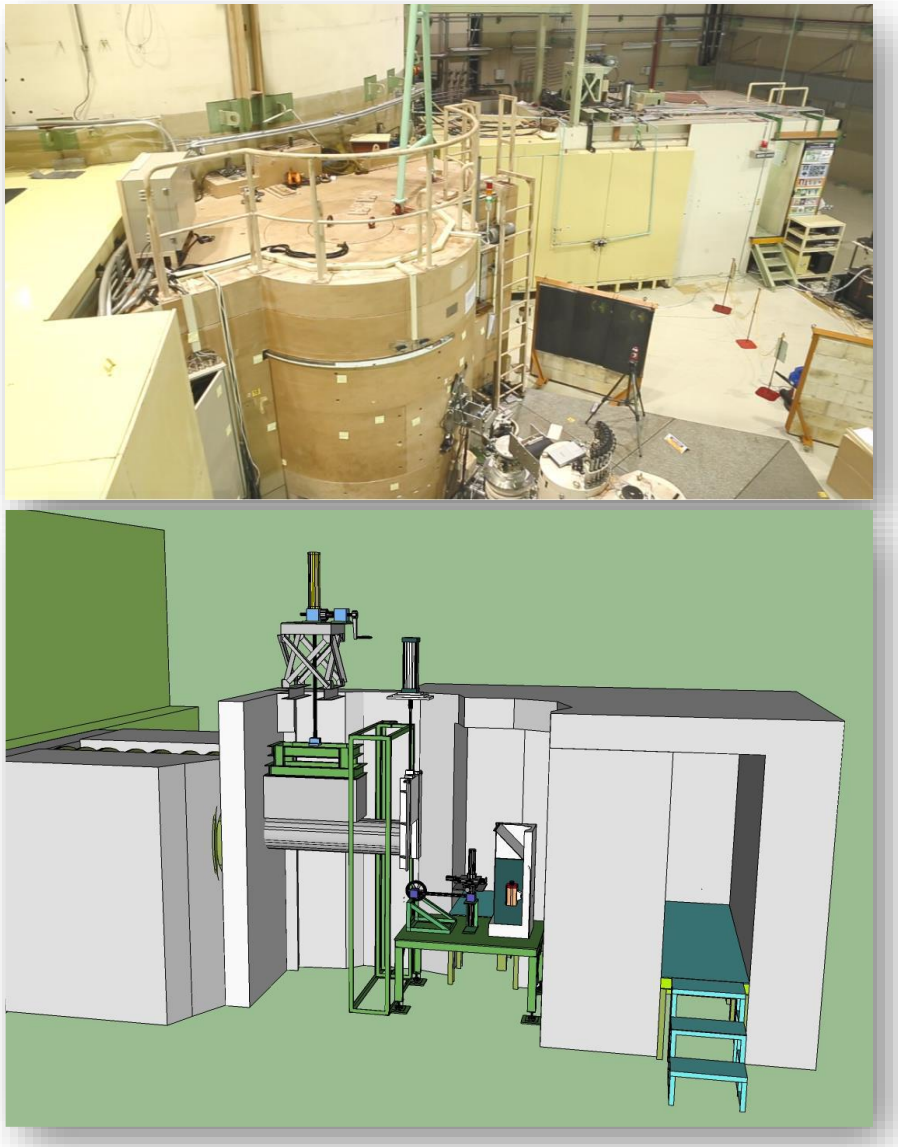
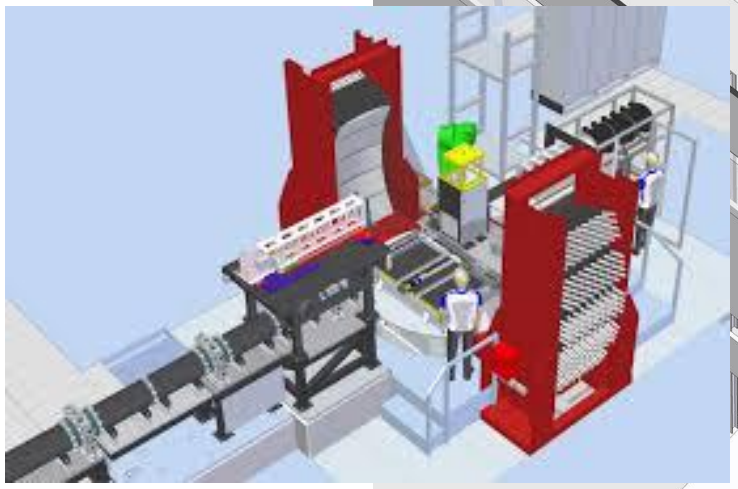
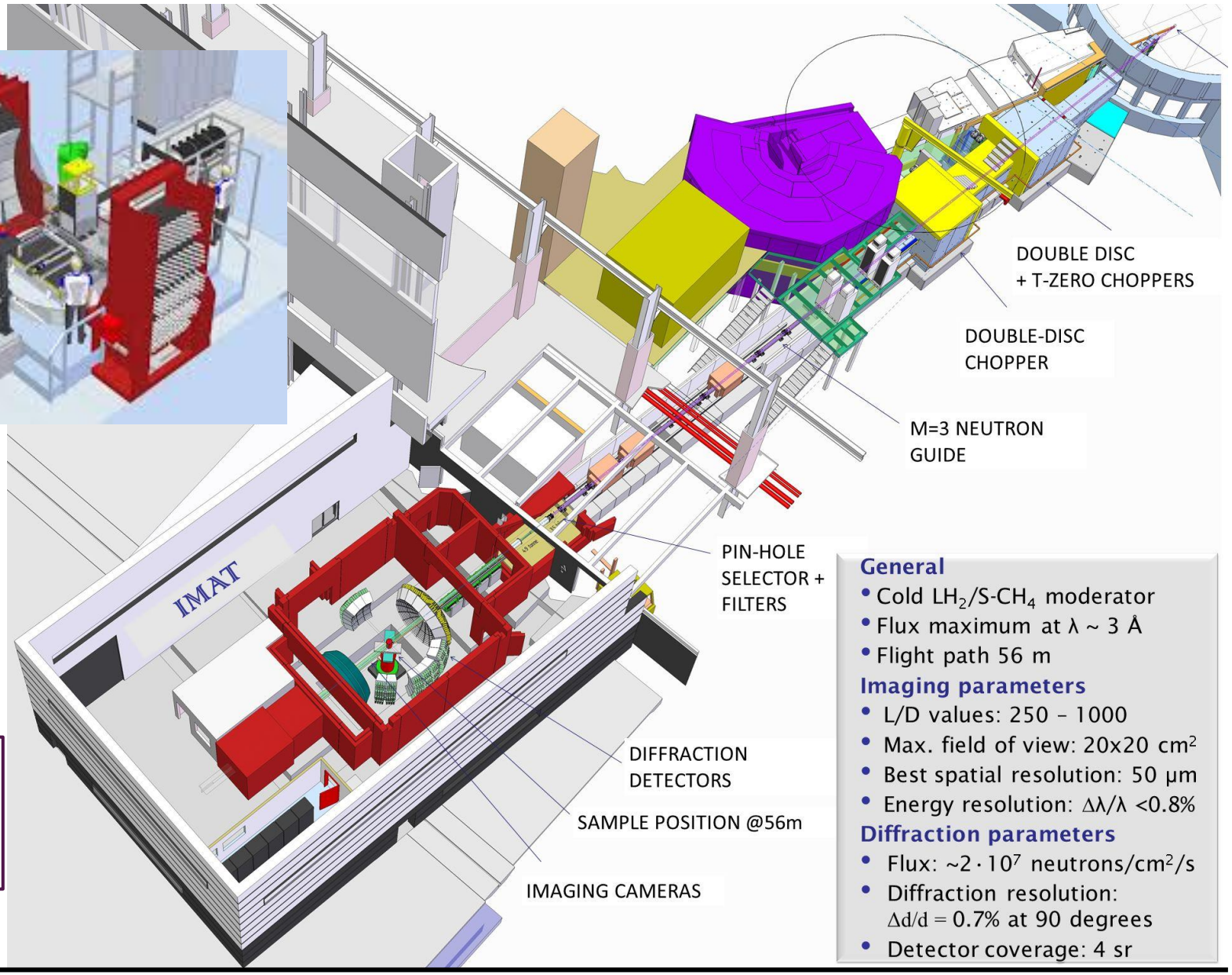


Fig 3. BRIN's Neutron Imaging facility at K.S.T BJ Habiebie Serpong - Indonesia



Neutron CT





supported by:
RAL - STFC under Contract Number **RB2420220**

Fig 4. Imaging for Material and Technology (IMAT) RAL ISIS



Neutron CT

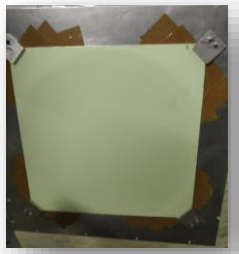
How does it Works?



Neutron Source



Sample



Scintillator
- ✓ Li_6ZnS 100µm and 50µm
- ✓ Gadox 50µm



Camera:
- ✓ ZWO



Mirror:
- ✓ TiO_2 (~90%)

Lens:
- ✓ 25mm
- ✓ 50mm
- ✓ 105mm





Computer

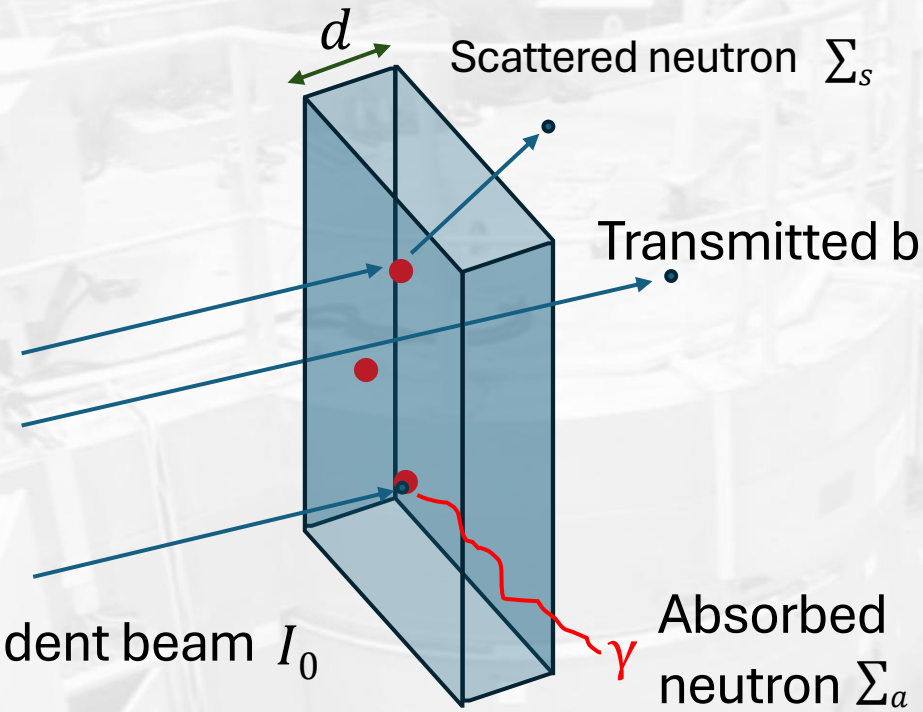
Fig 5. Fundamental of Neutron Imaging



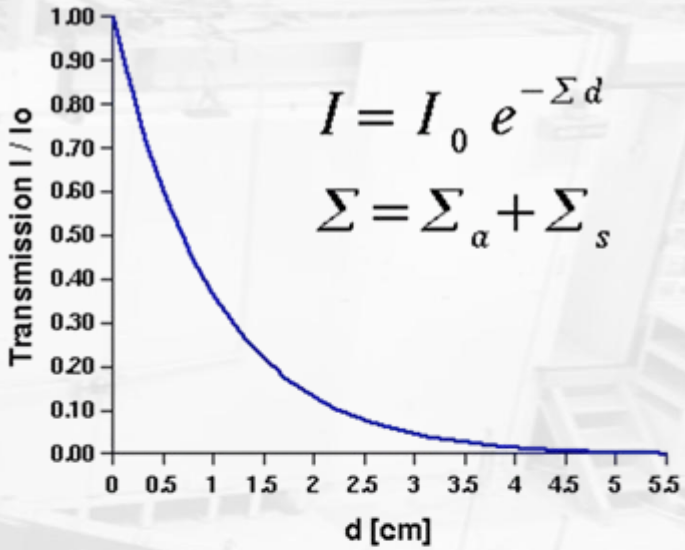
Neutron CT

Narrow Beam Attenuation

$$I = I_o e^{-\Sigma d}$$



Exponential Attenuation Law



Macroscopic Cross Section Σ

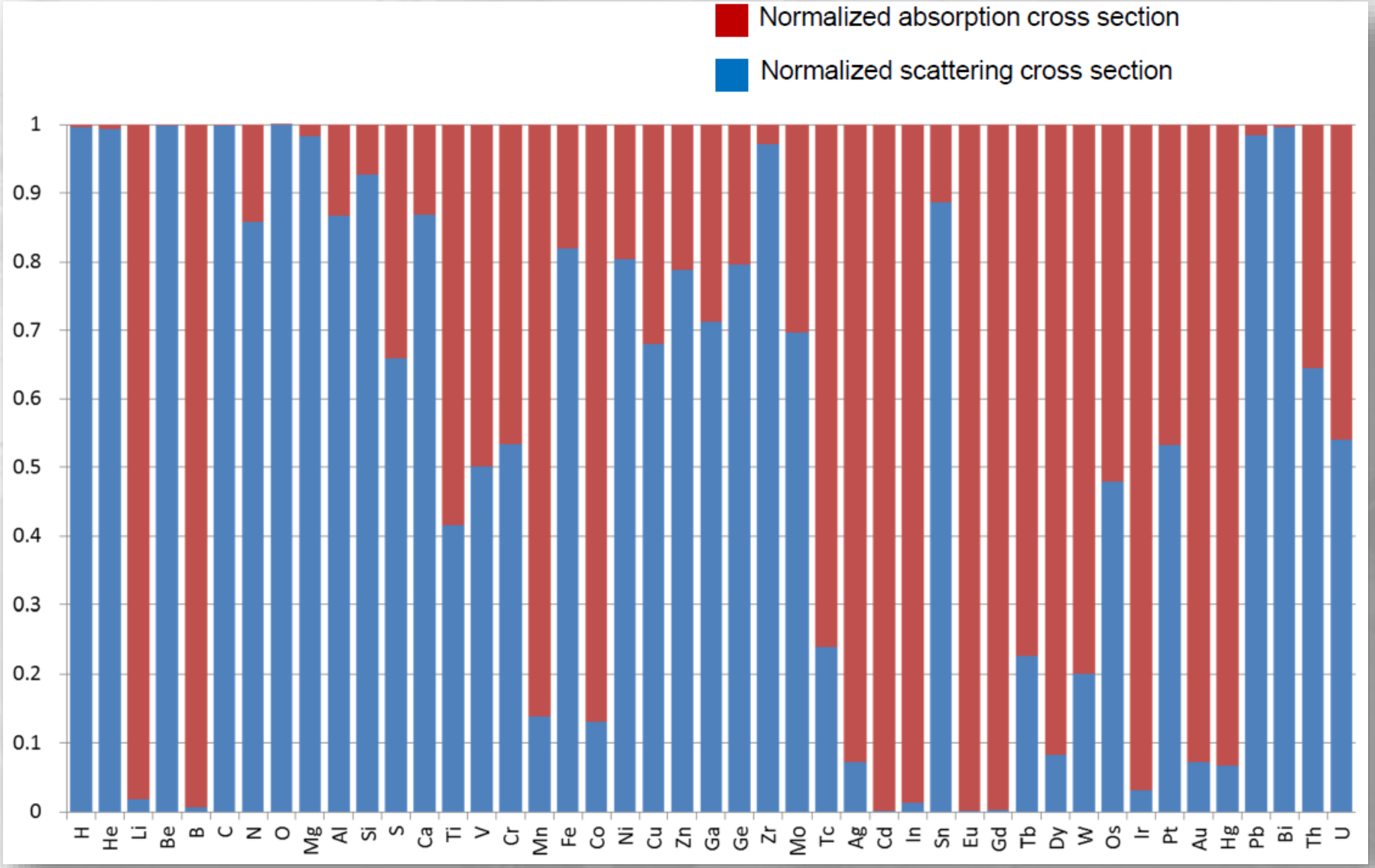
$$\Sigma = N\sigma \quad [cm^{-1}]$$

$$N = \frac{\rho}{A} N_A \quad [cm^{-3}]$$

N := number density $[cm^{-3}]$
ρ := material density $[g\,cm^{-3}]$
A := atomic weight $[g\,mol^{-1}]$
N_A := Avogadro number $6.022\,10^{23}\,[mol^{-1}]$



Neutron CT


Normalized absorption cross section
Normalized scattering cross section
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
H He Li Be B C N O Mg Al Si S Ca Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge Zr Mo Tc Ag Cd In Sn Eu Gd Tb Dy W Os Ir Pt Au Hg Pb Bi Th U



