



# Contribution of various techniques to U(VI) and Pu(IV) mass transfer kinetics in liquid-liquid extraction

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# Extraction kinetics of uranium(VI) and plutonium(IV) by N,N-dialkylamide

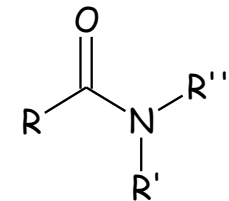
*towards the kinetics regime determination  
thanks to 3 technics*

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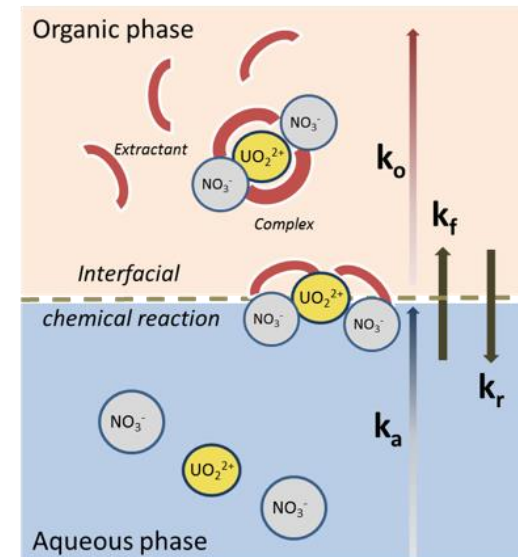


N,N dialkylamide

- Innovative processes for Plutonium multi-recycling based on a monoamide extractant [1-3]
  - Thermodynamical data acquired
  - Hydrodynamic and hot tests carried out
- Simulation of counter-current test in mixer-settlers or pulsed columns
  - ⇒ Determination of mass transfer coefficients of U(VI) and Pu(IV) extraction
  - ⇒ Determination of the kinetics regime
- Mass transfer theory applied to liquid-liquid extraction

$$J = k_o(C_o^i - C_o) = k_a(C_a - C_a^i) = k_f C_a^i - k_r C_o^i$$

$$\frac{1}{K_a} = \frac{1}{k_a} + \frac{1}{D \cdot k_o} + \frac{1}{k_f}$$



$k_o, k_a$ : diffusion rate constants  
 $k_f, k_r$ : chemical rate constants  
 D: distribution ratio

