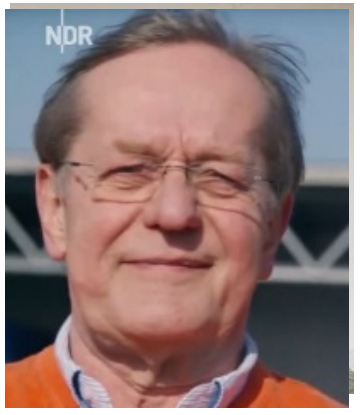
The 10th IWA Membrane Technology Conference & Exhibition for Water and Wastewater Treatment and Reuse

July 23-26, 2023, Washington University in St. Louis, USA

Please visit www.waterbackpack.org

ULPUF using Cake Layer Filtration combined with Electrocoagulation for Arsenic Removal

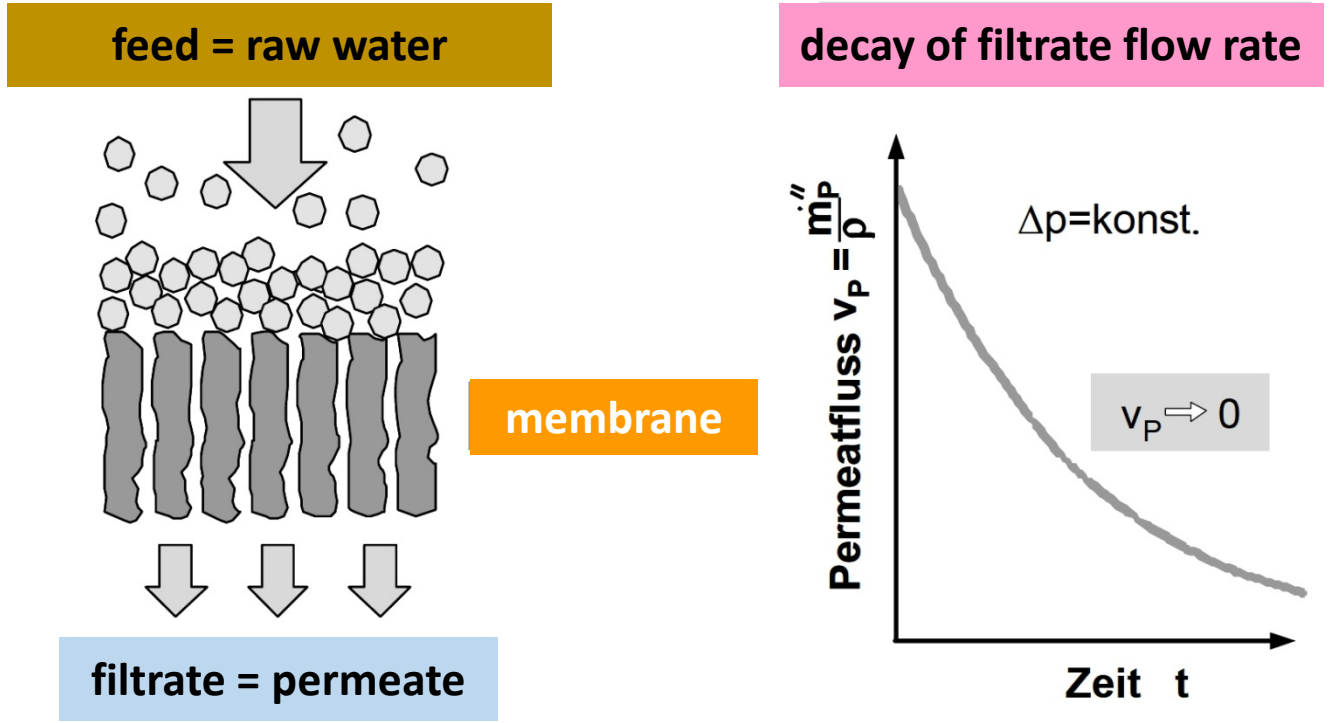
Franz-Bernd Frechen & Michael Garbowski,
University of Kassel, Germany



PAUL the water-back-pack

DEAD END FILTRATION IS NOT DEAD

- ✓ according to literature, the permeate flow will come to zero (with TMP between 0.3 and 10 bar)

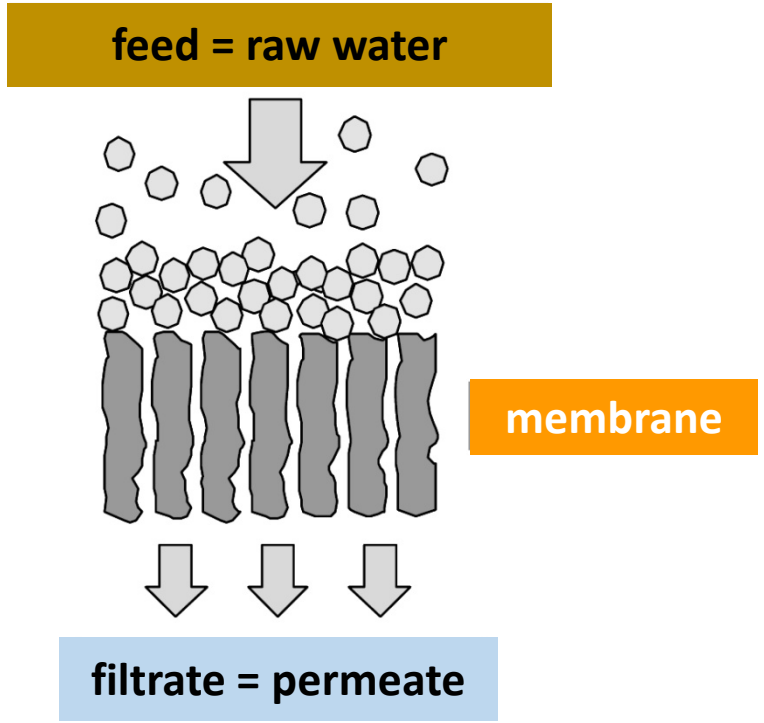


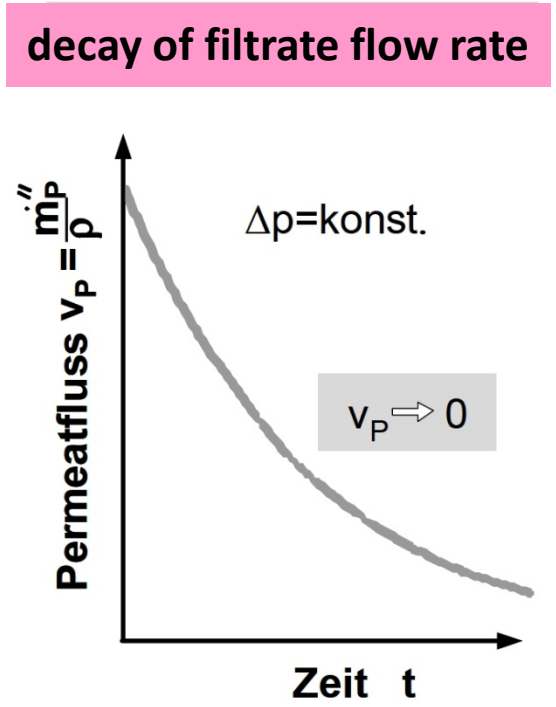
Melin/Rautenbach: Membranverfahren. 3rd edition 2007. ISBN 978-3-540-34327-1 Springer Berlin Heidelberg New York

Refer to Frechen (2014)

EVERY MEMBRANE FILTRATION IS DEAD END

- ✓according to literature, the permeate flow will come to zero (with TMP between 0.3 and 10 bar)
- ✓the question is: how to remove the cake layer?