Neutron CT

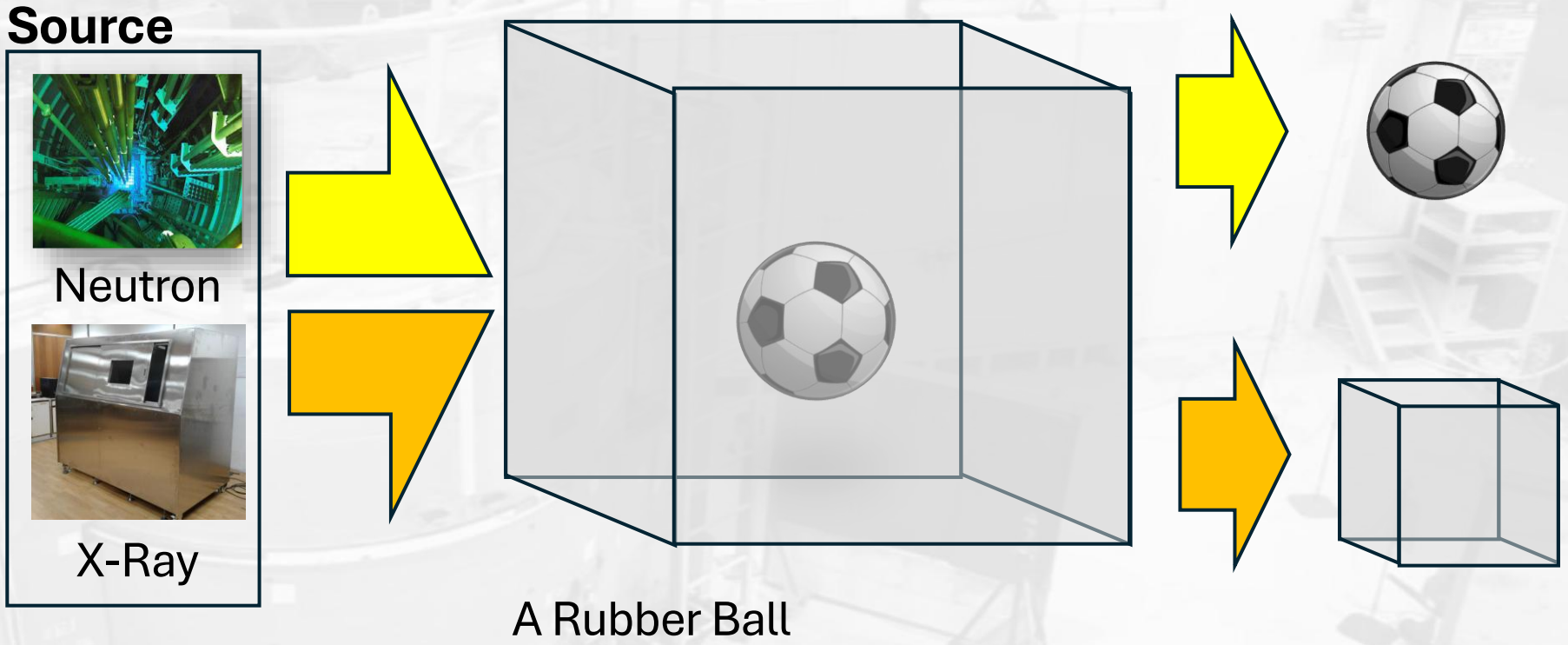
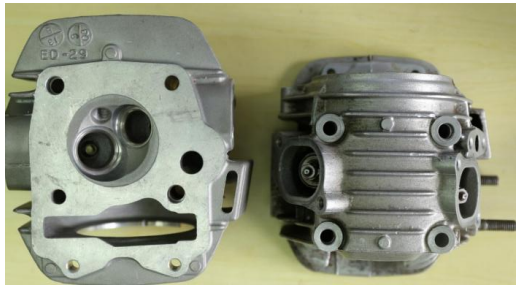


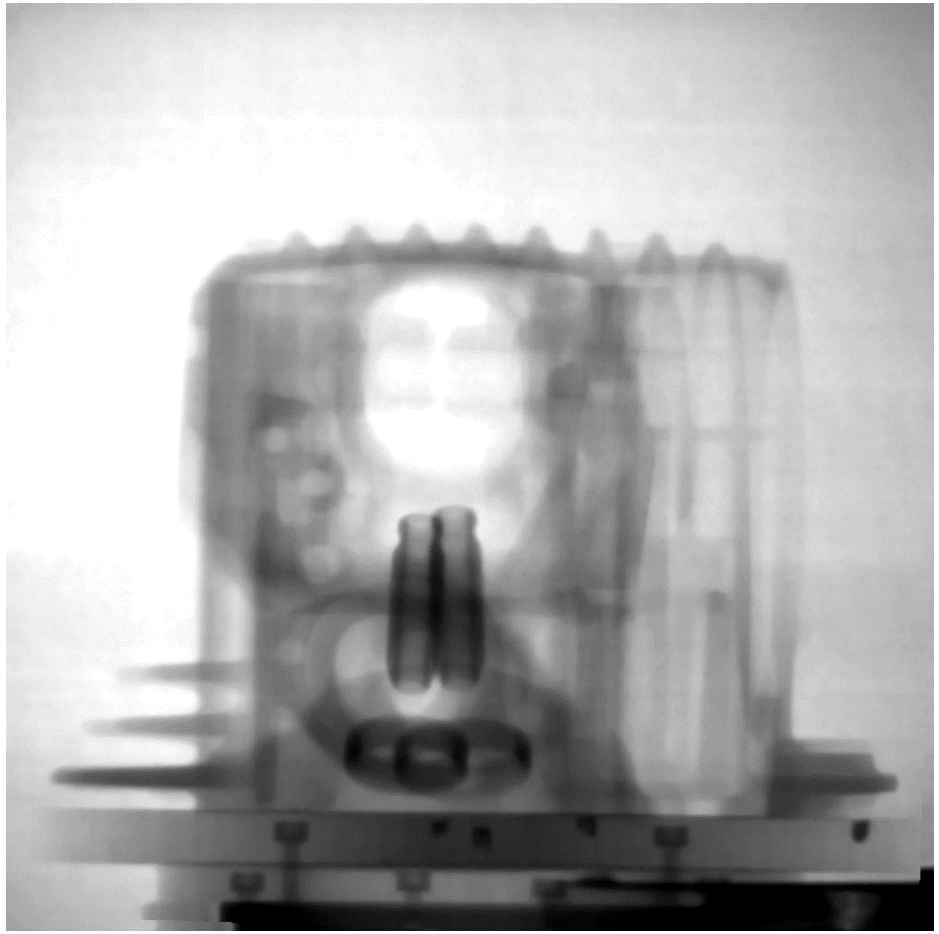
Fig 6. Neutron Vs X-Ray Imaging

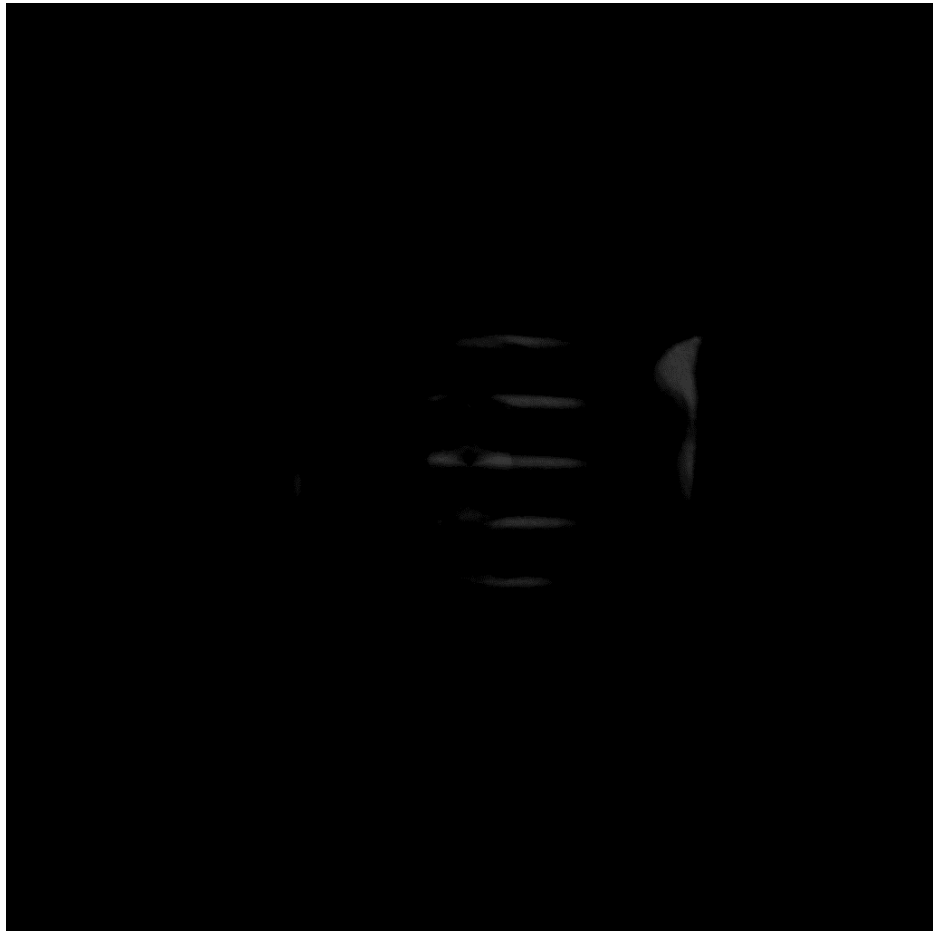


Neutron CT



Motorcycle's Engine Block





CT Data Acquisition → CT Data Reconstruction

NDT

Deep into : Neutron Vision

A New Window Into Enhanced Oil Recovery



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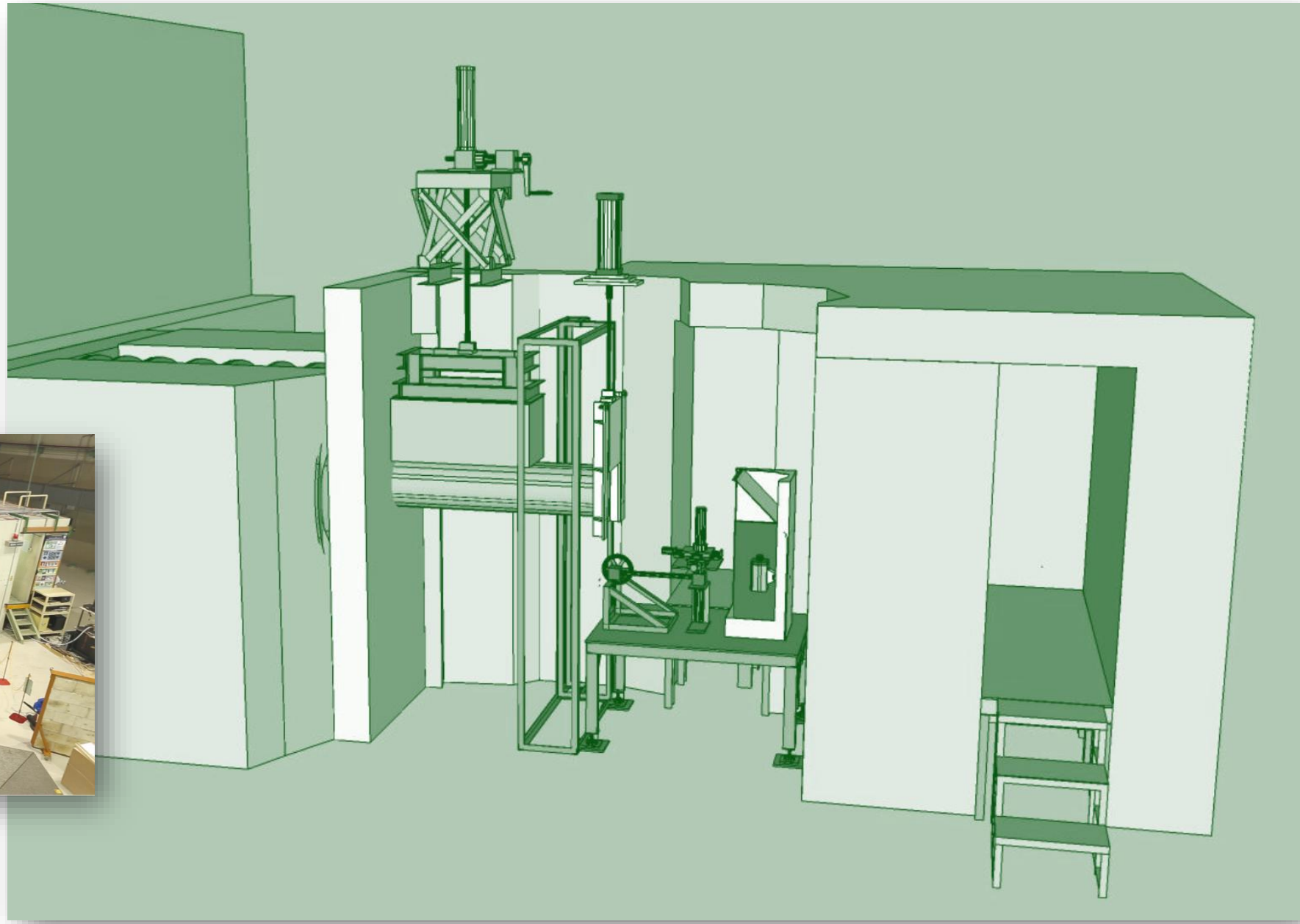
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Neutron CT







Neutron Vision

- ✓ The Complementary Technique of X-Ray Imaging
- ✓ Powerful tools to investigate samples non-destructively
- ✓ In 2019, **PERTAMINA** was looking for a New Solution to extract more oil from an old oil refinery
- ✓ Collaborate with University – TRISAKTI UNIVERSITY – Master of Petroleum and Earth Department :
  - Barea Core samples
  - Intermediate crude oil
  - Bagasse Surfactant



Neutron Vision

Berea Core



Fig 7. Berea Core, pore >20%, homogeneous material. Standard sample to study oil and surfactant interaction at the university

Berea core Component

Mineral	Berea (%w/w)
Quartz (SiO_2)	77.1
Kaolinite ($Al_2SiO_2O_3(OH)_4$)	5.3
Montmorillonite ($CaO_2(AlMg)_2Si_4O_{10}(OH)_24H_2O$)	2.6
Calcite ($CaCO_3$)	-
Calcium Silicate ($CaSiO_3$)	-
Albite, Calcian, ordered $(CaNa)Al(SiAl)_3O_8$	2.5
$NaO_3(AlMg)_2Si_4O_{10}(OH)_24H_2O$	-
Muscovite $(KNa)Al_2(SiAl)_4O_{10}(OH)_2$	7.3
Hydrotalcite $(Mg_6Al_2CO_3(OH)_{16}4H_2O$	-
Pumpellyte $(Ca_2FeAl_2(SiO_4)(SiO_7)(OH)2H_2O$	-



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Bagasse surfactant → Surfactant lignosulfonate → Used as injection fluid in the EOR

Why Bagasse Surfactant?

Total sugar cane crop in Indonesia 395,399.44 hectares

↓

Each hectare → 100 tons of bagasse → 39,539,944 tons per year

↓

After Milling processes → Bagasse become **waste**

+

Environmentally friendly



Neutron Vision

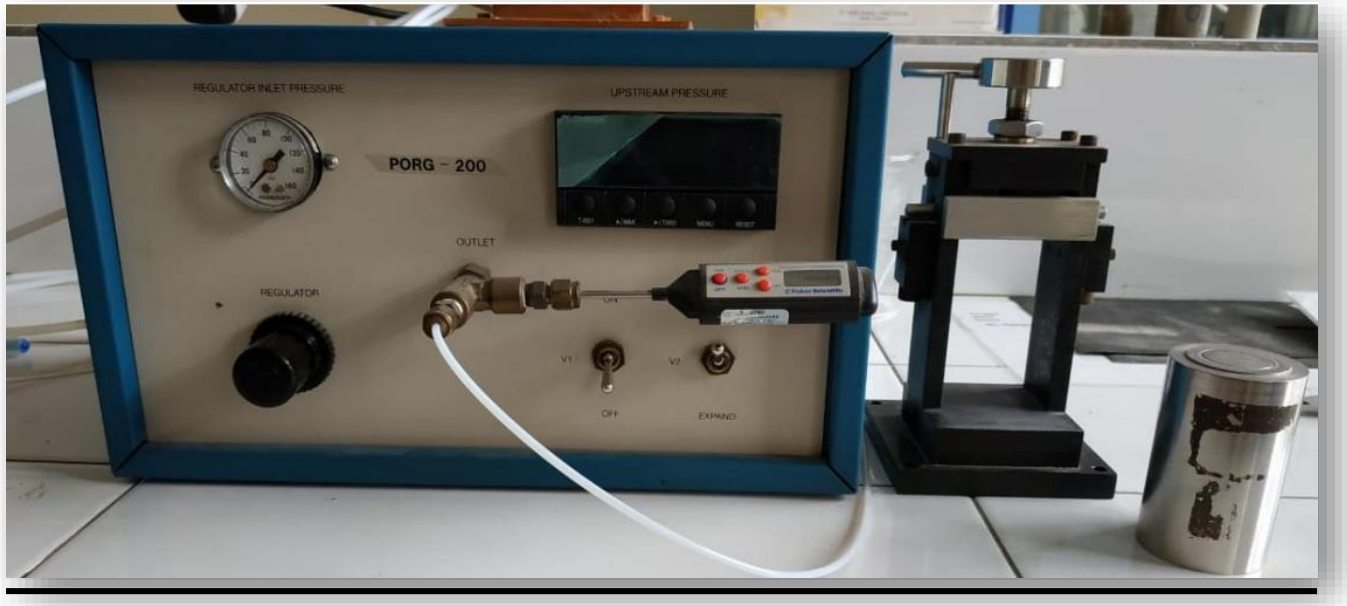


Fig 8. Porosimeter (PORG-200™ unit)