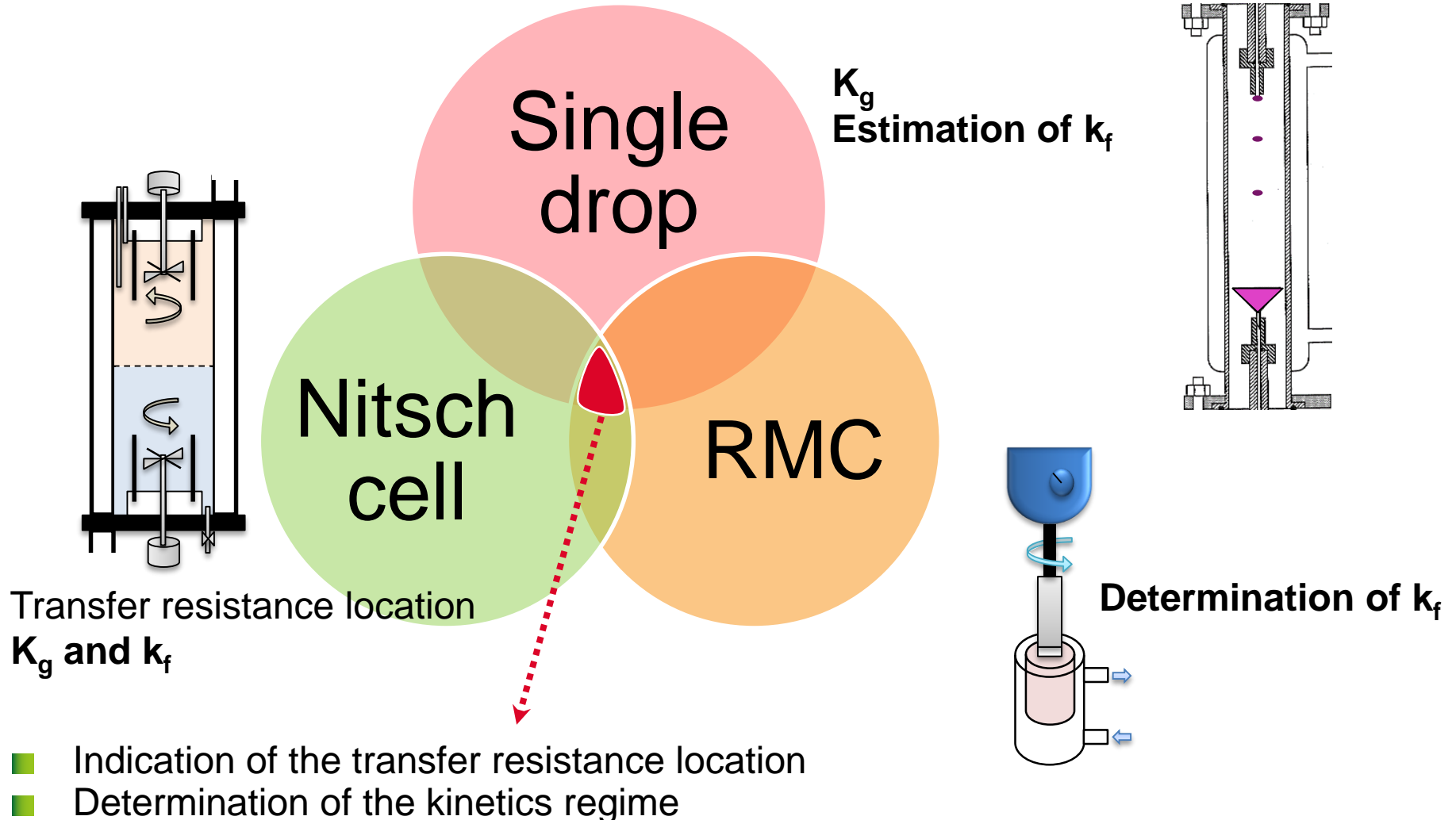
[1]: C. Musikas, P. Zorz, Process for the extraction of uranium (VI) and/or plutonium (IV), US 5132092, **1992**

[2]: Prabhu, D.R., et al., *J. Radioanal. Nucl. Chem.*, **1997**, 224(1-2) 113-117.

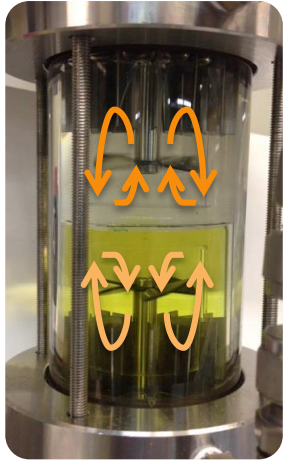
[3]: Pathak, P.N., et al., *Solvent Extr. Ion Exch.*, **2009**, 27(5-6) 683-694.

# Comparison of 3 technics

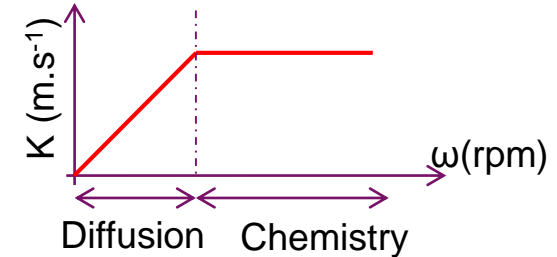
## Techniques with constant interfacial area [4]