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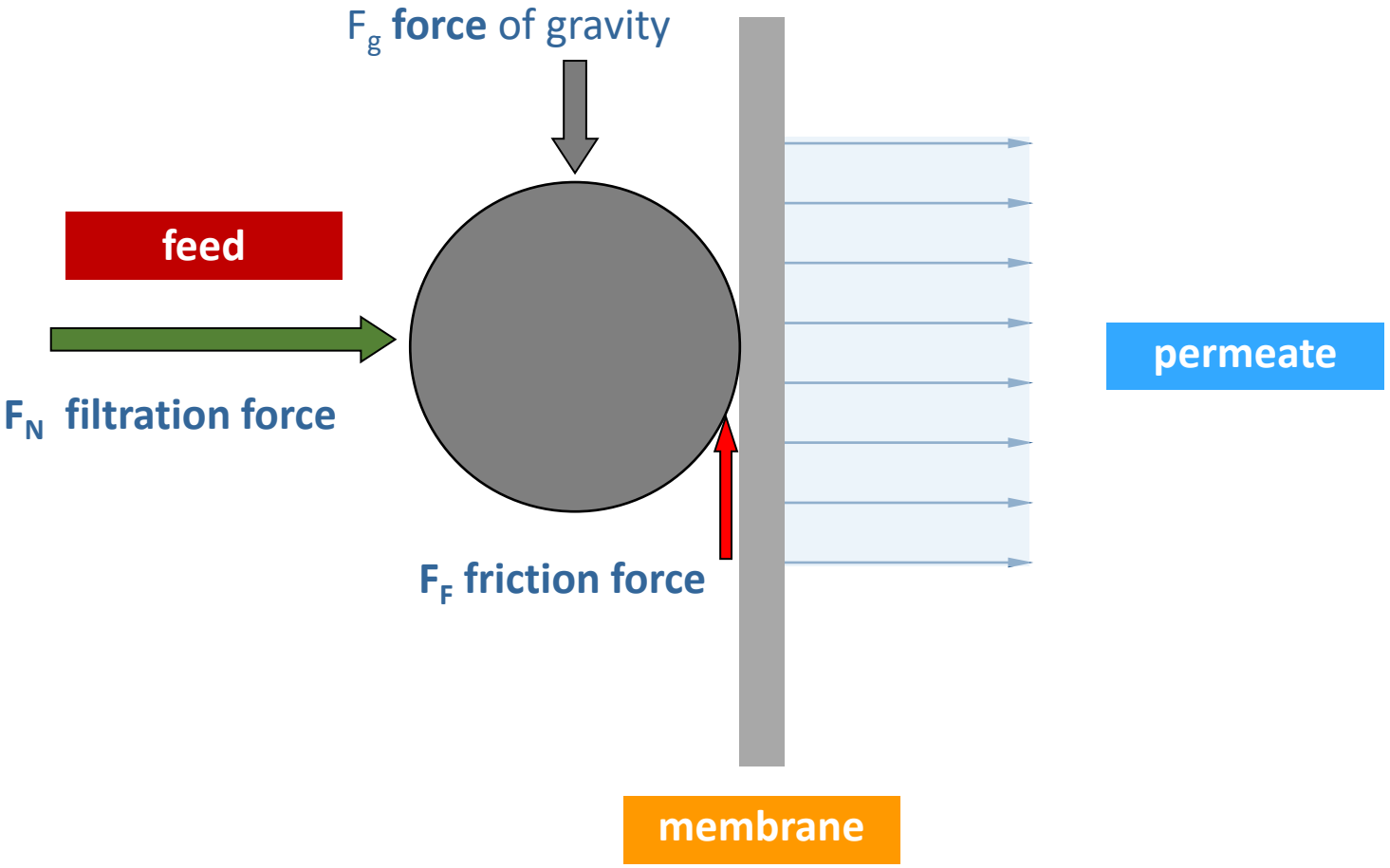
HOW TO REMOVE THE CAKE LAYER?

✓Flat sheets vertically mounted

✓ see forces effective on cake layer particle during filtration

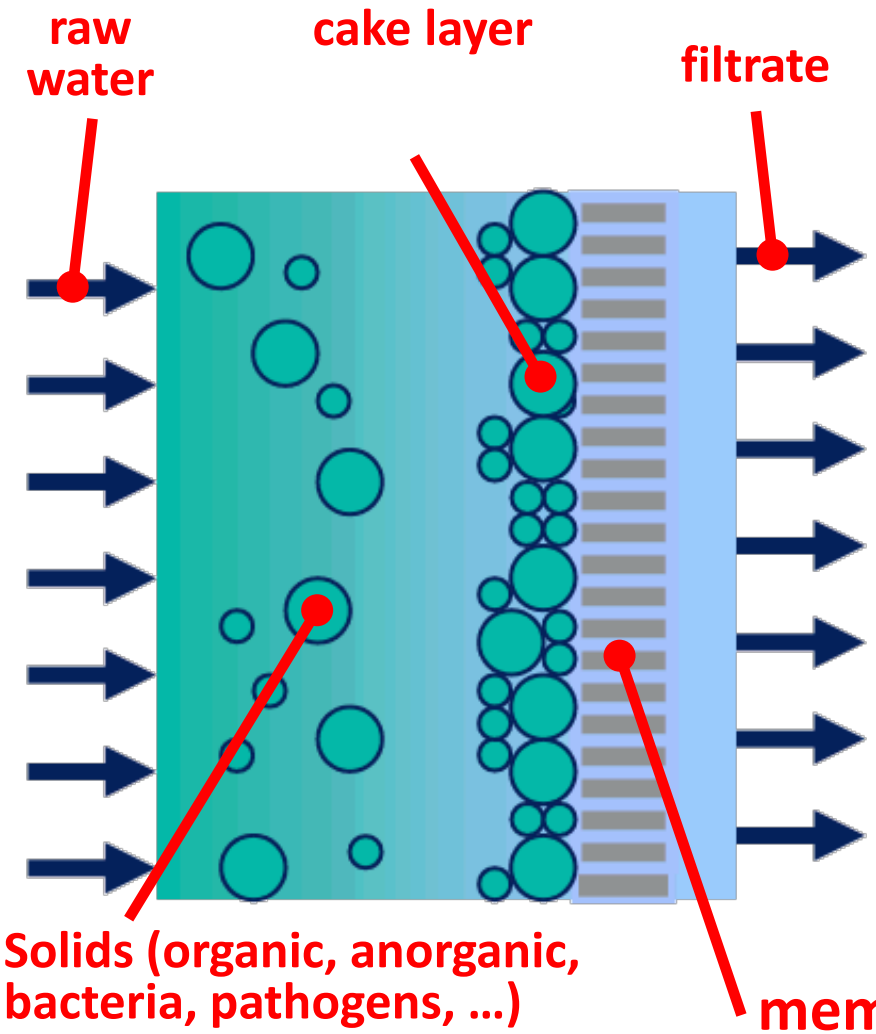


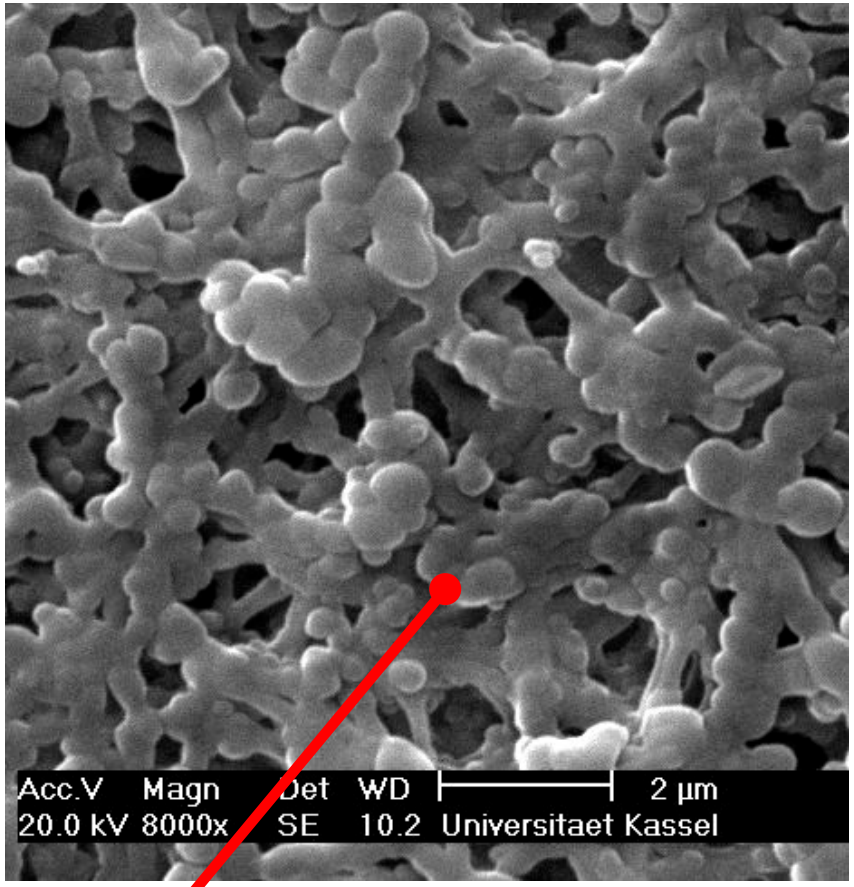
✓Inevitable precondition: ultra low TMP

✓Result: gravity lets the (surplus) cake slide down

Refer to Frechen (2014)