Fig 9. Injection systems – Core Flooding Systems



Neutron Vision

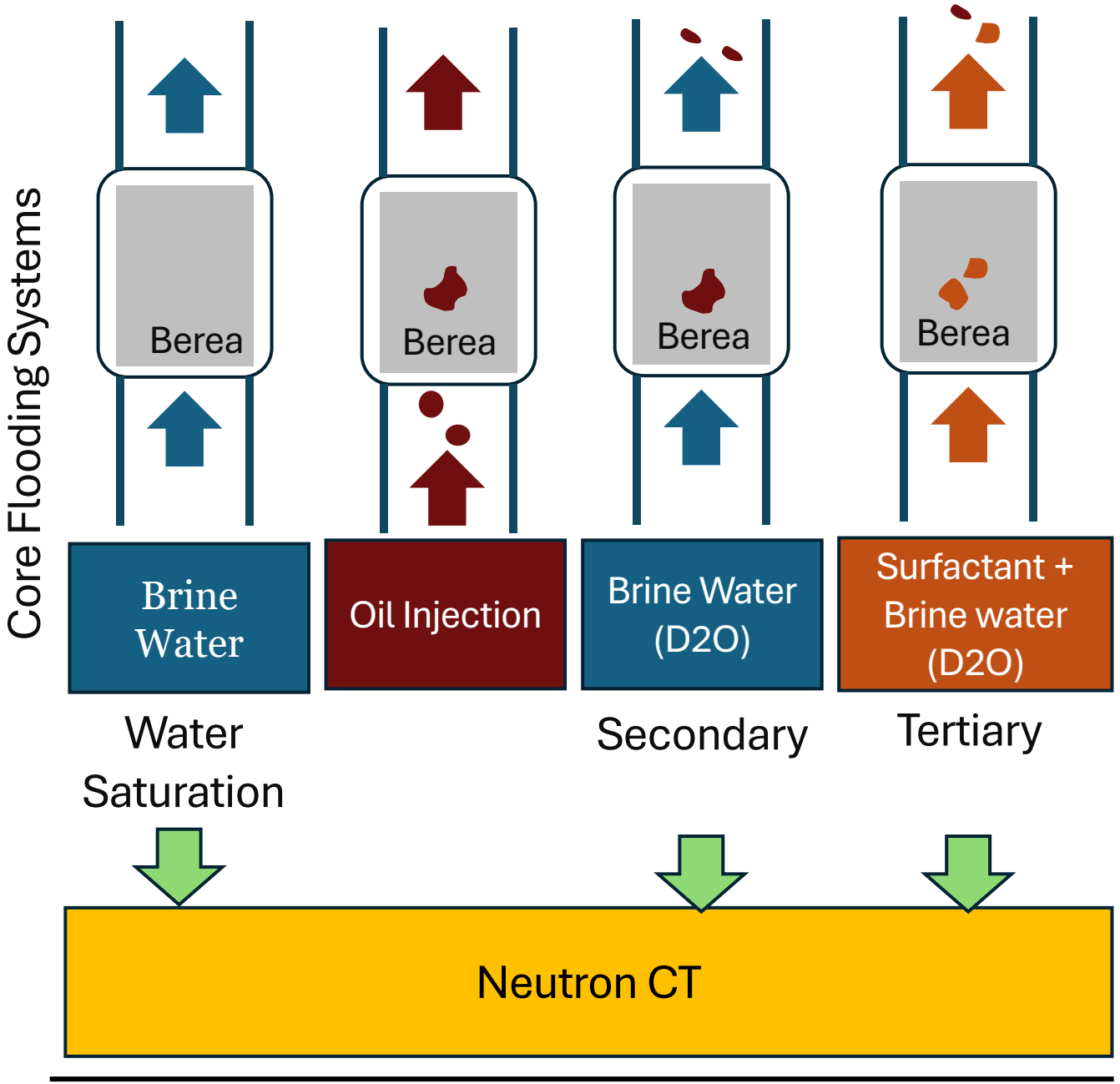


Fig 10. Experimental Setup

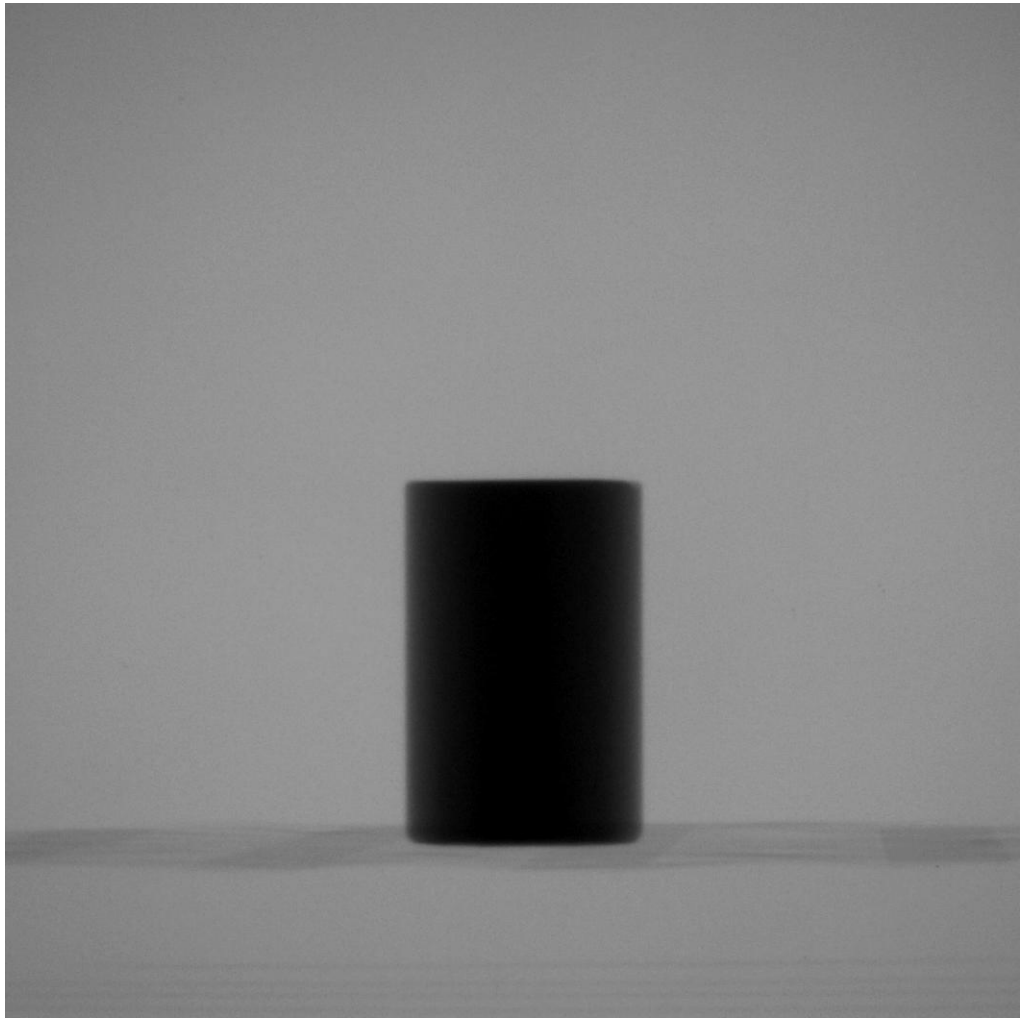


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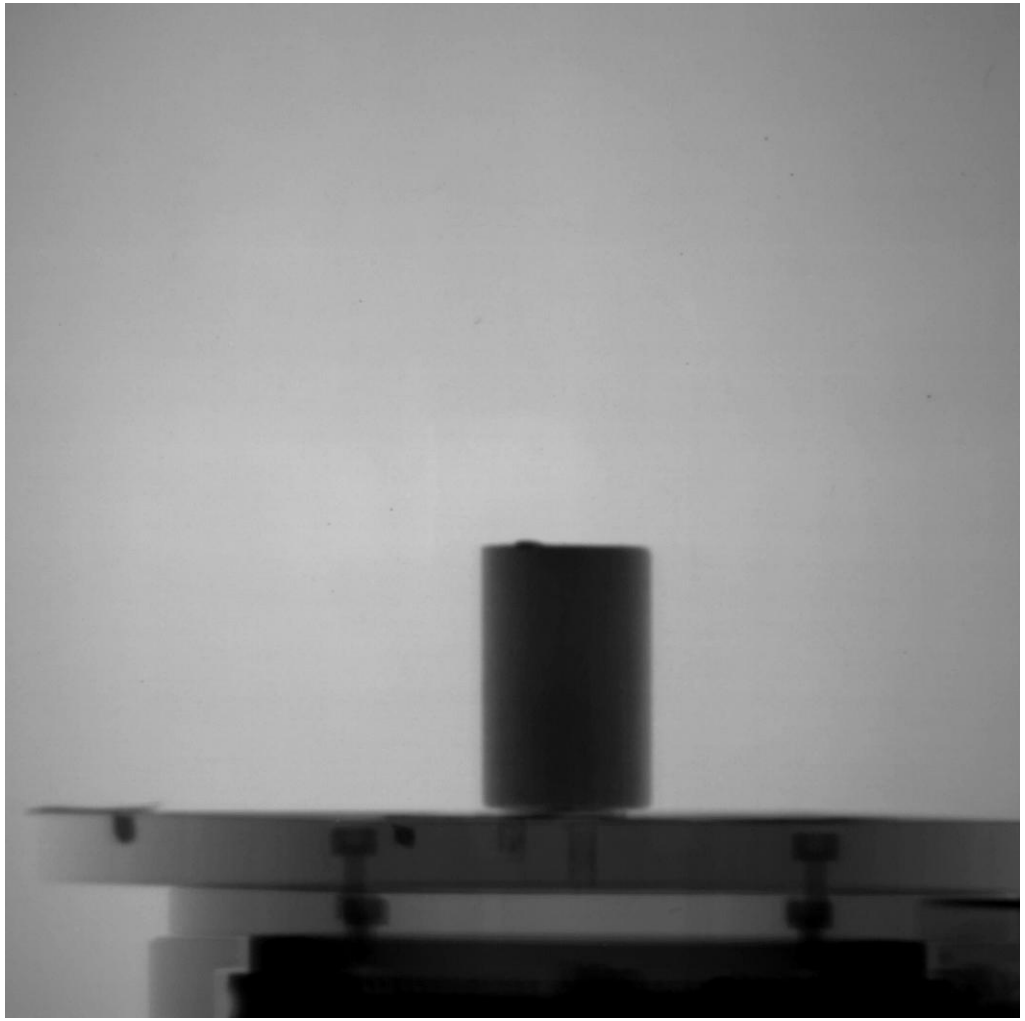
Preliminary Study

Water Saturation





X-Ray



Neutron

Fig 11. X-ray vs Neutron at Berea Sandstone Sample

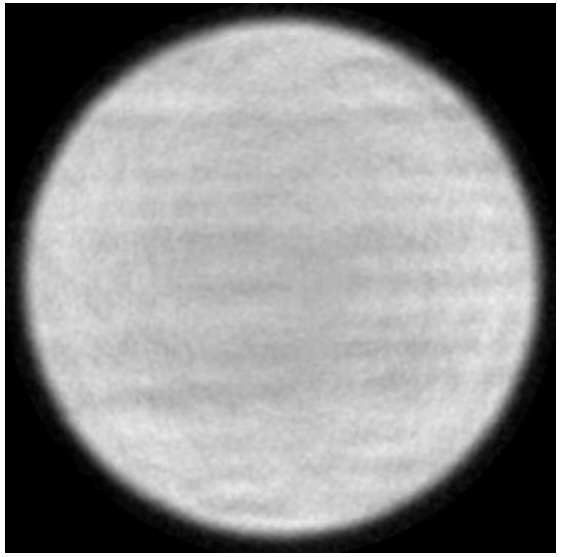


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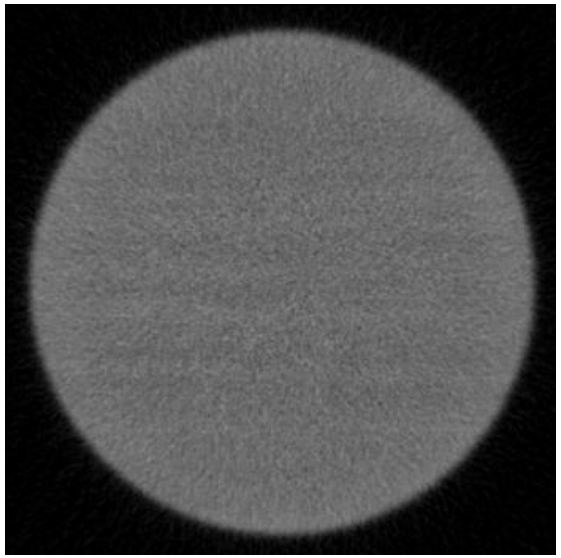
Preliminary Study

Water Saturation



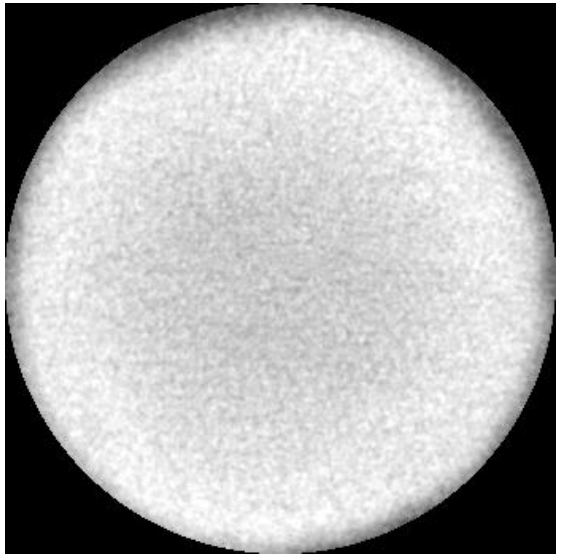


Neutron



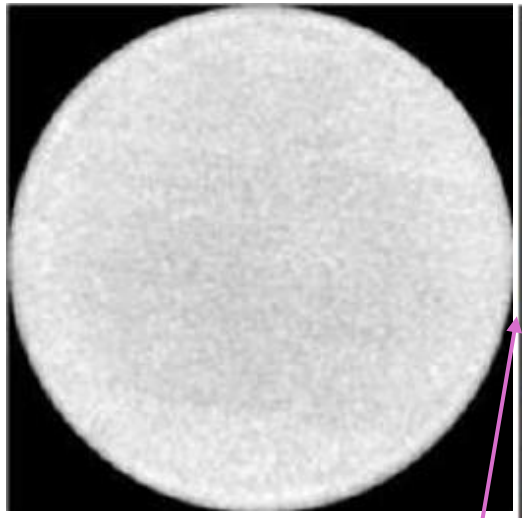
X-Ray

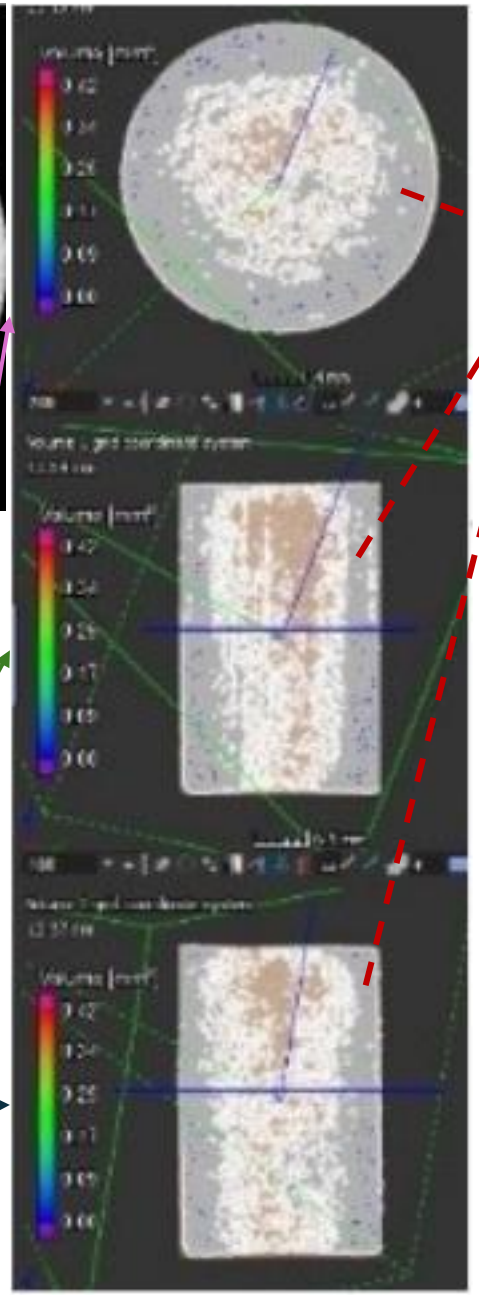
We Can see the water distribution → Brine Water Saturation (± 1 Day)

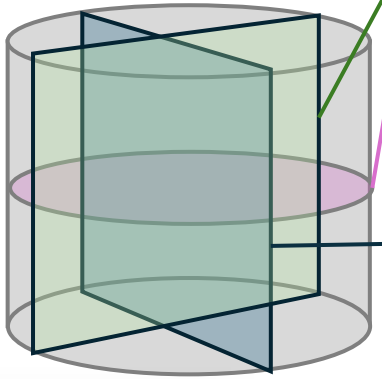


Soak it with Brine Water again for about ± 1 Day

Fig 11. X-ray vs Neutron at Berea Sandstone Sample



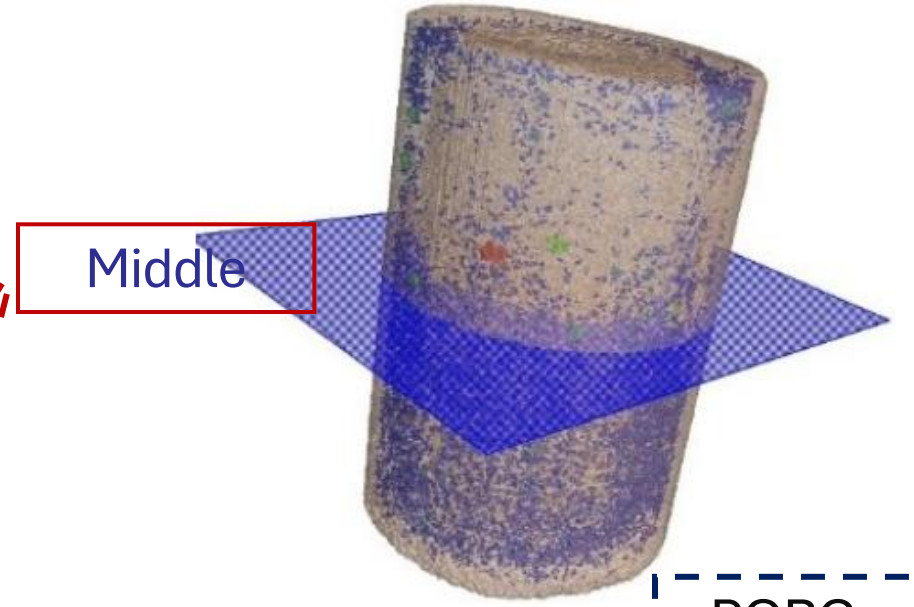




Neutron Vision

Preliminary Study

Porosity Measurement



PORG-200™ unit

Core No.	Diameter (cm)	High (cm)	Bulk Vol (cc)	Gas Porosity (%)	Neutron Porosity (%)
X3	2.462	3.793	18.061	20.486	20.11
X4	2.456	3.747	17.791	20.231	20.04
X7	2.460	3.770	17.926	20.832	20.78

Does NI really calculate the sandstone porosity?