## EXTRACTION KINETICS WITH U(VI): NITSCH CELL

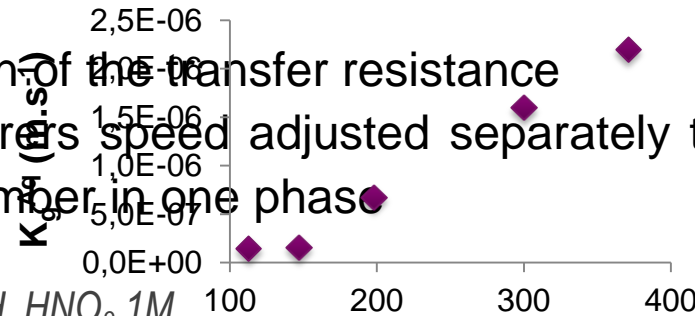


- Restricted stirring speed within the solvent : Chemical plateau unreached



- Location of the transfer resistance

- stirrers speed adjusted separately to keep a fixed Reynolds number in one phase



Organic phase: *N,N*-dialkylamide/TPH,  $\text{HNO}_3$  1M

Aqueous phase: 40 g.L<sup>-1</sup> U(VI)  $\text{HNO}_3$  5M

Temperature: 25°C

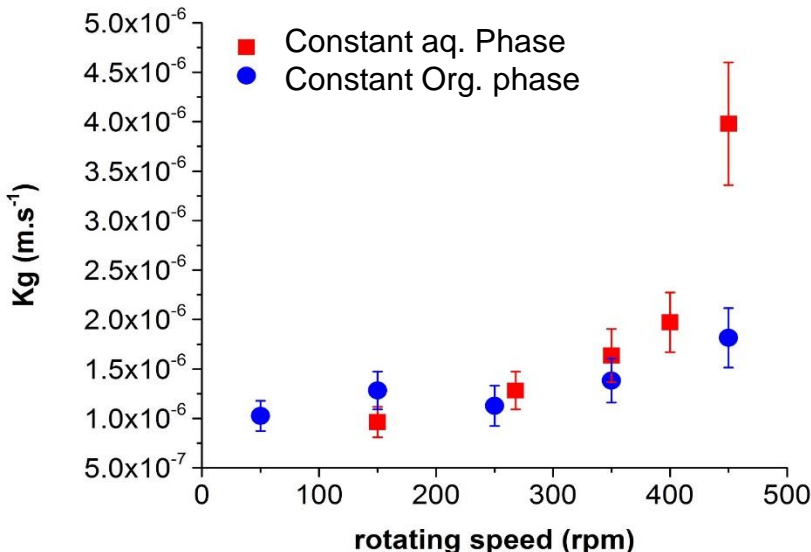
- Variation in aqueous phase

- low effect:  $K_g^{\text{aq}} \approx 1.3 \pm 0.3 \cdot 10^{-6} \text{ m.s}^{-1}$

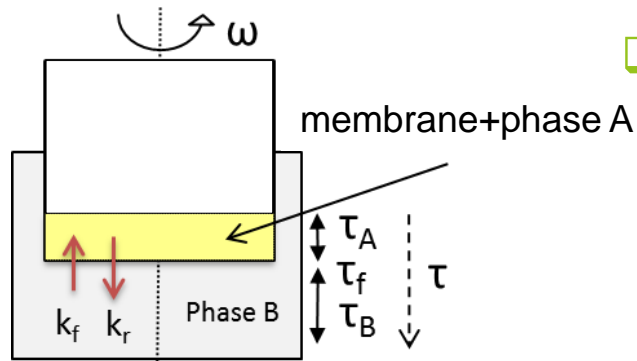
- Variation in organic phase

- High Impact:  $K_g^{\text{aq}} \approx 6.5 \pm 0.3 \cdot 10^{-6} \text{ m.s}^{-1}$