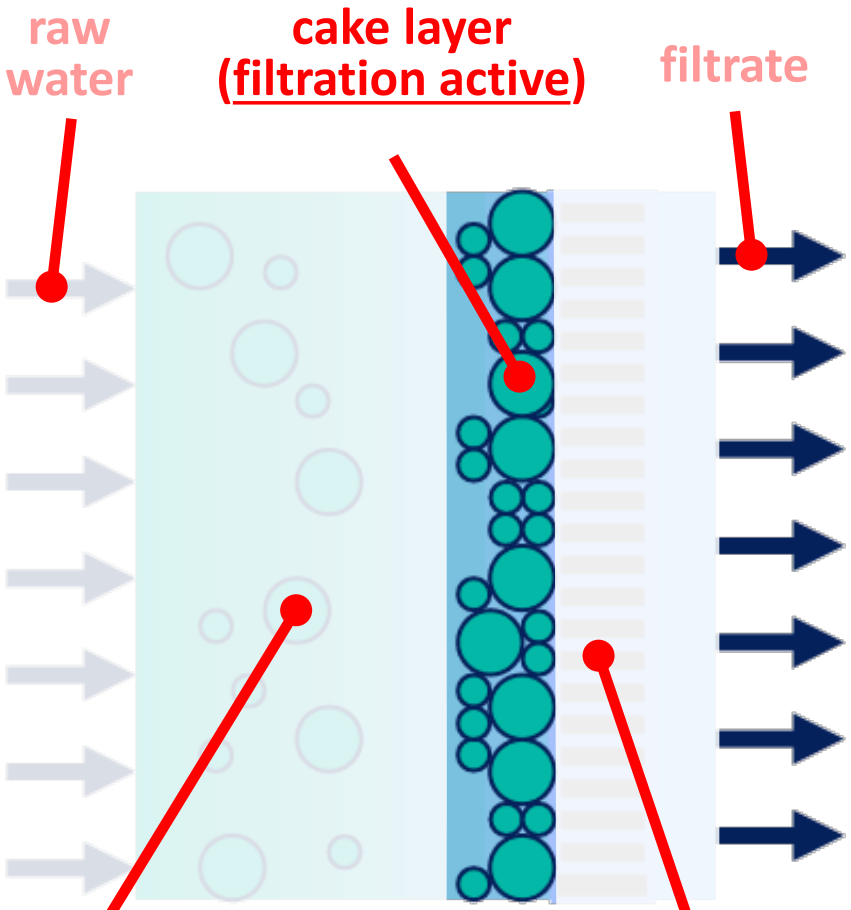
EFFECT OF ULP-UF (ULTRA LOW PRESSURE FILTRATION

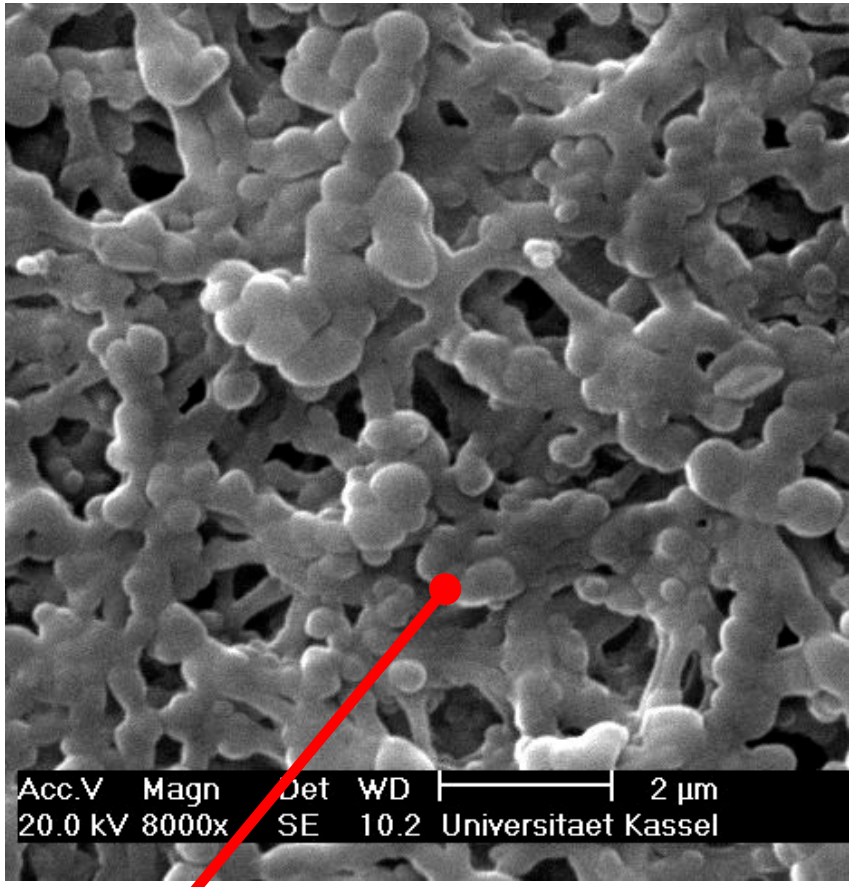




typical pore width 20 to 100 nm (0.020 to 0.100 µm)

CAKE LAYER FILTRATION IS DOMINANT





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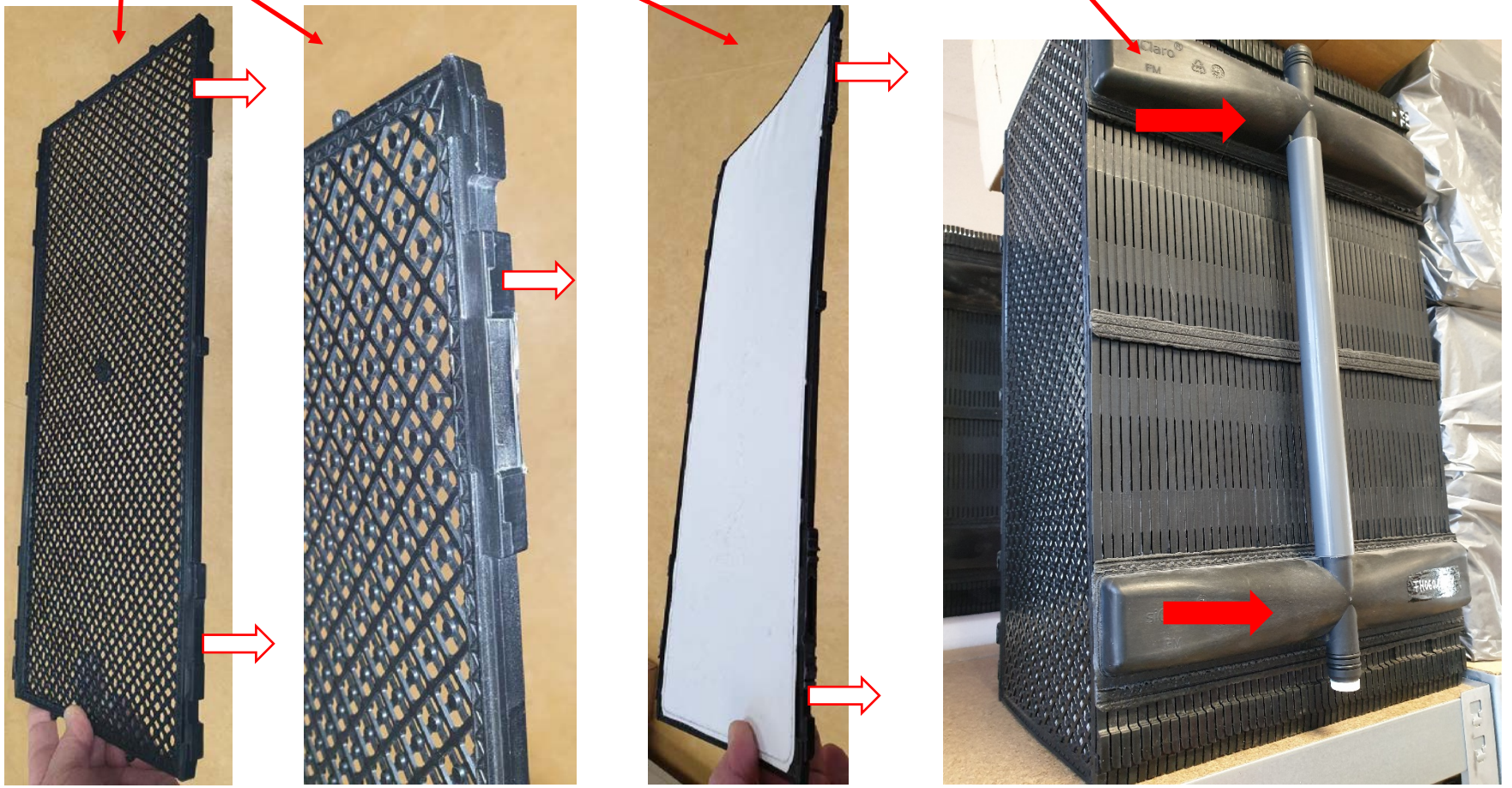
HAVE A LOOK AT PAUL THE WATERBACKPACK

the international water association

Flat sheet – flat sheet with membranes – membrane module (50 flat sheets)