Yes – in **wet conditions,** the sample has **homogeneous** material and data from PORG-200™



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Preliminary Study

Flow of Oil

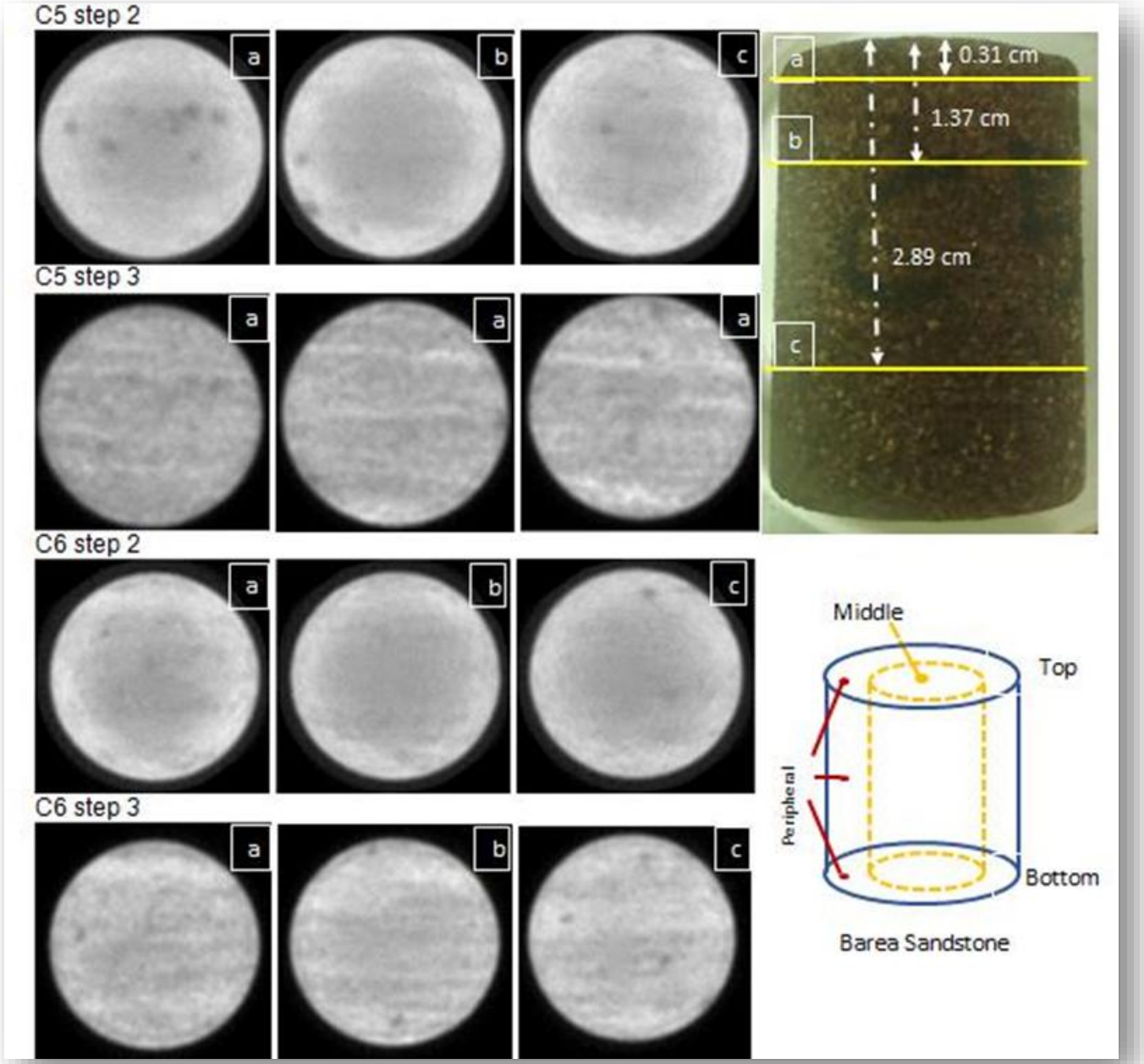


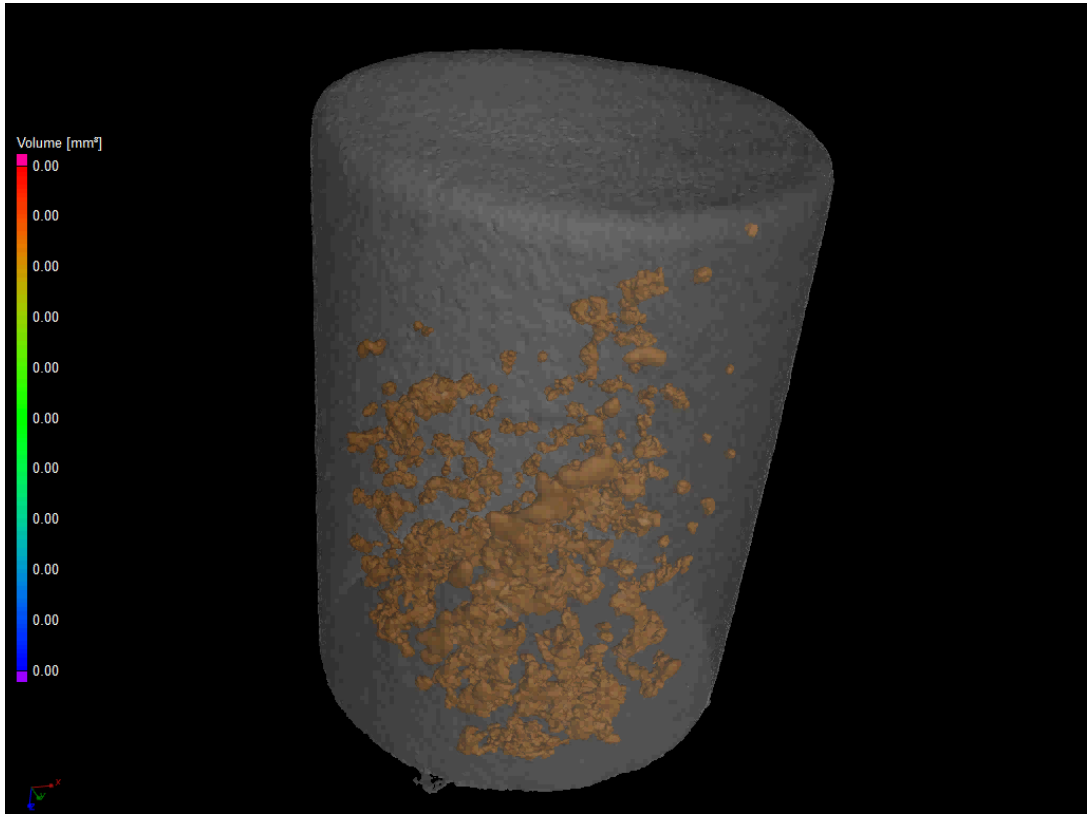
Fig 12. Flow of oil before and after bagasse surfactant



Neutron Vision



Oil Distribution on Berea Sandstone sample – 2nd (Brine water flooding)



Oil Distribution on Nerea Sandstone sample – 3rd (Surfactant flooding/EOR) – Cross section images (tomography)



Neutron Vision

Flow of water inside Berea sandstone

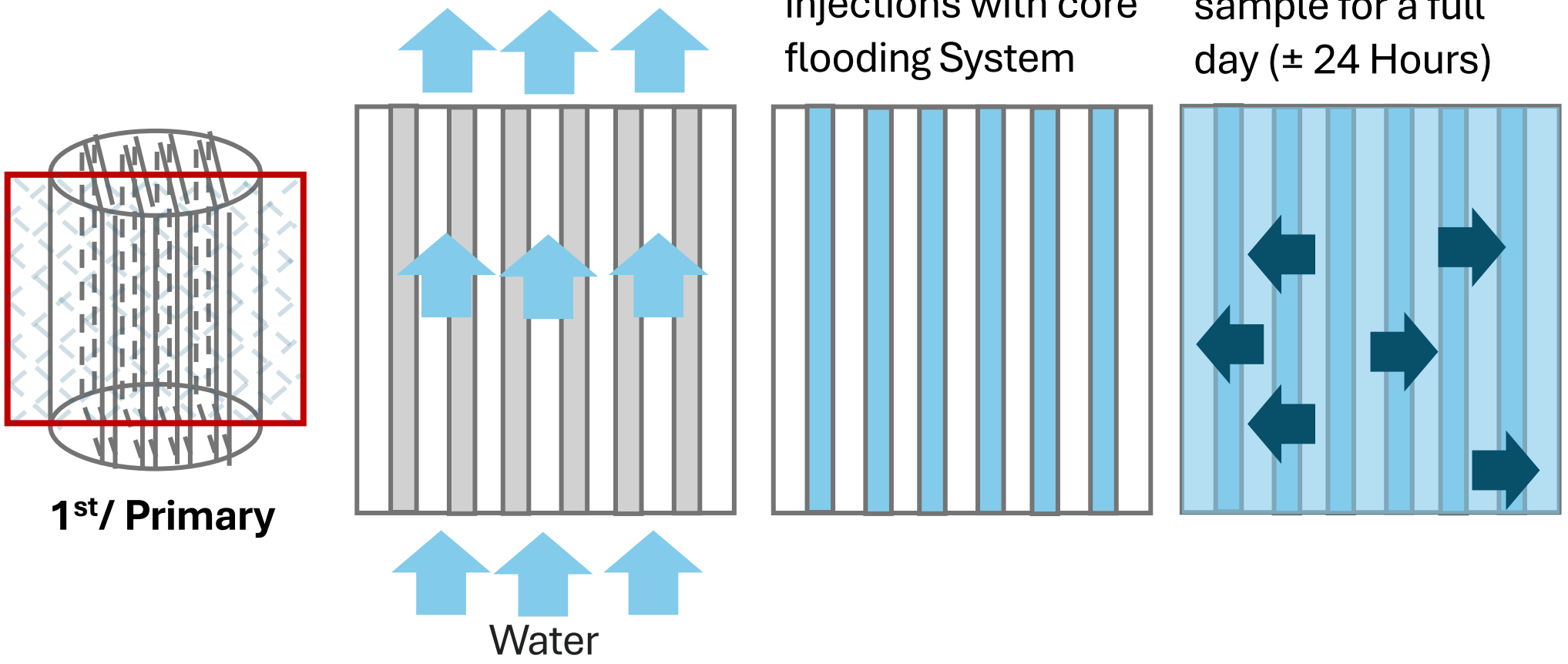
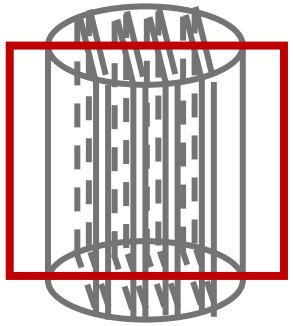


Fig 13. Flow of brine water inside the Berea sandstone sample



Neutron Vision

Preliminary Study



1st/ Primary

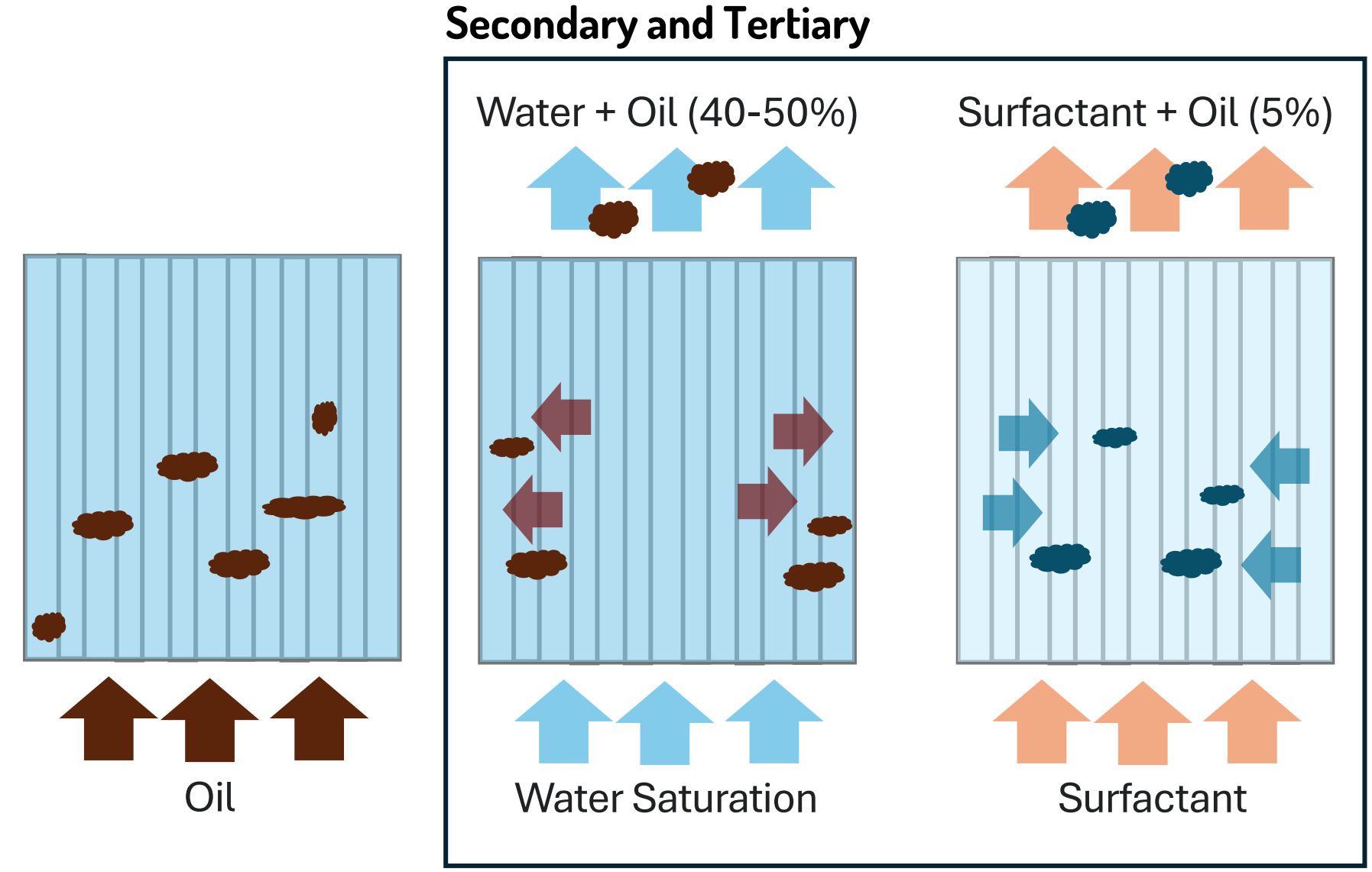


Fig 14. Flow of oil inside Berea before and after surfactant flooding



Neutron Vision

RGNZ/MGPB

Application of Neutron Computed Tomography in Enhanced Oil Recovery for Analysing Oil Distribution in Berea Sandstone using Bagasse Surfactant

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 552.1
DOI: 10.17794/rgn.2023.5.8

Original scientific paper

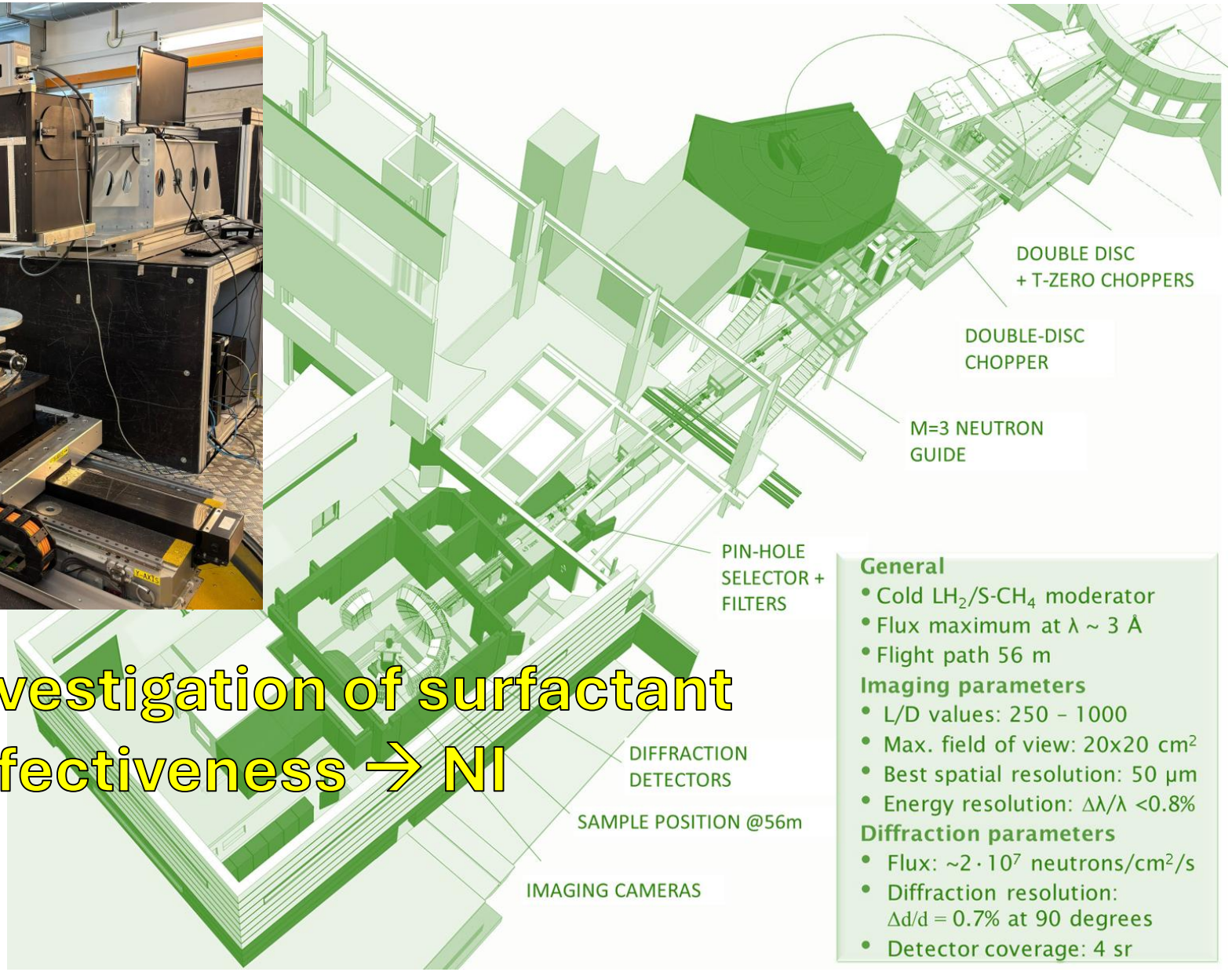
Rini Setiati[1*]; Fahrurrozi Akbar[2]; Gabriel Prasucipto Karisma[3]; Achmad Ramadhani[4]; Setiawan Setiawan[5]; Renato Aditya[6]; Muhammad Taufiq Fathaddin[7]; Sulistioso Giat Sukaryo[8]; Bharoto Bharoto[9]; Iwan Sumirat[10]

https://hrcak.srce.hr/file/448538



Neutron CT





NEXT STEPS ....!