- ✓ Resistance of the U(VI) transfer located in the solvent



# EXTRACTION KINETICS WITH U(VI) AND PU(IV): ROTATING MEMBRANE CELL



□ Direct determination of the chemical constant,  $k_f$ :

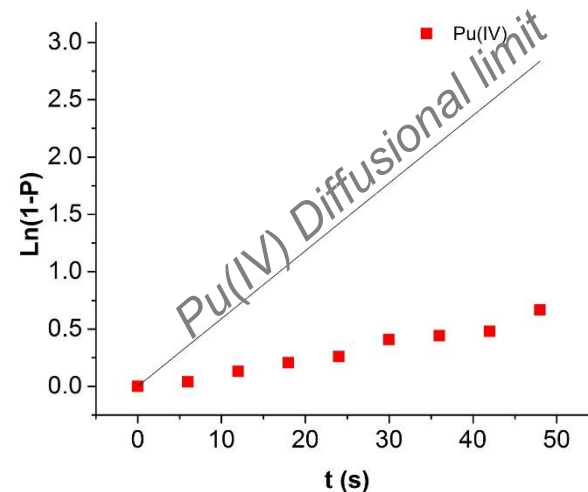
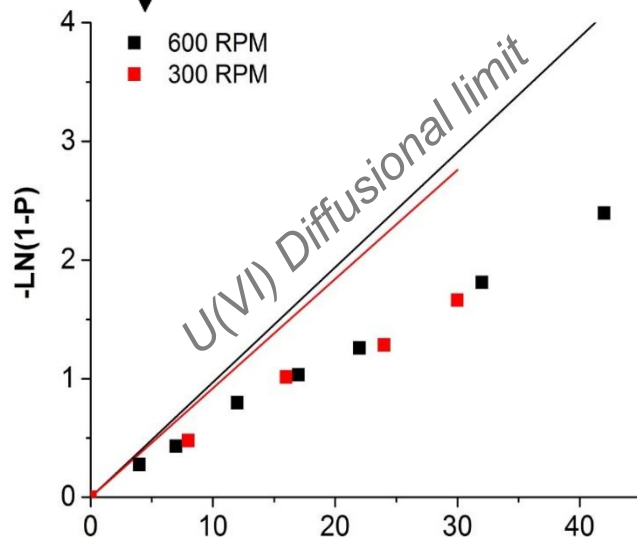
Measure of the proportion (P) of the solute transferred from A to B