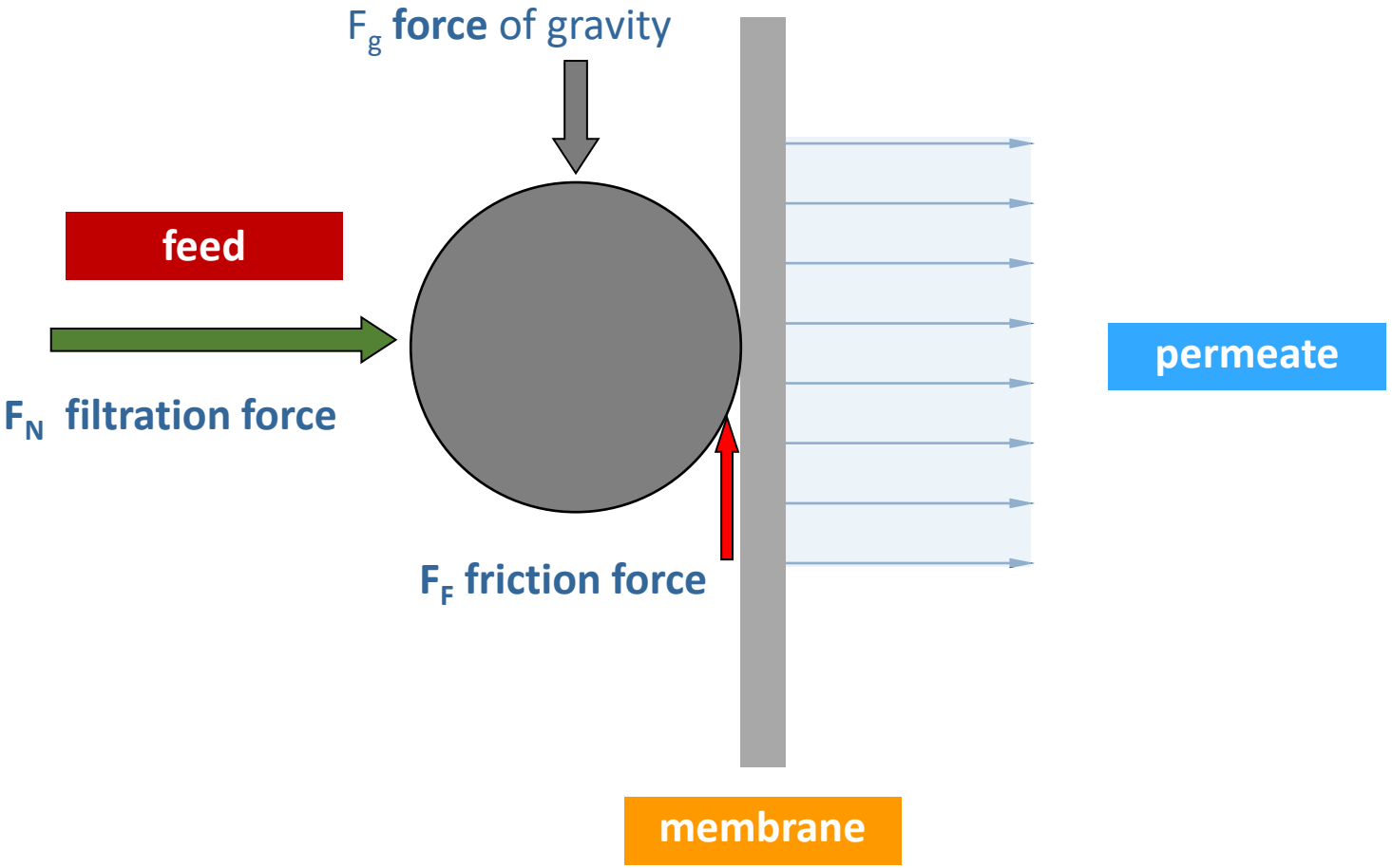
⇨ outlet from flat sheet (2 per sheet) ➡ filtered water collection channel

In emergencies and for permanent supply

WHY IS ULP-UF (ULTRA LOW PRESSURE) SO IMPORTANT

✓Flat sheets vertically mounted

✓ see forces effective on cake layer particle during filtration



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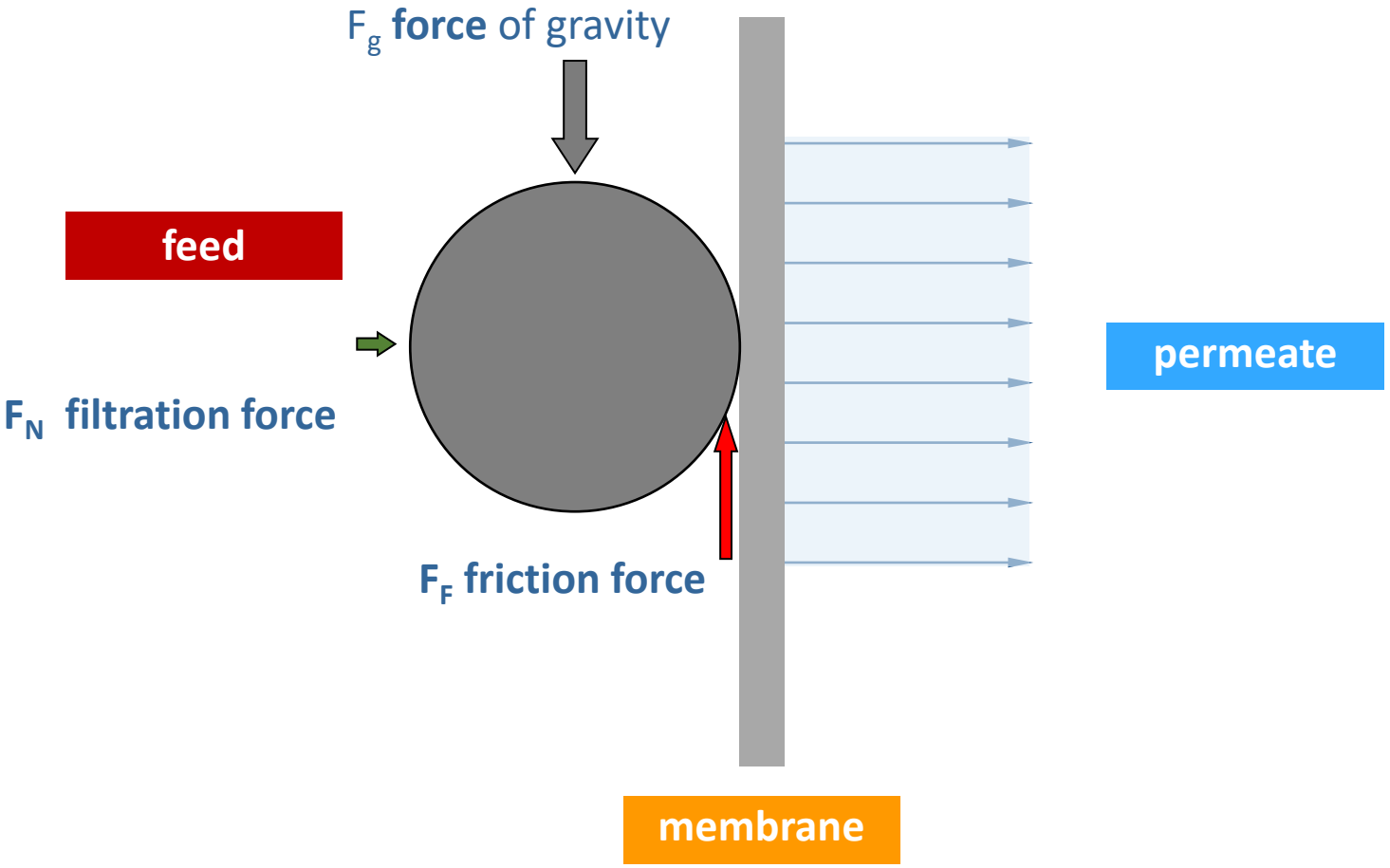

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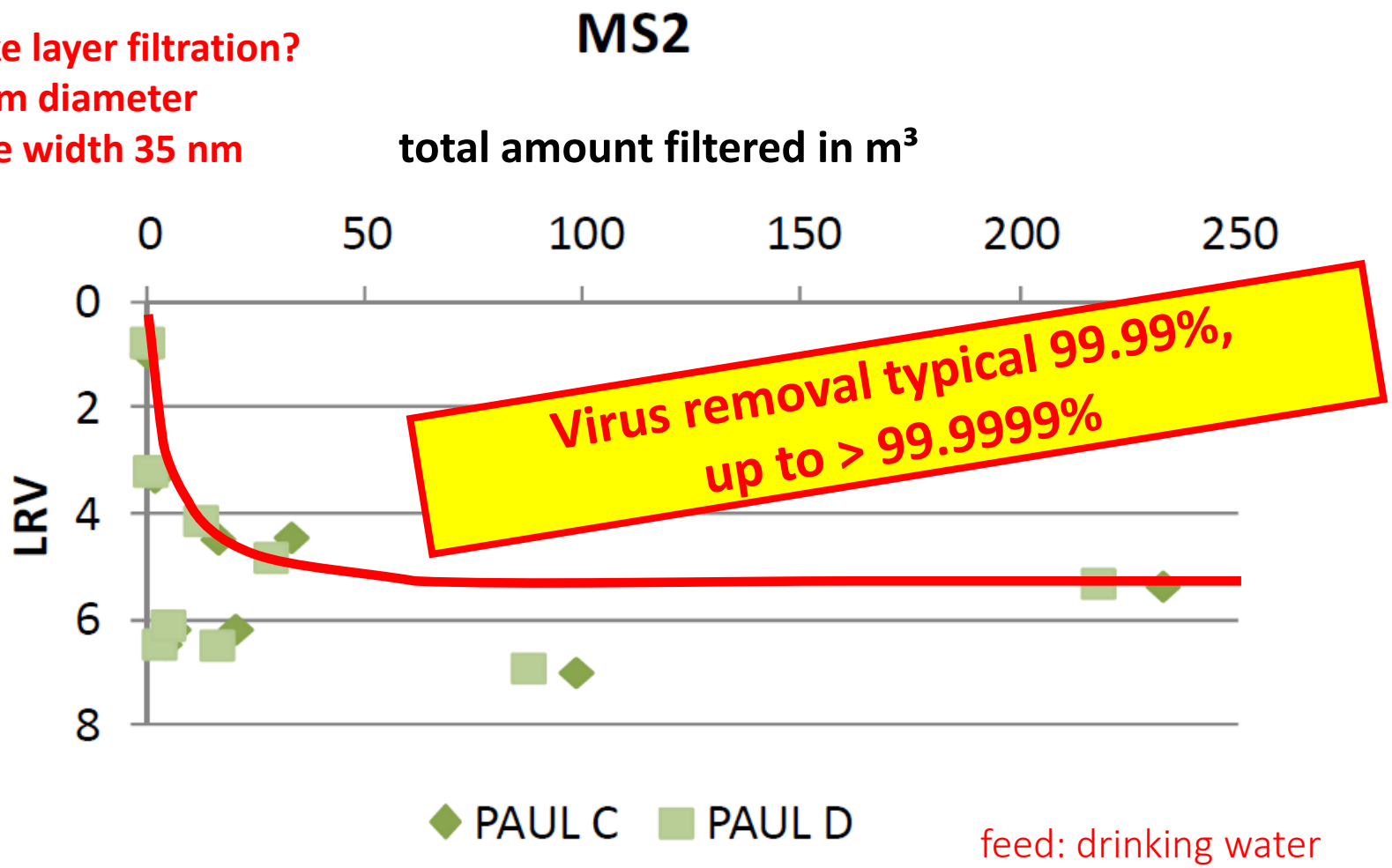
CAKE LAYER FILTRATION IS MATERIALIZED BY:

What about Cake layer filtration?
Virus MS2: 26 nm diameter
membrane: pore width 35 nm



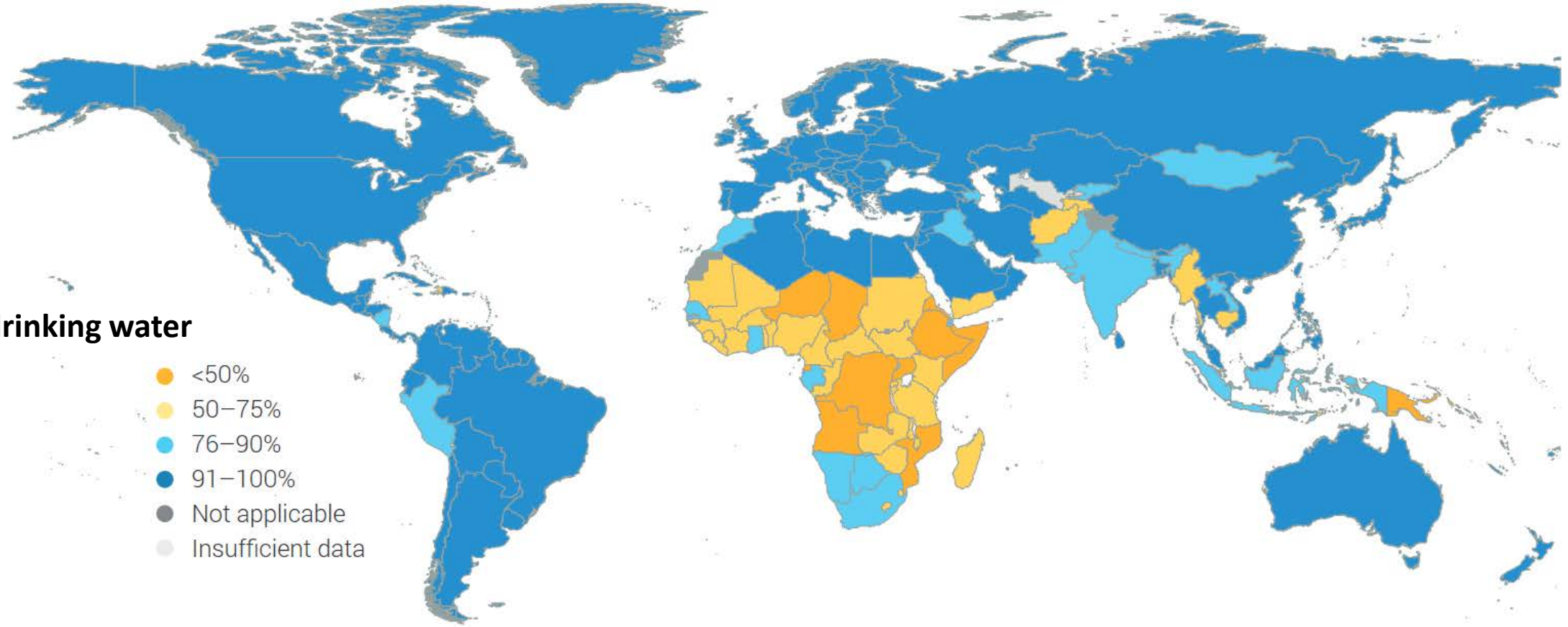
feed: drinking water

analyzed by Federal Environment Agency, Dessau/Roßlau

PROBLEM

- More than 2 billion people have no access to safe drinking water
- Most serious in low income countries (**LIC's**)
- Thus, a large demand exists for "low-cost" and "easy to use" technology

Access to safe drinking water (UNESCO 2019)



PROBLEM 1 – HOW TO GET WATER

This is a holistic water-engineering task, taking all measures and their combination into account!!

- **Rainwater harvesting in ponds and cisterns**
- Rivers
- Natural Lakes
- Groundwater (wells) ... and any **combination**

PROBLEM 1 – POSSIBLE SOLUTION: FILTRATION

The WaterBackpack PAUL is in use worldwide since 2010 (flooding in Pakistan)

To be removed: **particles** like

- Bacteria
- Virus
- Pathogens
- turbidity

... and **many other ingredients** ...!

Low cost technology: **U**ltra-**L**ow **P**ressure **U**ltra**f**iltration **ULPUF**

- Gravity driven (GDM), thus:
- **pressure controlled process**
- Particle removal
- No **energy**, no **chemicals**
- Easy to use even for illiterates
- Mobile unit, can be used in **Emergencies**
- Lifetime 10 years, **no spare parts** needed

permanent water supply

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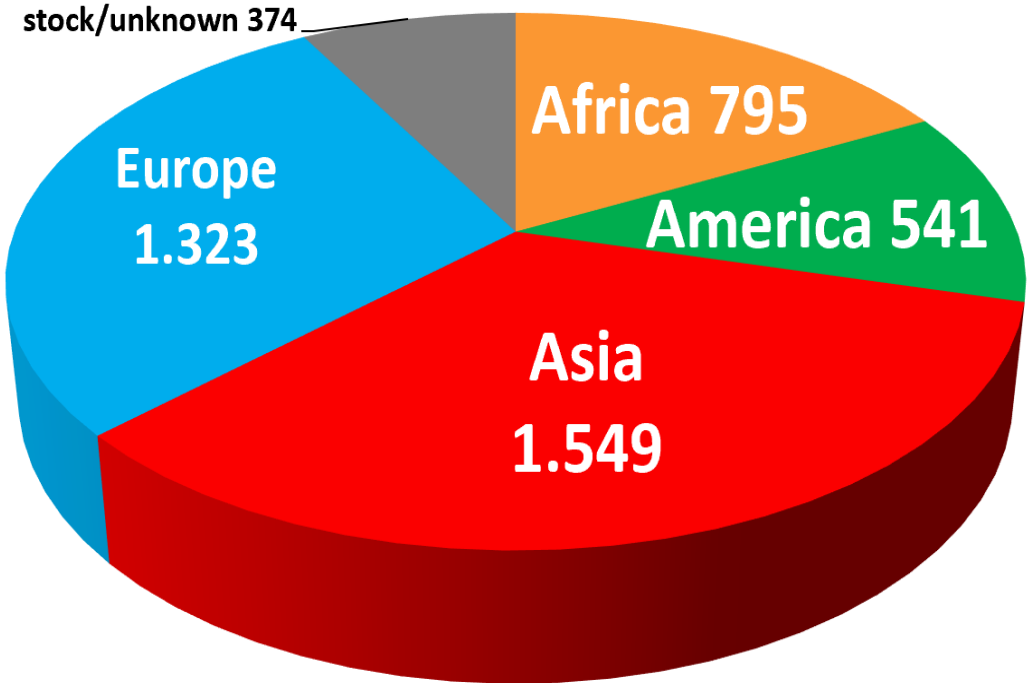
permanent water supply