Investigation of surfactant effectiveness → NI



Sample Preparation

- ✓ Light Crude Oil:
  - 33° API and
  - 39 ° API
- ✓ Berea Sandstones
- ✓ Methyl Ester Sulfonate (MES) palm oil surfactants with (2% and 0.5% Concentration)
- ✓ D_2O

*API: American Petroleum Institute

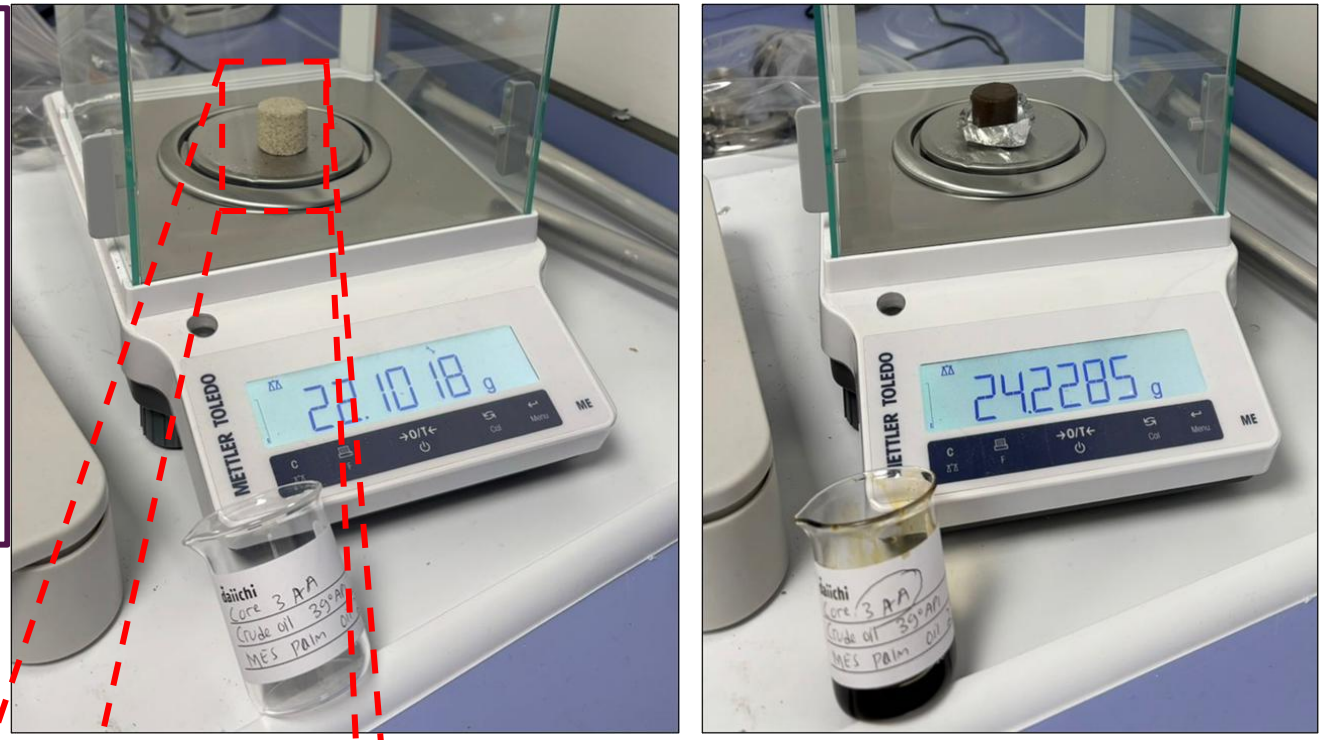
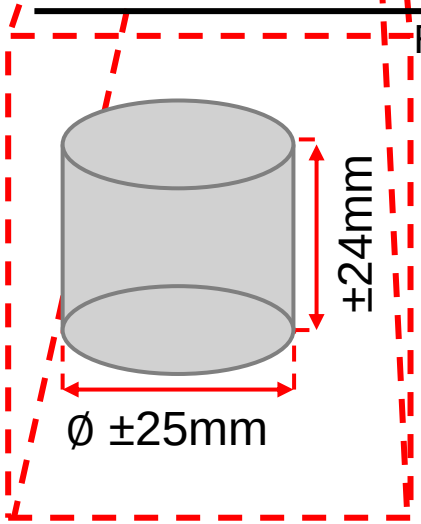


Fig 15. Berea Sandstone before and after oil addition





Sample Preparation

Why **MES Palm Oil** Surfactant?

- It is widely used by oil industries → Its High performance
- Eco-friendly
- Cost Effective anionic biosurfactants
- Massive reduction of Interfacial Tension (IFT) → lowering the IFT from **~30mN/m** to ultralow values **(~10^{-2} to 10^{-3} mN/m**)
- Allowing trapped oil droplets to deform, snap out the capillarity traps → increase the oil production



Sample Preparation

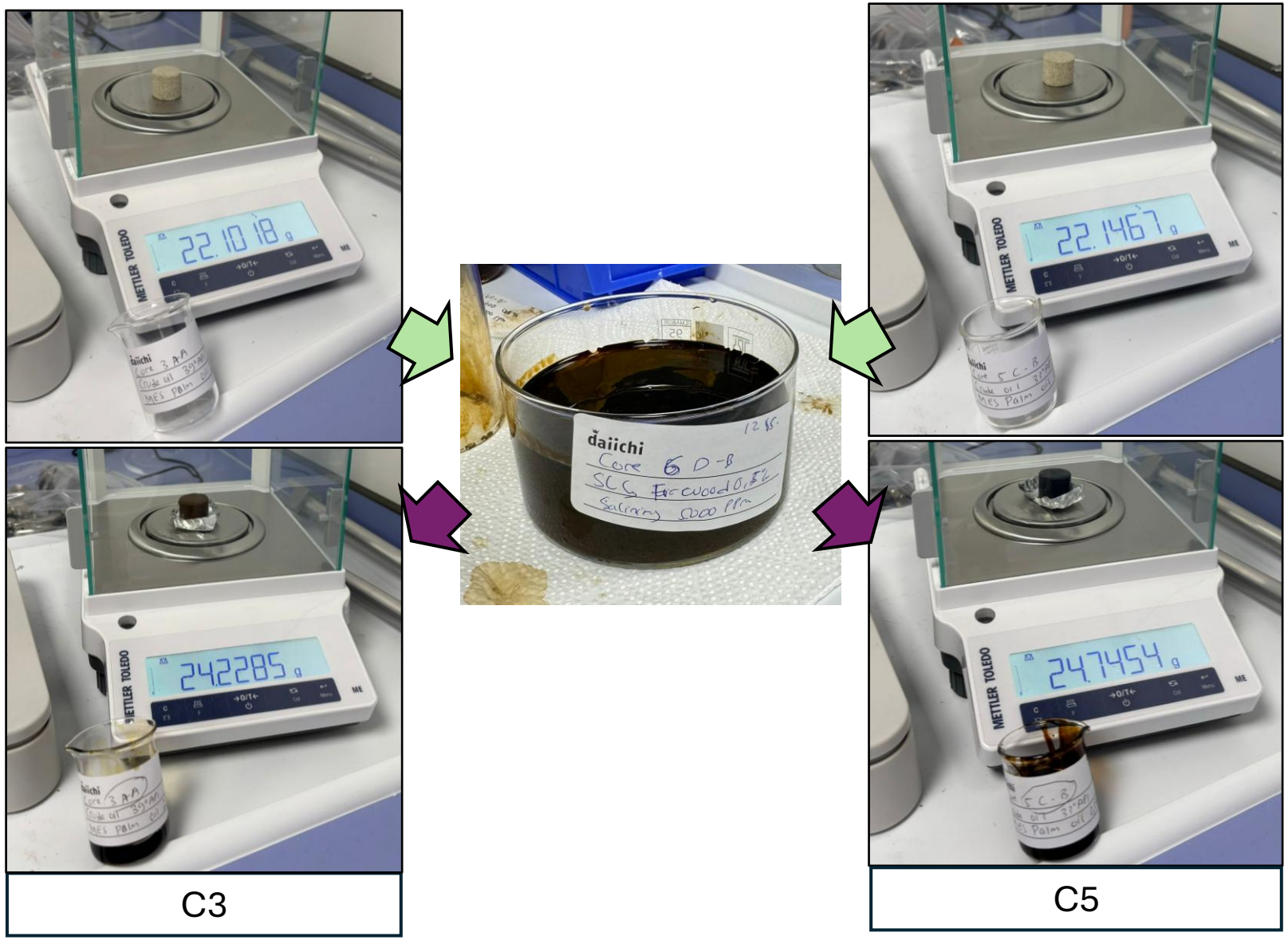
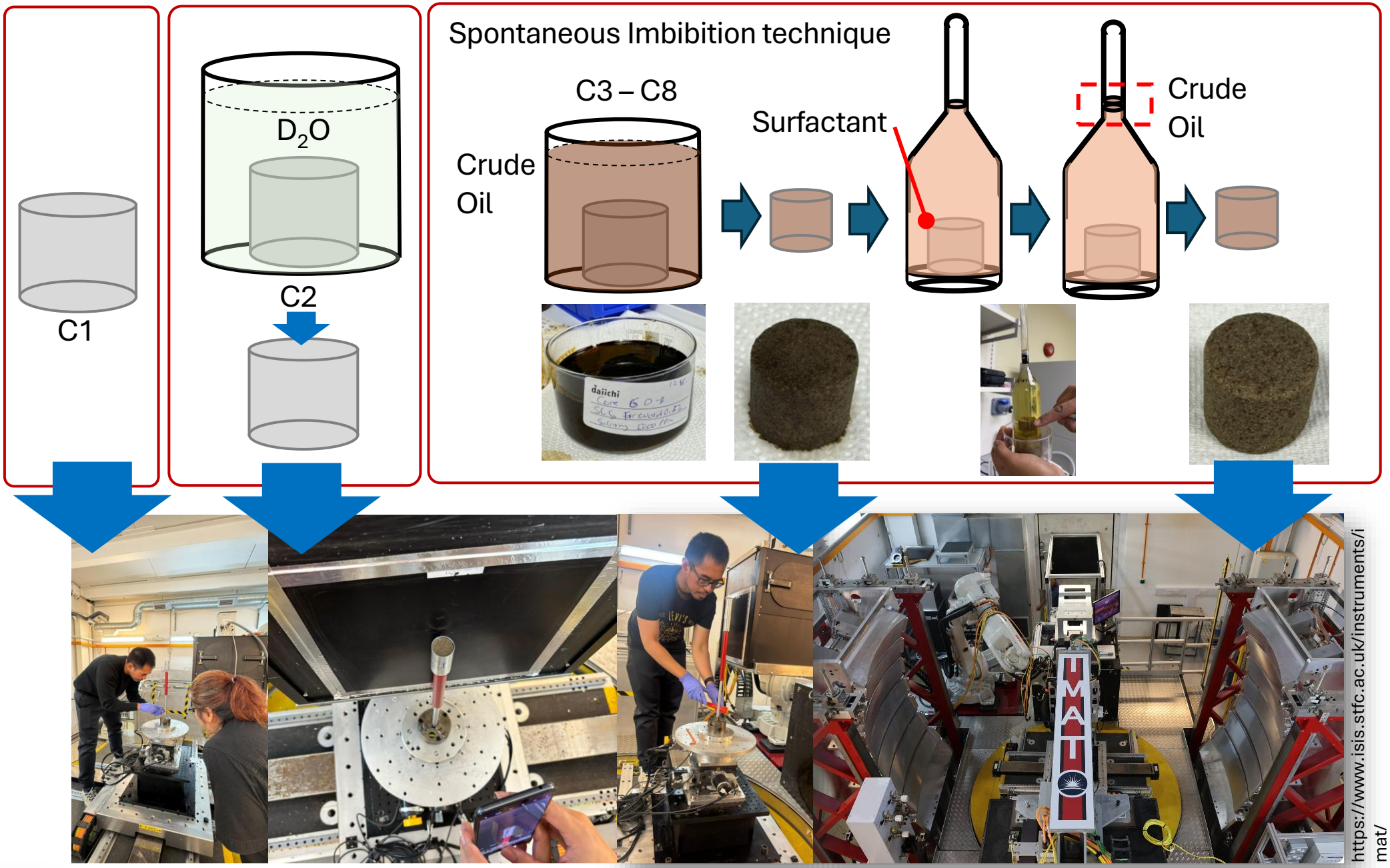


Fig 16. Berea samples C3 and C5: before and after oil addition



Method



https://www.isis.stfc.ac.uk/instruments/imat/

Fig 17. Experimental setup – imbibition technique

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Method



Fig 18. Spontaneous Imbibition Technique



Method

Table 1. Initial measurement

Core	Crude Oil	Surfactant	Concentration	Imbibition at the Amott cell (ml)				OOIP (ml)	Remining Oil (ml)
				0 min	30 min	2 hours	3 days		
C1- Dry	-	-	-	-	-	-	-	-	-
C2-D2O	-	-	-	-	-	-	-	-	-
C3	39°API	MES palm oil	2%	0.3	0.4	0.8	1.15	1.785	0.635
C5	33°API	MES palm oil	0.50%	0.1	0.3	0.5	1.25	2.186	0.936
C7-Oil	39°API	-	-	-	-	-	-	-	-
C8-Oil	33°API	-	-	-	-	-	-	-	-

*OOIP: Original Oil In Place
*American Petroleum Institute

We will check it using CT

NDT

Result and Discussion

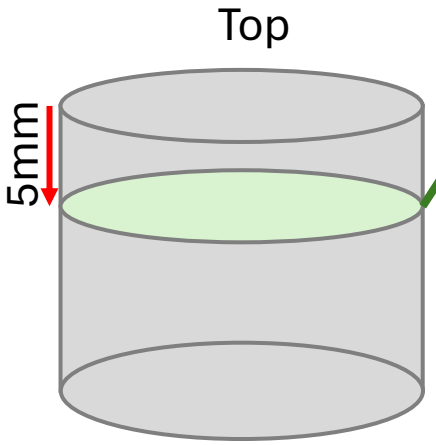


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Result and Discussion

Tomograms



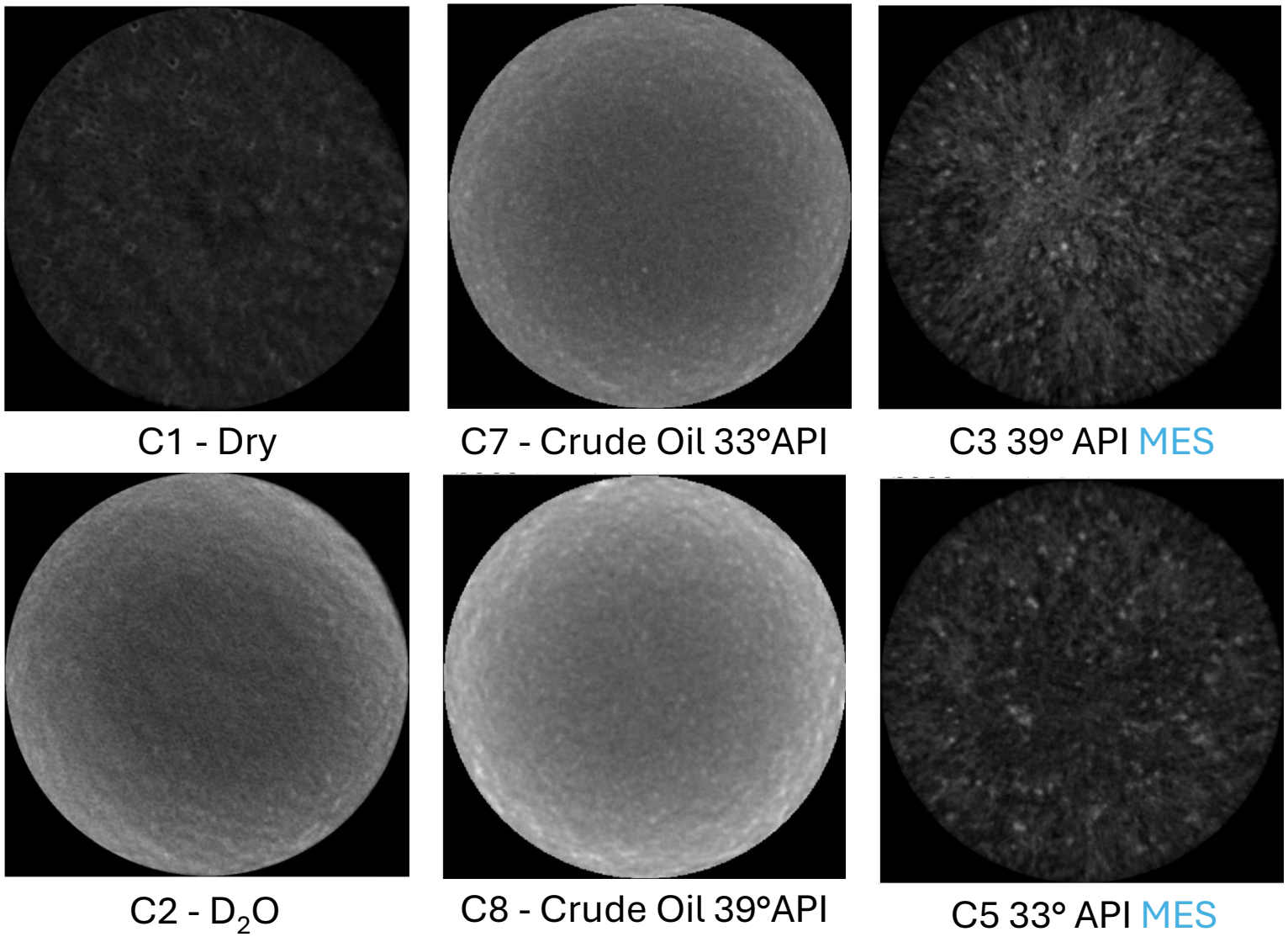


Fig 19. Tomogram images of C1 – C8 at 5mm position from the top

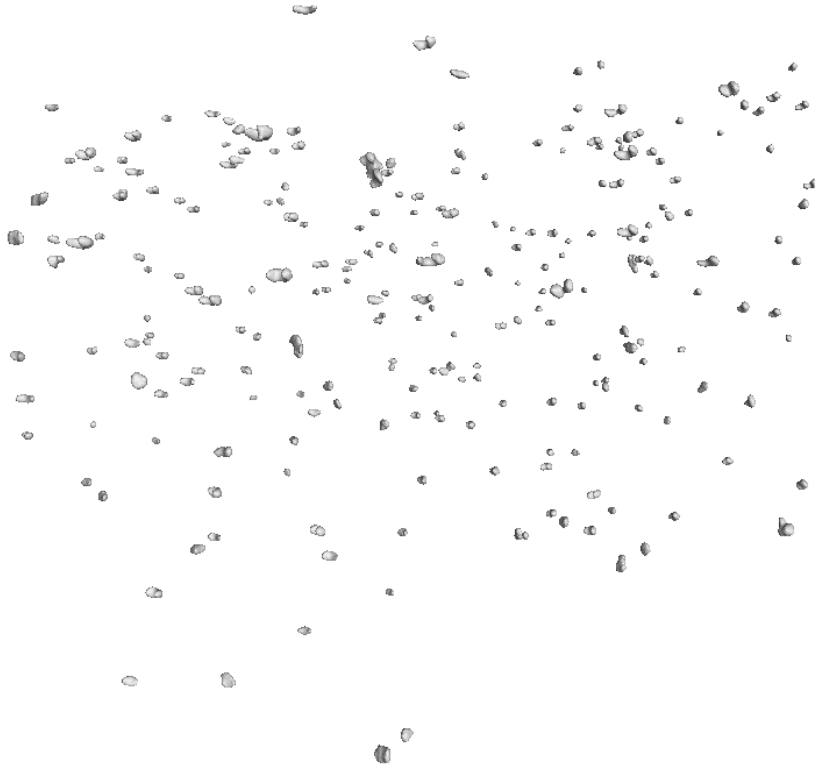


Result and Discussion

CT – 3D- C1 - Dry Reconstruction



~2k/65k



Impurities

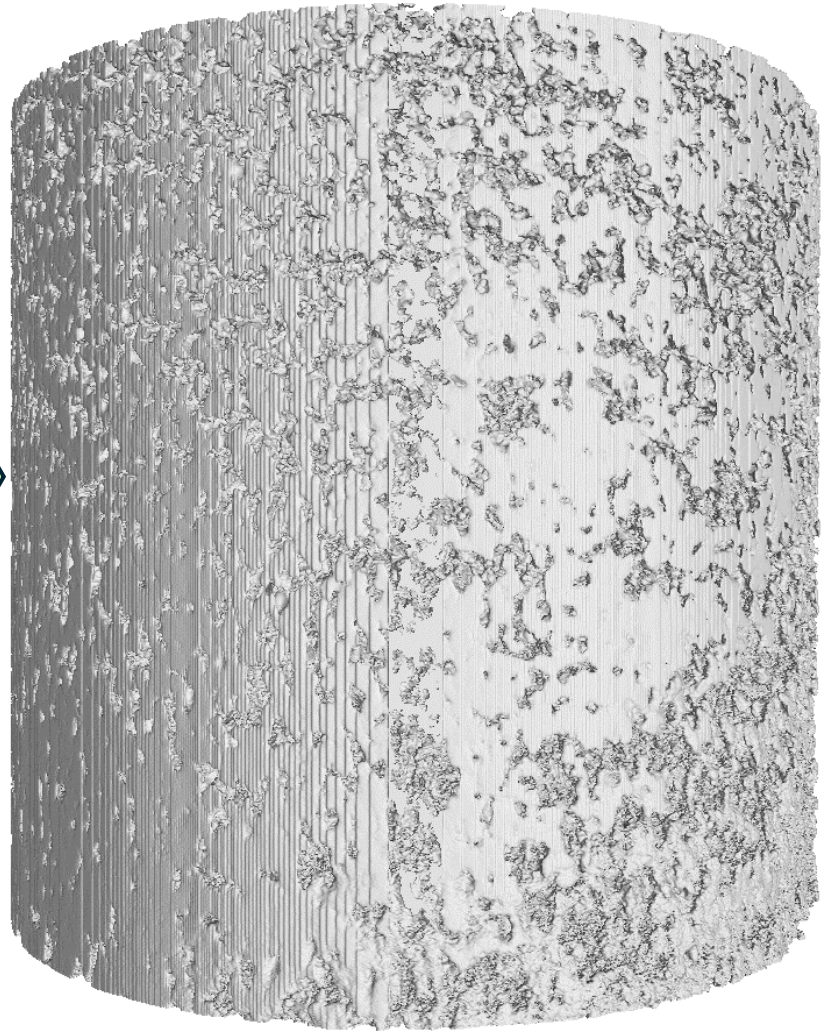


Fig 20. A 3D visualization of C1 – Using VG Studio Max 3.0



Result and Discussion

CT – C1 - Dry

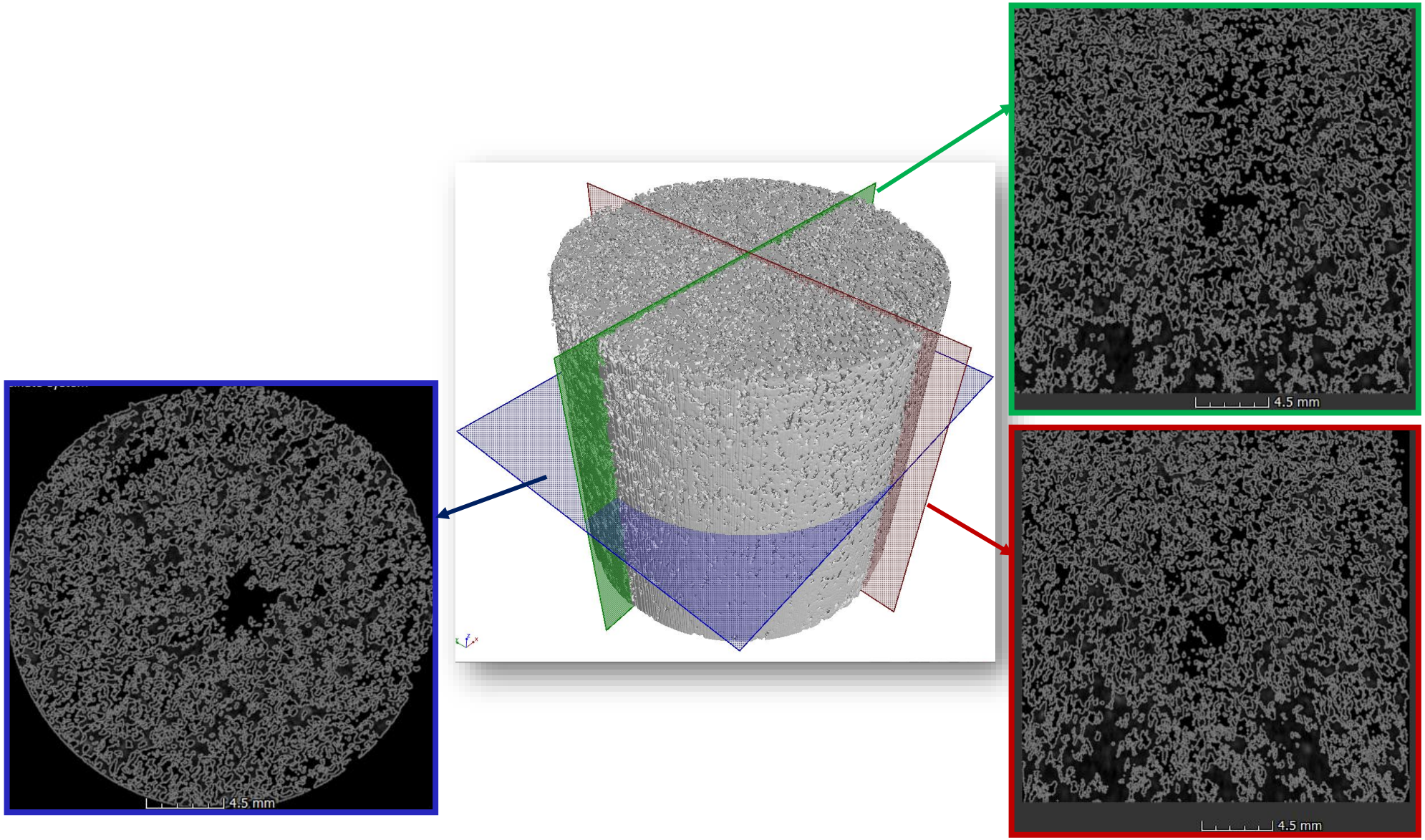


Fig 21. 3D Slicing Visualization of C1 – TOP View – Front View – Right View



Result and Discussion

CT – C2 – D_2O

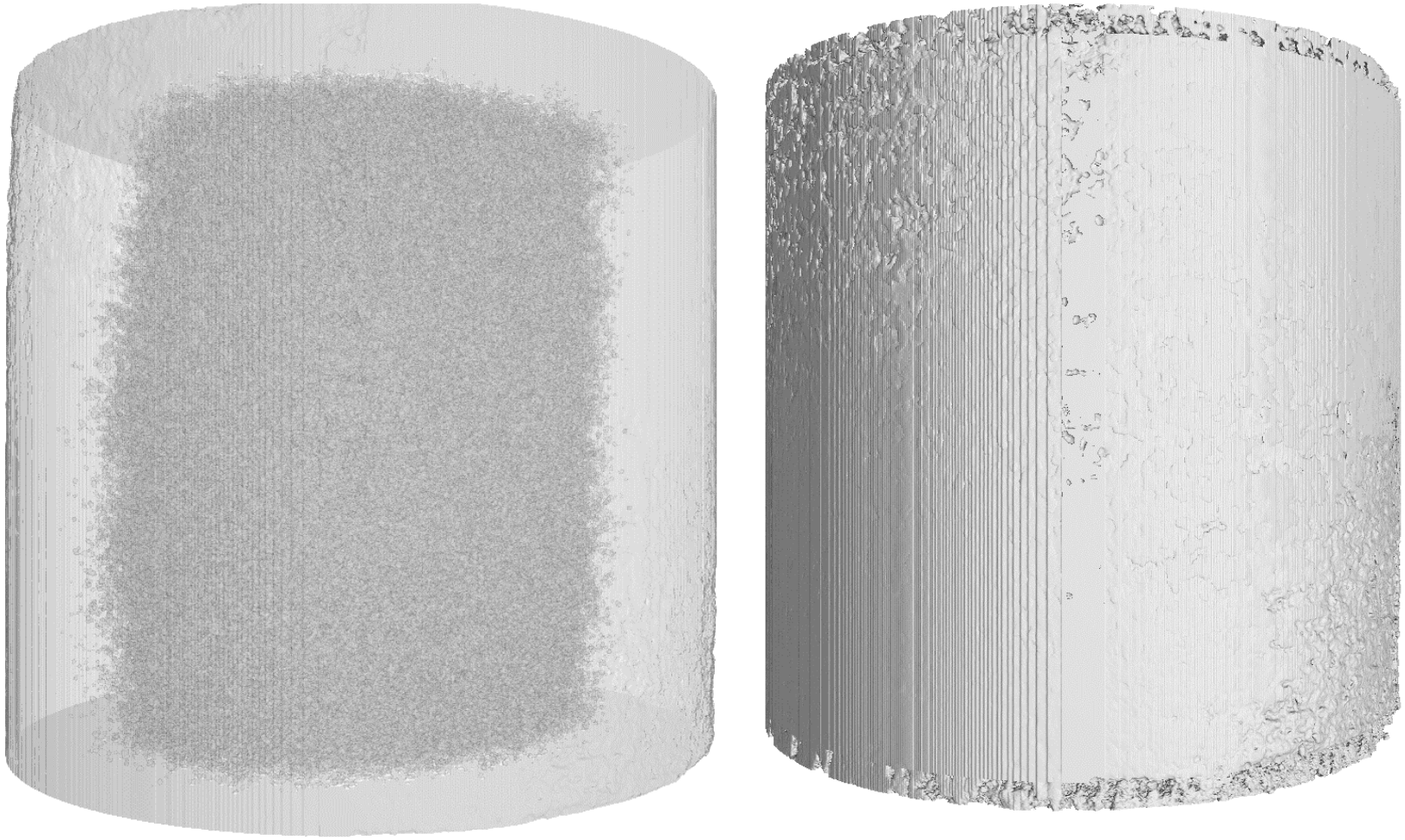


Fig 22. 3D Visualization of C2 – D2O



Result and Discussion

CT – C2 – D_2O



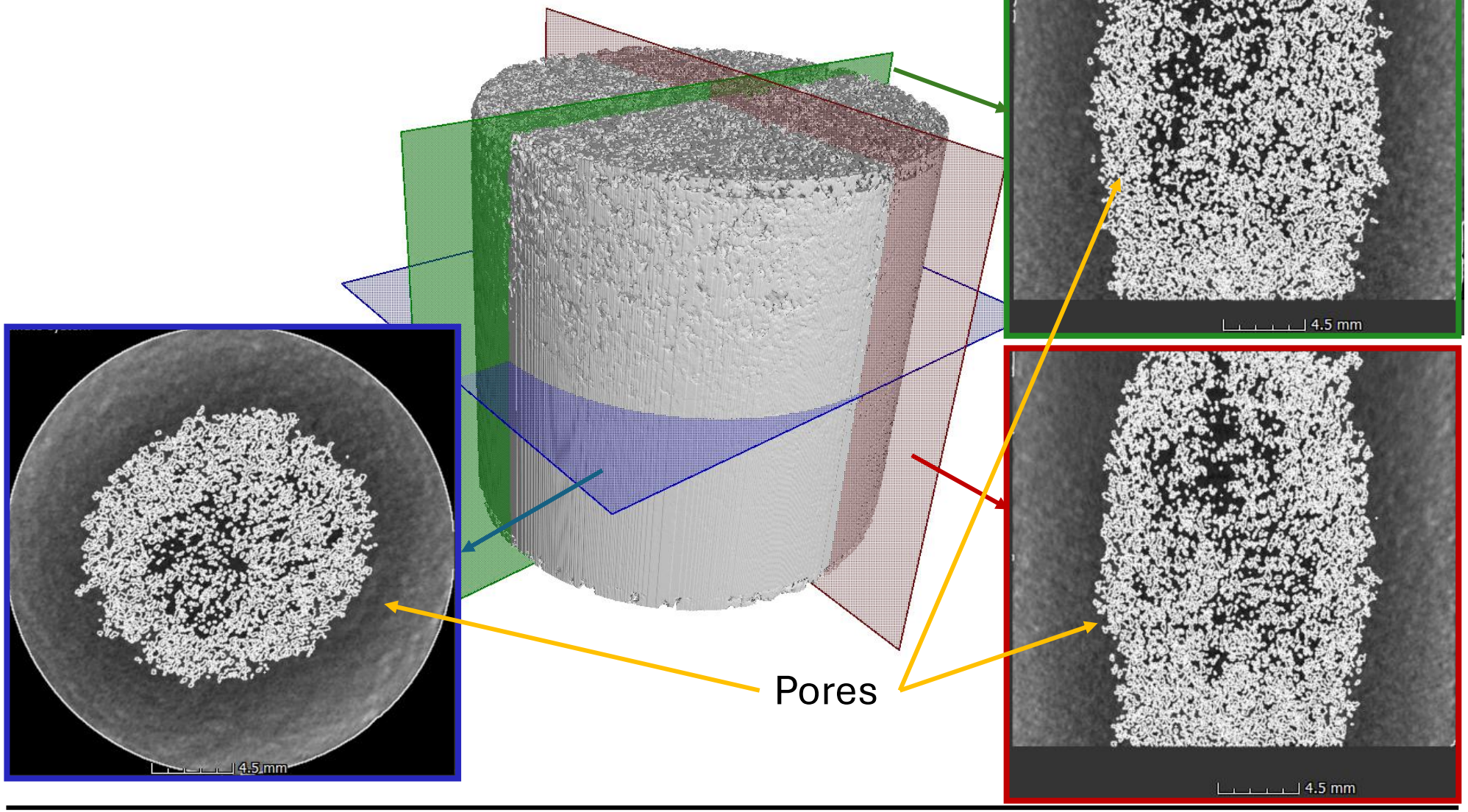
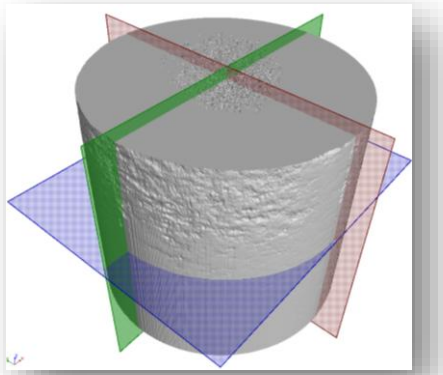