July 2023

4 592 PAUL in 91 countries



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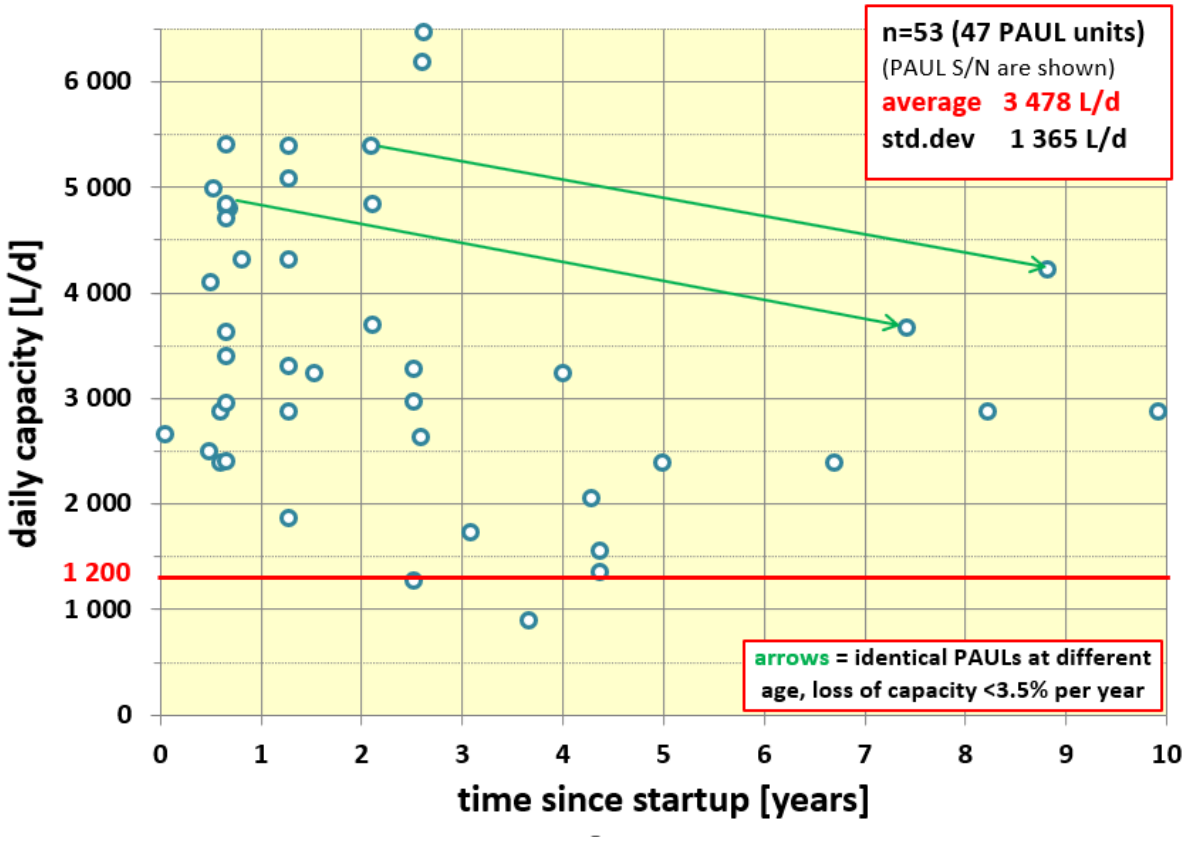


PROBLEM 2 – ARSENIC CONTAMINATION

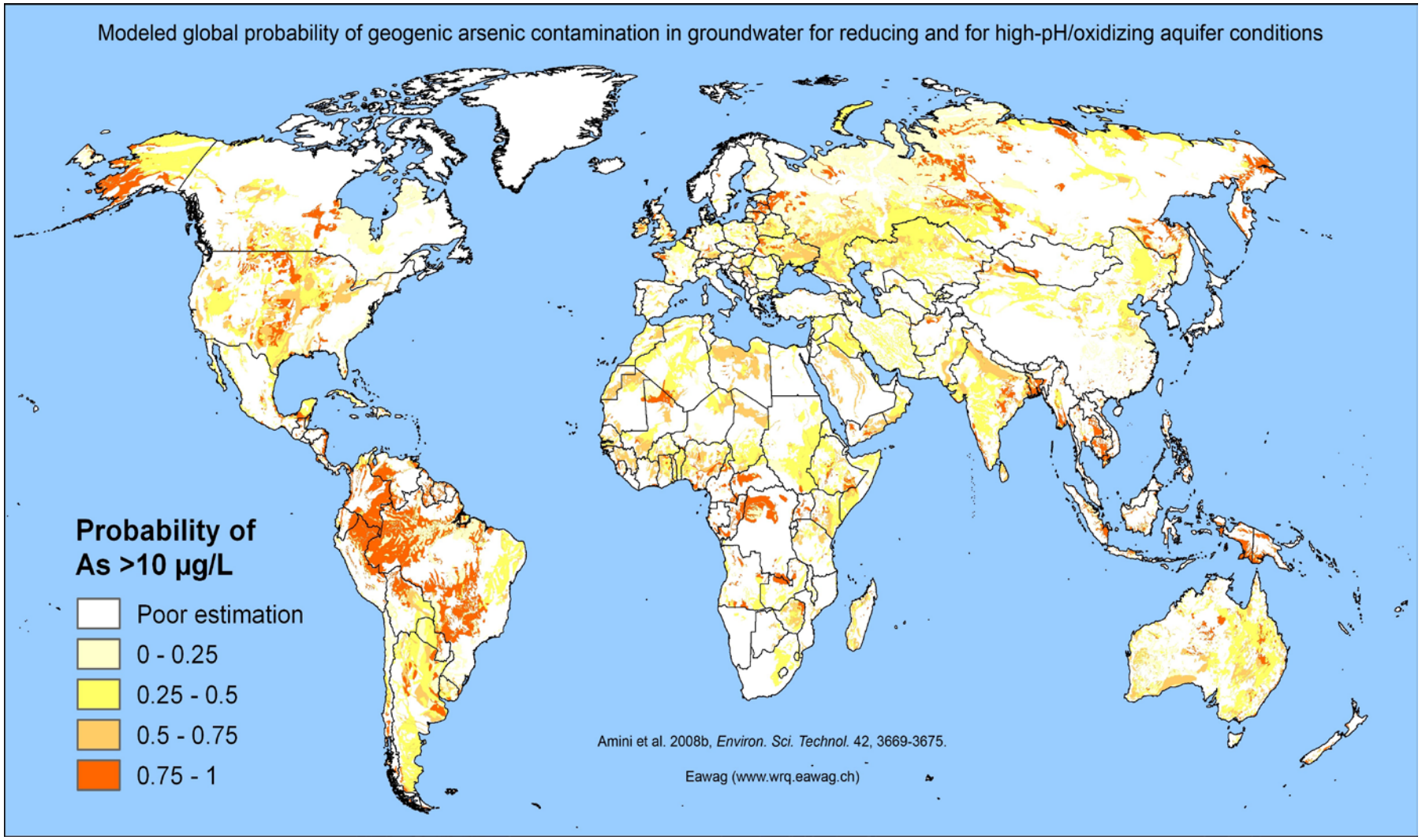
the international water association

More than 200 million people have to rely on "drinking water" with arsenic concentrations above the WHO limit value:

c_{As} > 10 µg *As*/L

Challenge here with **PAUL**:
As is partly **dissolved** and this fraction cannot be removed by filtration alone.
Thus, **two consecutive steps** are needed:

- **Conversion into particles**
- **subsequent filtration**

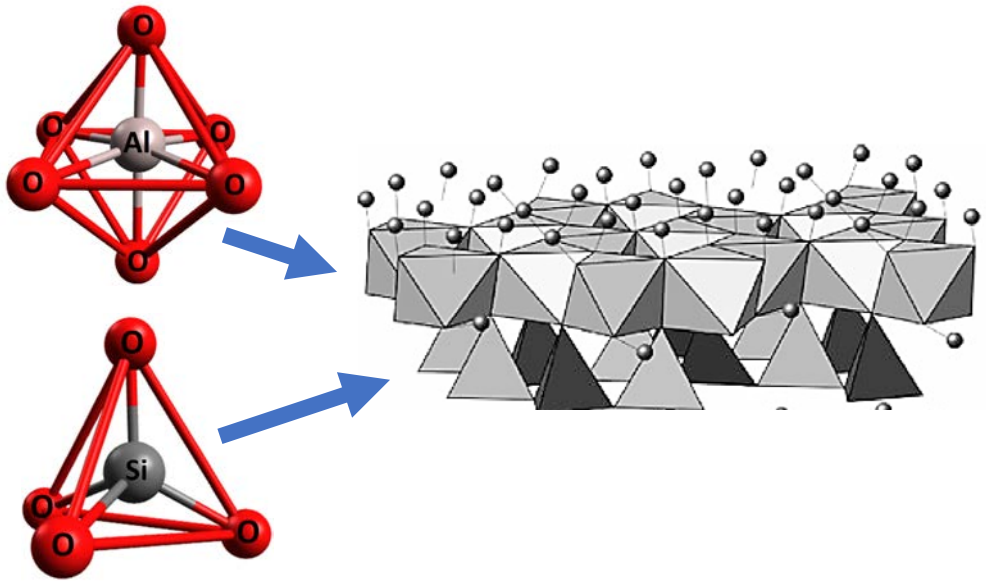


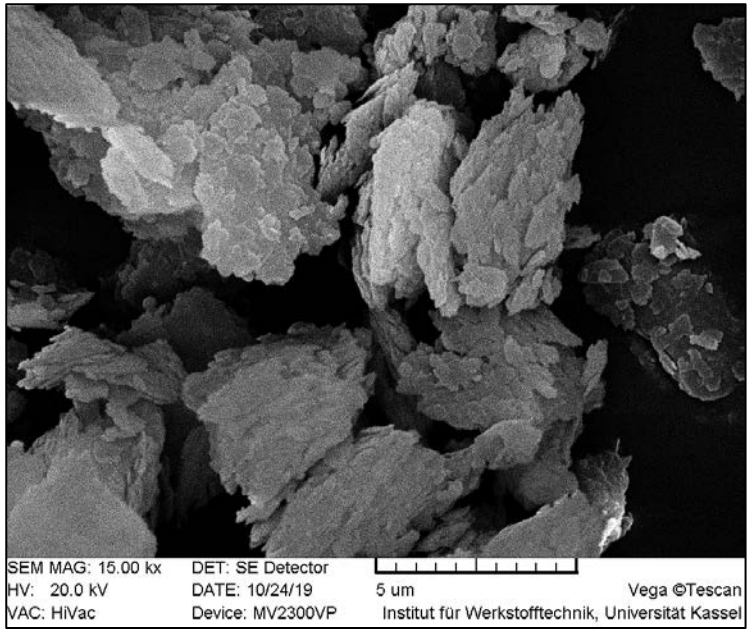
SOLUTION – ADSORPTION USING CLAY

How to convert dissolved ***As*** into particulate matter?

- Adsorb ***As*** on **burned clay** (or similar materials), easily available locally in most areas
- Silicate particles, diameter < 2µm
- High specific surface up to 8000 m²/g
- Surface positive charged
- To be used as absorbent
- Subsequent filtration

MeO_6-Oktaeder





OR ADSORPTION USING ELECTROCOAGULATION

How to convert dissolved ***As*** into particulate matter?

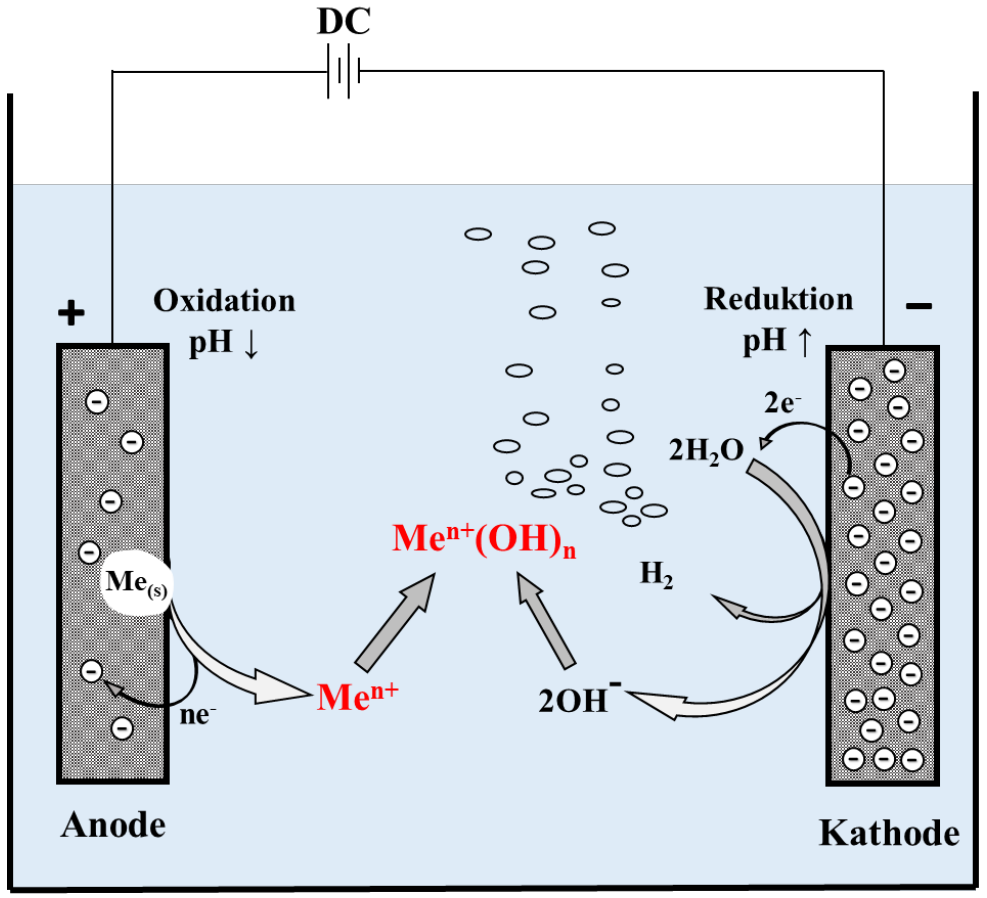
- Generate **aluminium** hydroxide or **iron** hydroxide in an electrocoagulation cell, in our case **Aluminium** as the anode
- possible with **solar power**
- ***As*** will be adsorbed by **hydroxides** generated

How to operate an EC-Cell

- Operated galvanostatic until predefined loading dose is reached

Operational parameters:

- **Current I** [A]
- **Duration of electrolysis t_{EC}** [h]
- **Loading dose q** [(A*s)/L]