Fig 23. 3D Slicing Visualization of C2 – TOP View – Front View – Right View

Result and Discussion

C7: 39°API and
C8: 33 °API



Core	CT (ml)
C7-39ºAPI	2.172
C8-39ºAPI	1.969

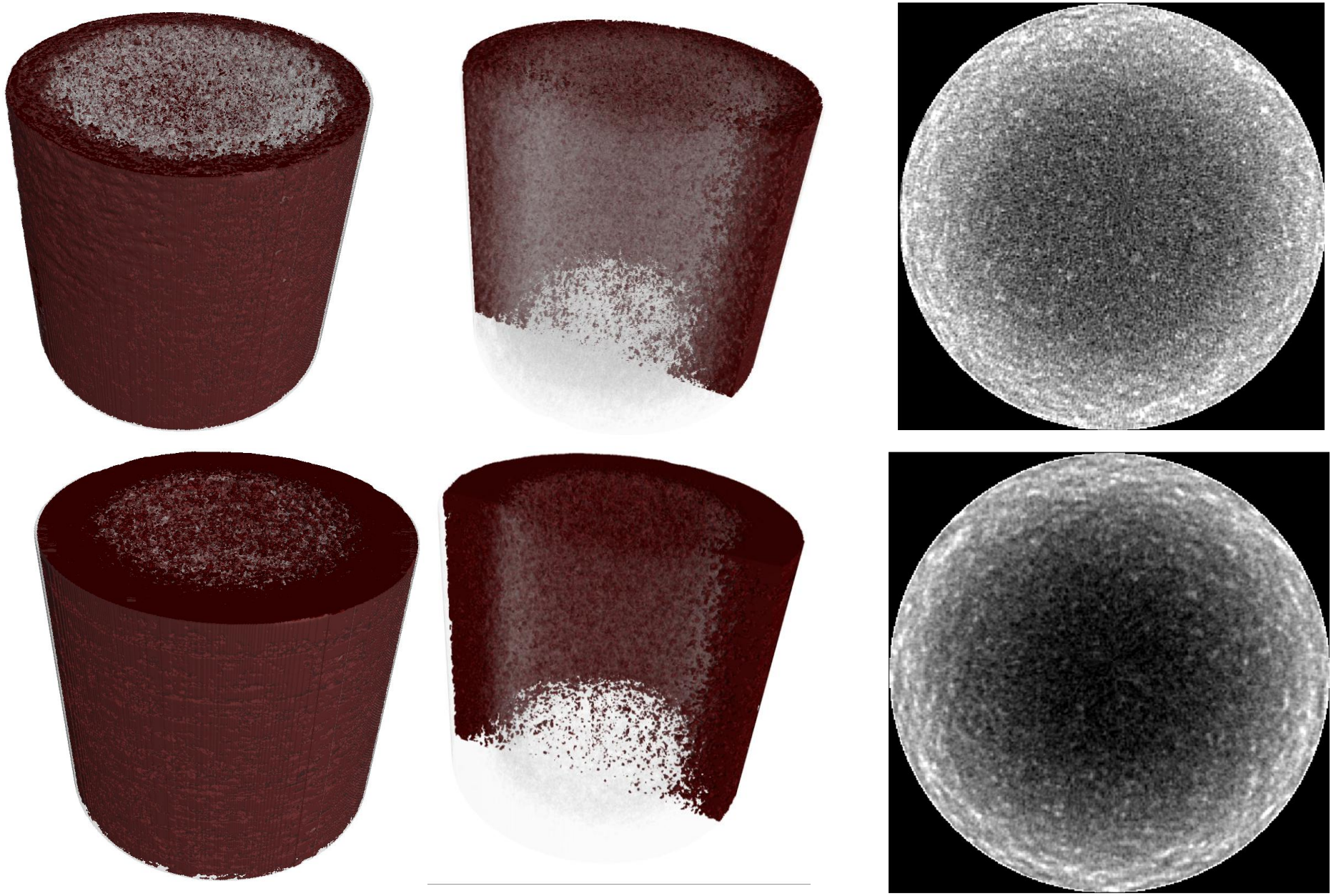
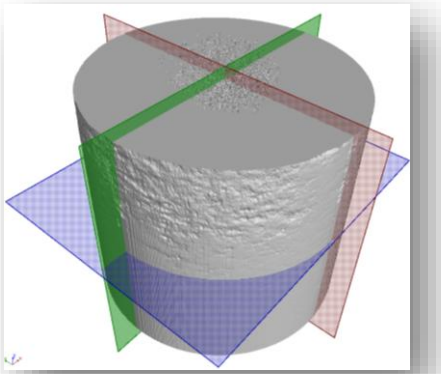


Fig 24. 3D Visualization of Light Crude oil , 39°API and 33°API inside the Berea Sandstone sample

Result and Discussion

C7: 39°API and
C8: 33 °API



C7: 39°API

C8: 33°API

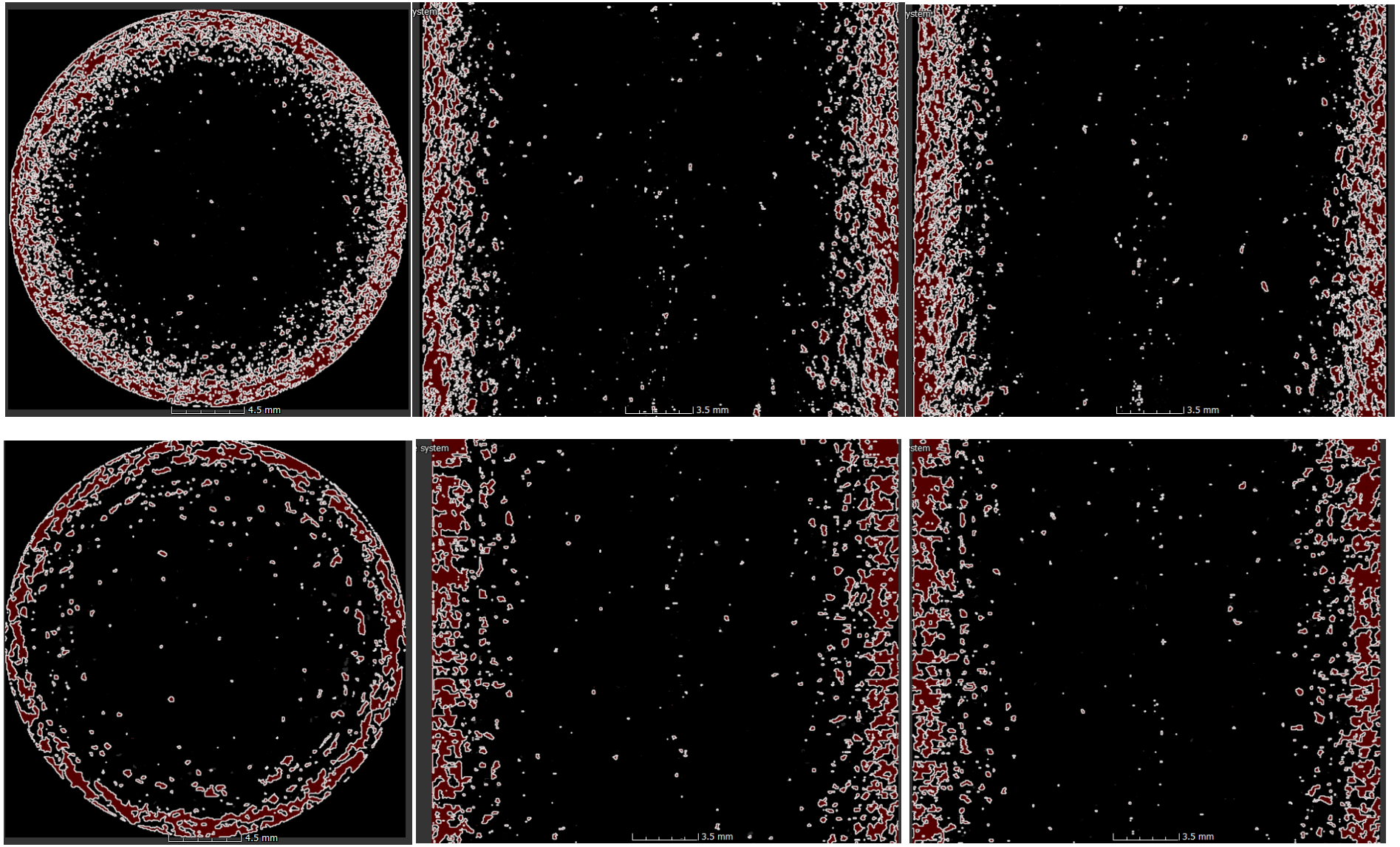


Fig 25. 3D Slices of Light Crude oil , 39°API and 33°API inside the Berea Sandstone sample



Result and Discussion

C7: 39°API

The 39° API oil has lower viscosity. It makes the oil easily penetrate the sandstone sample and reach the sandstone core.

From the CT measurement, we can calculate that the total crude oil detected was **2.172ml**

White / Bright color is oil
Grey color is sandstone material
Black is pore

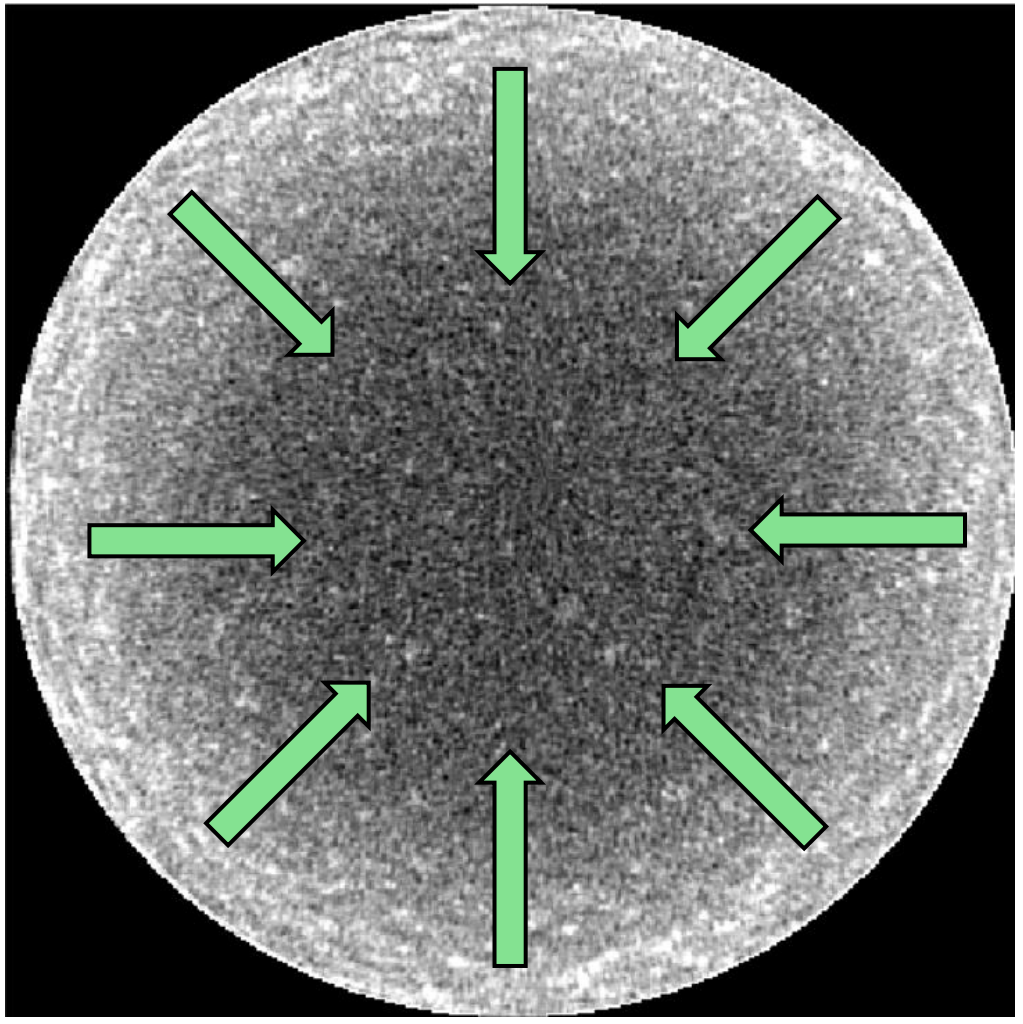


Fig 26. The oil movement from the peripheral to the core / center of the sandstone



Result and Discussion

C8: 33°API

The 33° API oil has more viscosity than 39° API oil. It makes the oil **slightly harder** to penetrate the sandstone. As we can see, there was not a lot of oil that could reach the center of the core

From the CT measurement, we can calculate that the total crude oil detected was **1.969ml**

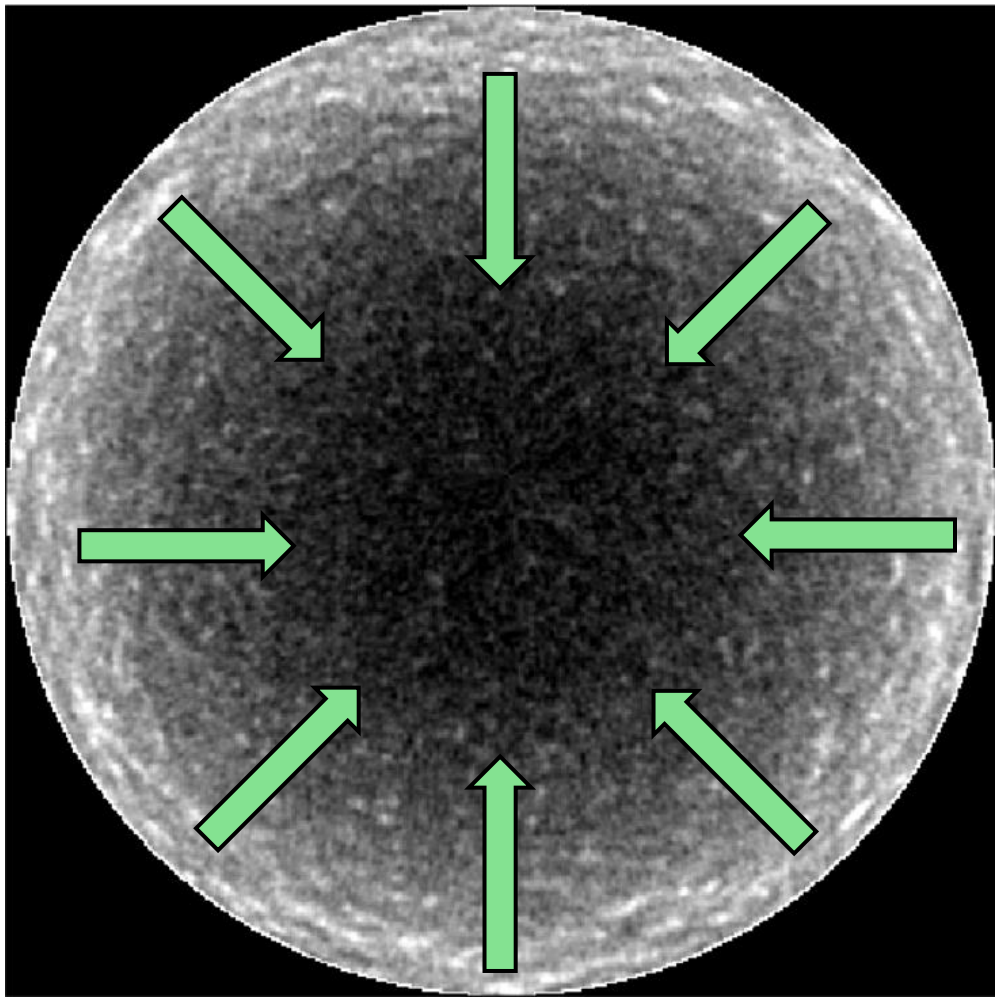


Fig 27. Movement of Oil inside the Berea sandstone sample

Result and Discussion



For Comparison :

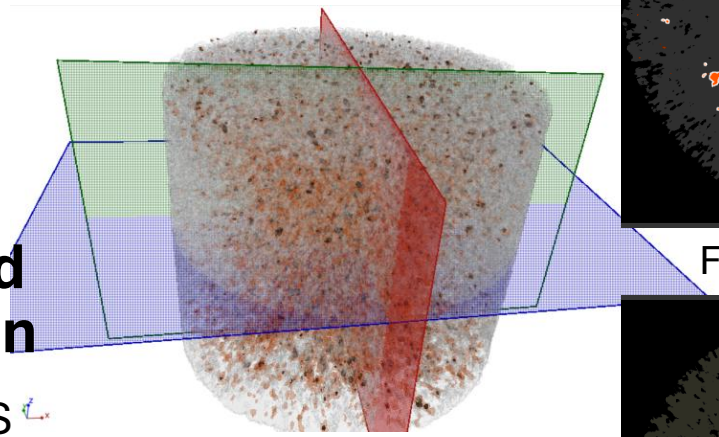
- ✓ Water has 1.0 cp
- ✓ Human blood 4 – 6cp at 37°C

- ✓ 33 API Crude: This is a light crude oil, but it is denser and **more viscous than a 39 API oil**. Data shows that a 33-35 API oil can have a viscosity roughly in the range of 4.5 to 6 cp (centipoise), while a 38-39 API oil can have a viscosity around 2.8 to 3.1 cp.
- ✓ 39 API Crude: This is a lighter crude. Its lower viscosity means it faces **less internal resistance to flow**, **allowing it to move through the tiny pore spaces** of the rock more freely.

Figures 24 and 25 show that most oil was trapped in the periphery of the sandstone. This happens because we soak the sandstone in a beaker container. The process of oil entering rocks naturally through the pores of the rocks. The first interaction between crude oil and rocks occurs at the edge



Result and Discussion



CT – C3 – MES
2% - 39°API



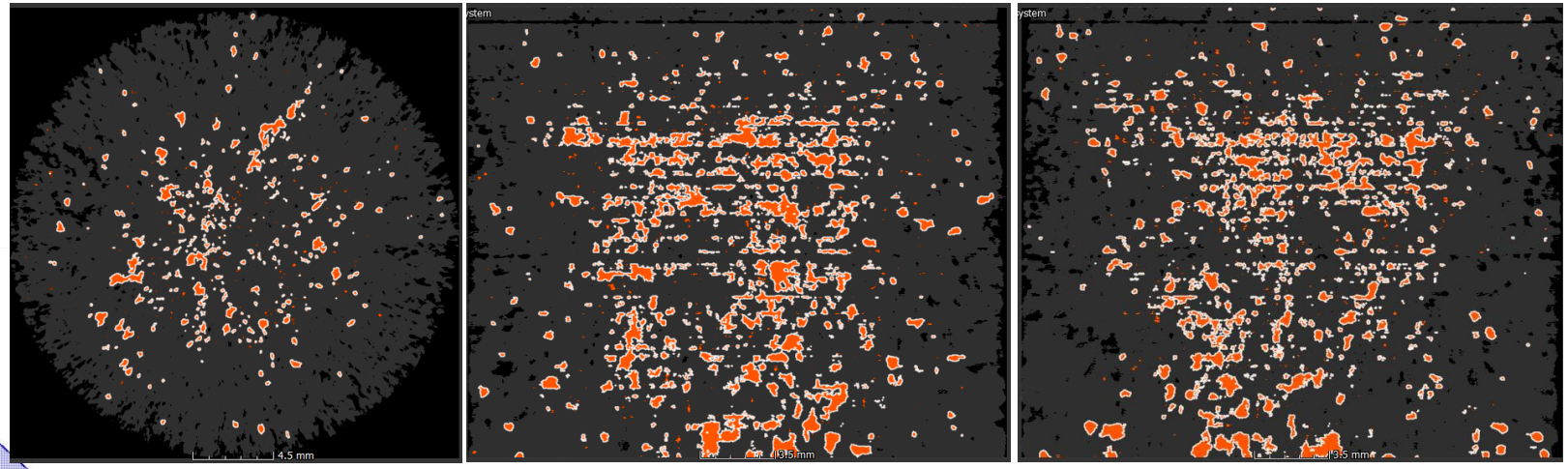


Fig 28. 3D Slicing Visualization of C3 – TOP View – Front View – Right View - Total

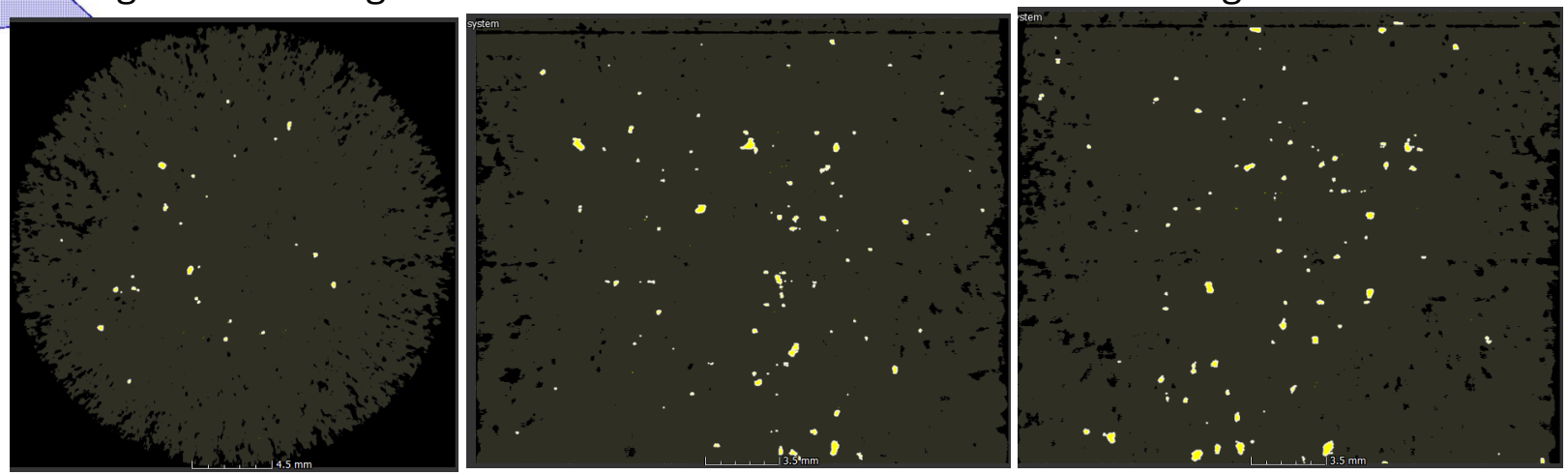


Fig 29. 3D Slicing Visualization of C3 – TOP View – Front View – Right View – High Concentration of Oil + Surfactant

OOIP	Amott Cell (ml)	Oil Remining (ml)	Oil Inside (CT(ml))	Oil High Con (CT (ml))
1.785	1.15	0.635	0.6235	0.028

4%



Result and Discussion

C3: 39°API MES (2%)

C5: 33°API MES (0.5%)

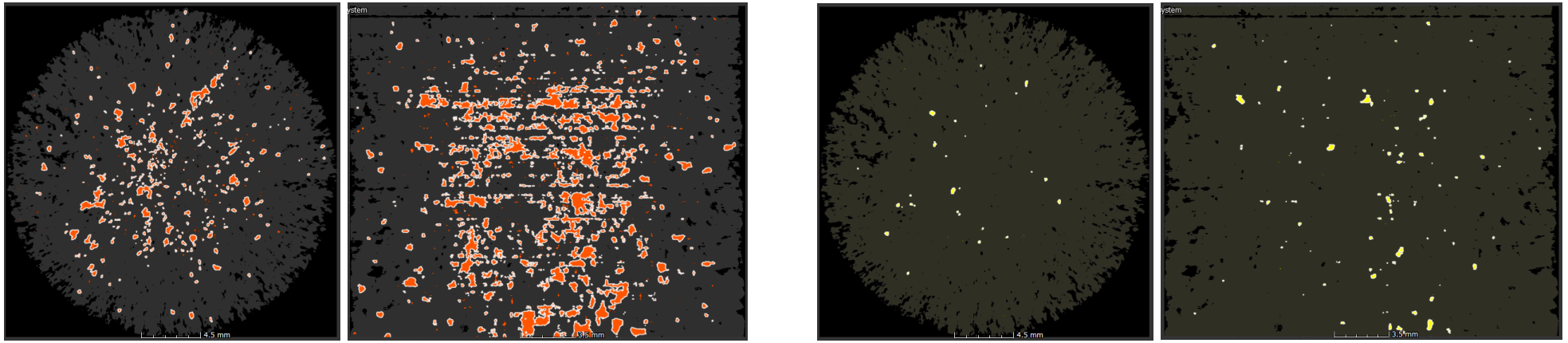


Fig 30. C3: 39°API MES (2%). The oil was go through to the center of the core (the are which more porous than the peripheral area).

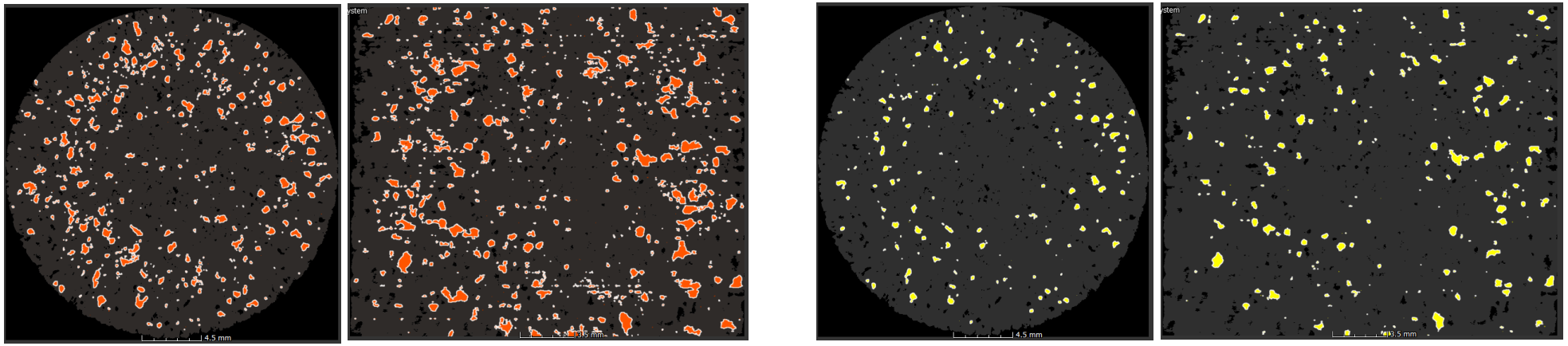


Fig 31. C5: 33°API MES (0.5%). The oil did not concentrate in the center area. It still spreading inside the sandstone sample

Core	OOIP	Amott Cell (ml)	Oil Remining (ml)	Oil Inside (CT(ml))	Oil High Con (CT (ml))
C3	1.785	1.15	0.635	0.6235	0.028
C5	2.186	1.25	0.936	0.937	0.287

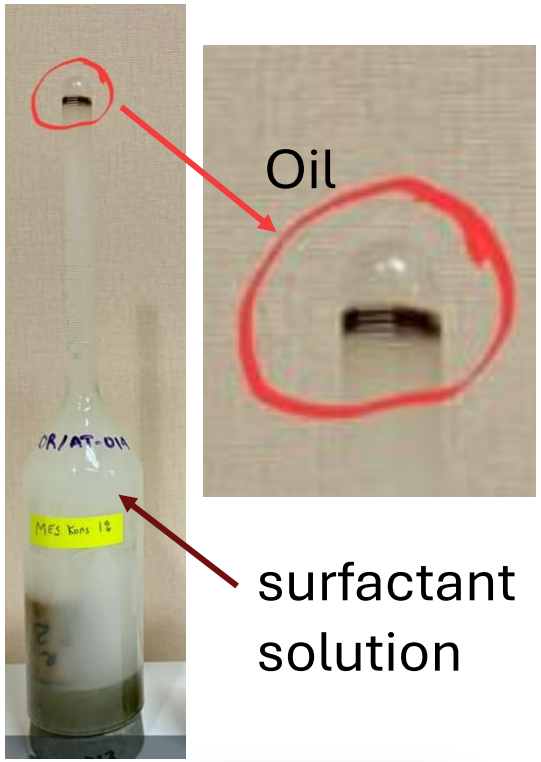
30.6%

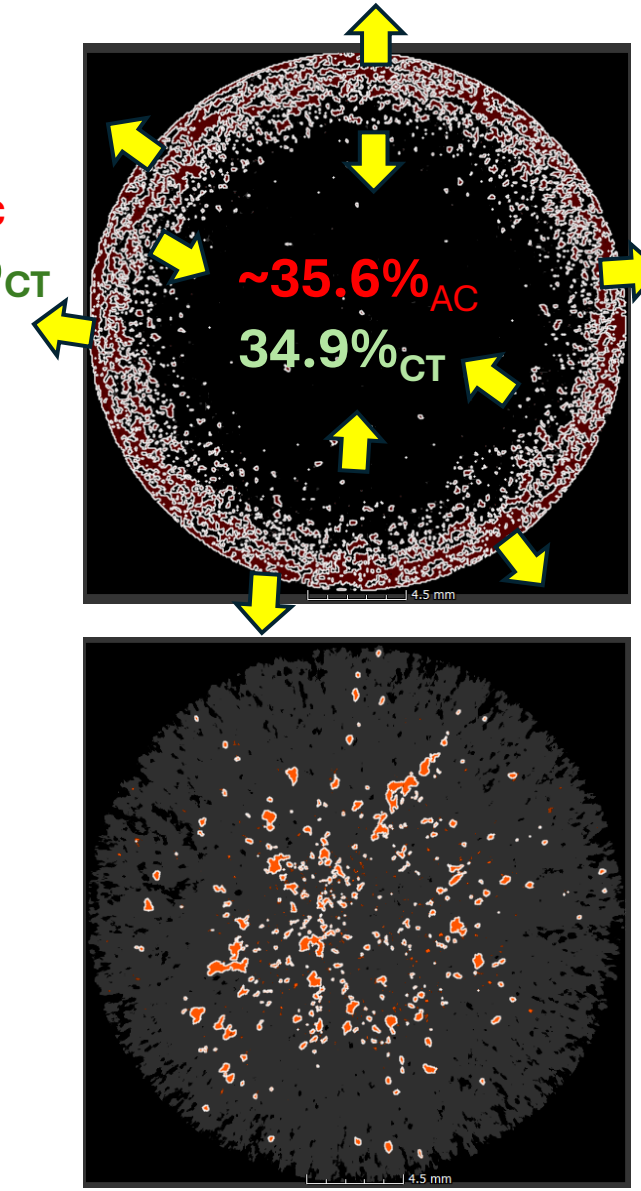
BRIN

Science and Technology Facilities Council

Result and Discussion

C3: 39°API MES (2%)
C5: 33°API MES (0.5%)





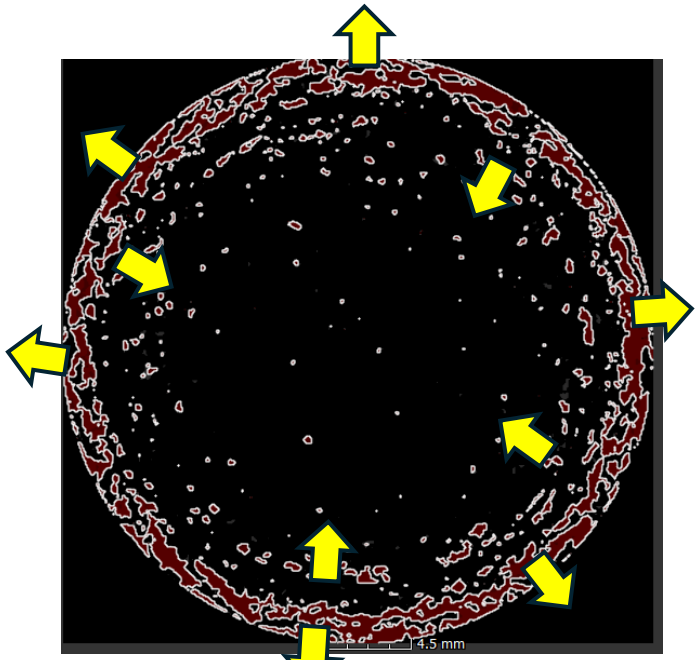
- ✓ C3: 39°API MES (2%). The oil went through to the center of the core (which is more porous than the peripheral area).
- ✓ This means that the MES palm oil surfactant was able to mobilize the oil from near the peripheral area to the center.
- ✓ The oil, which was exactly placed at the edge, was released to the surface of the Amott cell.
- ✓ It was recorded that 1.15ml oil release on 3 days of soaking, let the 0.635ml remining based on measurement calculation. While the CT measurement got 0.6235ml inside the sandstone.

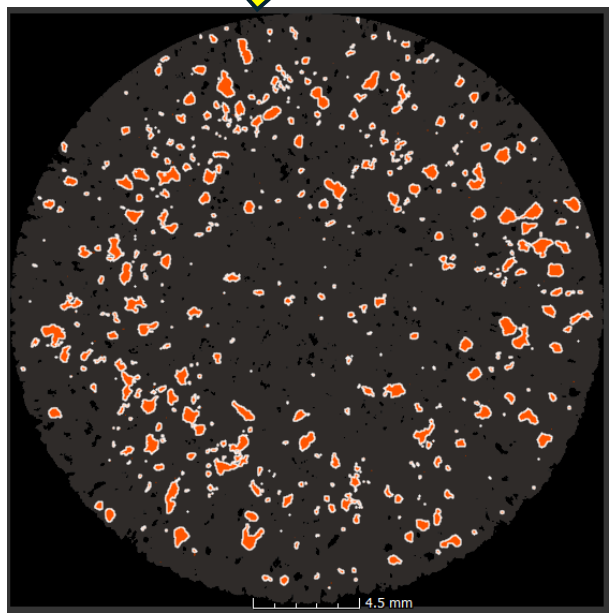
Where is another 0.0115ml? Could it still be in the compound in the surfactant solution environment?



Result and Discussion

C3: 39°API MES (2%)
C5: 33°API MES (0.5%)





- ✓ C5: 33°API MES (0.5%). The oil was not able to reach the porous area/center of the sandstone sample (only a few of them reached it).
- ✓ The 0.5% concentration of MES palm oil was not good enough to decrease the IFT (interfacial tension) of the oil. It made the surfactant fail to mobilize the oil inside the sandstone sample.
- ✓ The experimental results (using a Mott cell) show that, after 3 days of soaking, the oil was extracted ~1.25 ml from 2.186ml (OOIP) (57% release), and ~0.936 ml (43%) was still inside the sandstone. The CT got different results by 0.957ml inside the sandstone (44%).



Result and Discussion

C3: 39°API MES (2%)





Conclusions

- ✓ Neutron CT was successfully used to see the dynamic flow of water and oil (before and after surfactant) inside the Berea sandstone sample
- ✓ Porosity measurement on the Berea sandstone sample is possible in wet conditions, homogeneous material and initial data from a porosimeter
- ✓ Each surfactant has its own characteristics in binding oil.
- ✓ MES palm oil can break down oil, as well as reducing the IFT of oil in rocks; this can be seen in the C3 results, where only 0.028ml (4%) oil is still concentrated, while a MES surfactant binds the rest



What NEXT?

- ✓ We look forward to other surfactant innovations that can effectively mobilize oil within sandstone.
- ✓ We are also developing AI as a tool to help us understand surfactant-oil interactions more deeply → real-time observations (Operando)/ 4D dynamic NCT.
- ✓ We welcome collaborative research on this topic.

Thank You!





Fahrurrozi A
Instrument / Beamline Scientist
Neutron Imaging and Artificial Intelligence
fahr006@brin.go.id