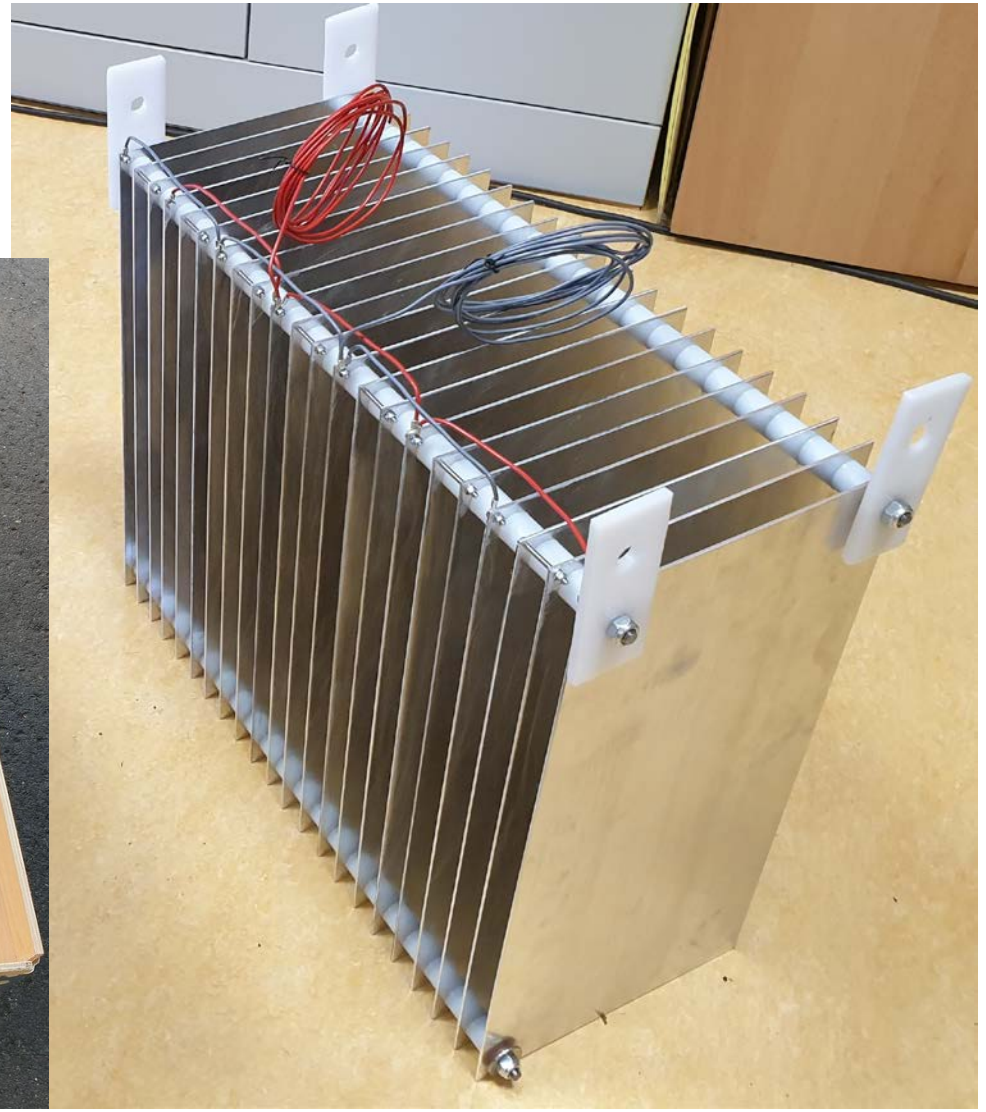


ADSORPTION USING ELECTROCOAGULATION

We sent two EC-Cells to Pakistan for testing to

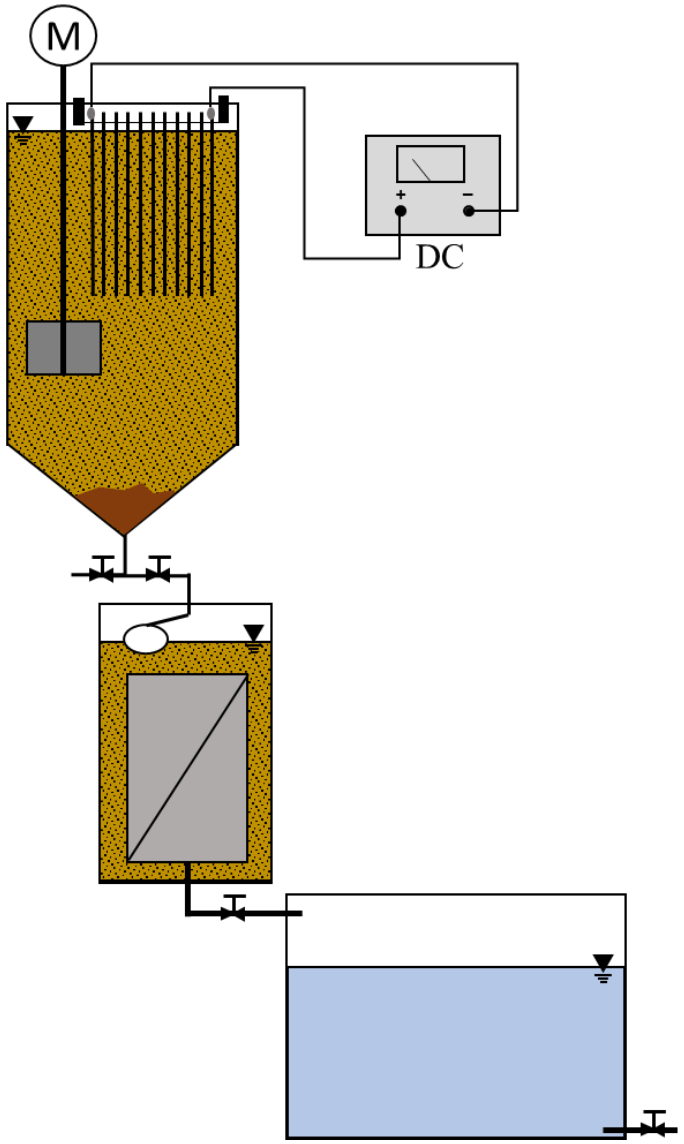
Prof. Dr. Rasool Bux Mahar, Director,
U.S.-Pakistan Center for Advanced Studies in Water (USPCASW),
Mehran University of Engineering and Technology, Jamshoro.

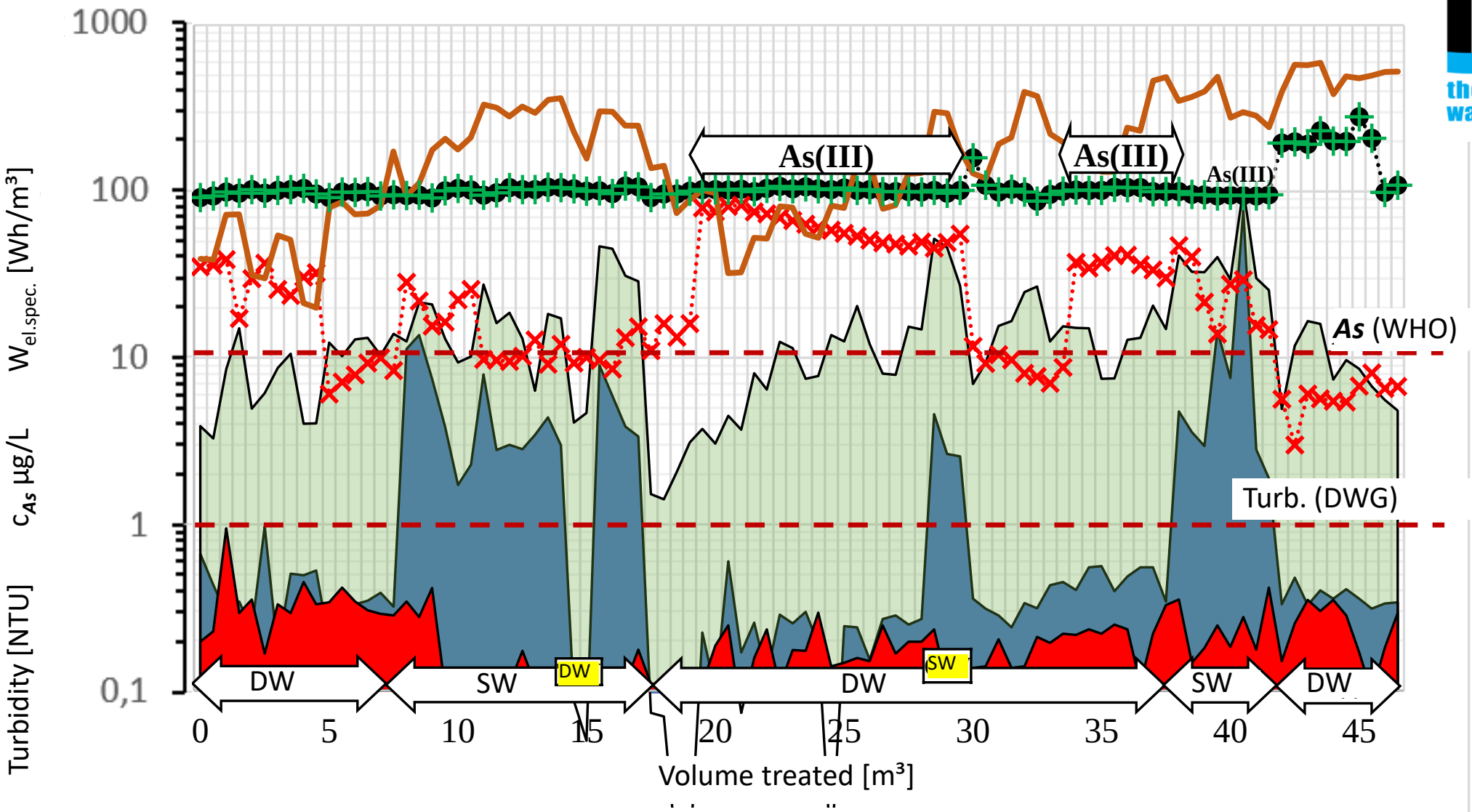
- One with **iron** anodes
- One with **aluminium** anodes



PILOT PLANT

- Tank with EC-cell, 500 Liter (stirrer optional)
- 22 Aluminium electrodes 400 mm x 200 mm x 2 mm
- 8 or 20 mm distance between electrodes
- Direct power source (I_{max} =3 A; U_{max} = 30 V)
- Galvanostatic operation with I = 1.5 A; I = 2.0 A; I = 2.8 A;
- Can be operated by **solar power**
- ***As*** will be adsorbed by **aluminium hydroxides** generated




1000
100
10
1
0,1
$W_{el.spec.}$ [Wh/m³]
c_{As} µg/L
Turbidity [NTU]
As(III)
As(III)
As(III)
As (WHO)
Turb. (DWG)
DW
SW
DW
DW
SW
SW
DW
0
5
10
15
20
25
30
35
40
45
Volume treated [m³]
Turb. influent
Turb. after EC
Turb. effluent
As influent
As after EC
As effluent
W el. specific

SUMMARY

Parameter	C-ULPUF	EC-ULPUF
Arsenic removal	$E_{As(III),max}$ = 37% $E_{As(V),stable}$ = 91%	$E_{As(III),max}$ = 70% $E_{As(V),stable}$ = 96%
Technology	Very low tech	Low tech
Regulation	Estimation of clay amount via diagram	Estimation of loading dose via diagram
Amount of sludge	Minor to very high, depending upon clay material	Very low (aluminium cell), high (iron cell)
Handling of arsenic residues	Dispose in a sealed area or use for cement production	Dispose in a sealed area or use for cement production
Challenges	Assure sufficient $t_{contact}$; sludge management	Passive layer removal; cake layer control
Cost per m³	**0.64 €/m³ - 2.23 €/m³**	**0.47 €/m³ - 1.64 €/m³**

C-ULPUF and more of EC-ULPUF results will be covered in future publications. See also next slide

SUMMARY

Research was done by Michael Garbowski and presented as a PhD publication as follows:

Arsenentfernung mit Ultra-Low-Pressure Ultrafiltration (ULPUF)-Kombinationsverfahren zur Wasseraufbereitung in Entwicklungsländern

Michael Garbowski

PhD thesis, University of Kassel

ISBN 978-3-7376-0959-3
DOI: https://doi.org/doi:10.17170/kobra-202108034474

See also:

Small-scale water supply system (SSS) for remote and rural areas in developing countries (2018)

Andrade, J.A.Ordonez

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http://nbn-resolving.de/urn:nbn:de:0002-405511

https://kup.uni-kassel.de