Organic phase: *N,N*-dialkylamide/TPH,  $\text{HNO}_3$  1M

Aqueous phase 1:  $40 \text{ g.L}^{-1}$  U(VI)  $\text{HNO}_3$  5M

Aqueous phase 2:  $50 \text{ mg.L}^{-1}$  Pu(IV)  $\text{HNO}_3$  5M

Temperature:  $25^\circ\text{C}$



□ Extraction of U(VI) at 300 and 600 rpm

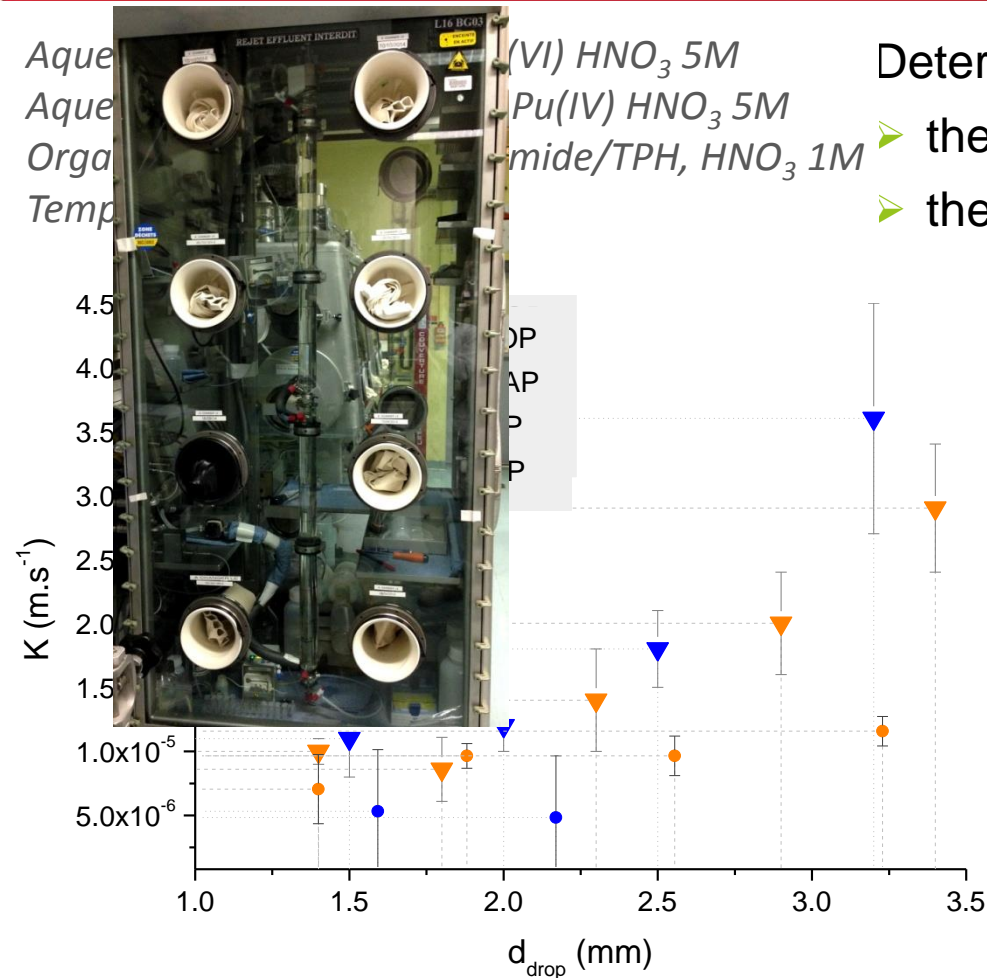
✓  $k_f (\text{m.s}^{-1}) = 1.9 \pm 0.5 \times 10^{-5}$

□ **Molecular diffusion** seems to control the U(VI) transfer

□ Pu(IV) under study but  $\mathcal{D}(\text{Pu(IV)})$  to be acquired



# EXTRACTION KINETICS WITH U(VI) AND PU(IV): SINGLE-DROP TECHNIQUE



Determination of  $K_g$  (Aq or Org) depending on

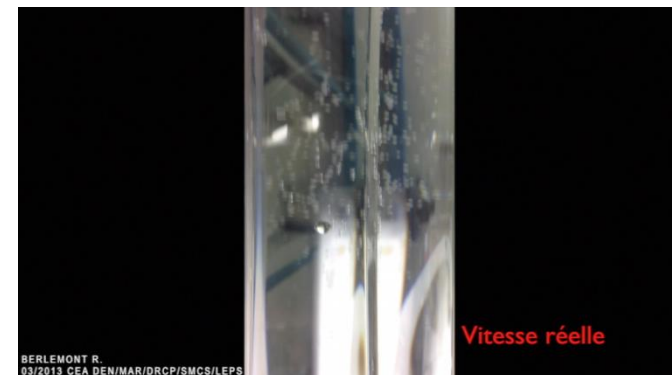
- the continuous phase
- the drop diameter

## Falling drop configuration (COP)

- ✓ Increase of the  $K_g$  U(VI), Pu(IV) with the drop size
- **internal circulation** inside the aqueous droplets supposed

## Rising drop configuration (CAP)

- ✓ Lower effect on  $K_g$  U(VI), Pu(IV) of the Organic drop size
- High resistance to the transfer



- Similar transfer of U(VI) and Pu(IV) during extraction
- Diffusional resistance in organic phase
- Diffusional control supposed

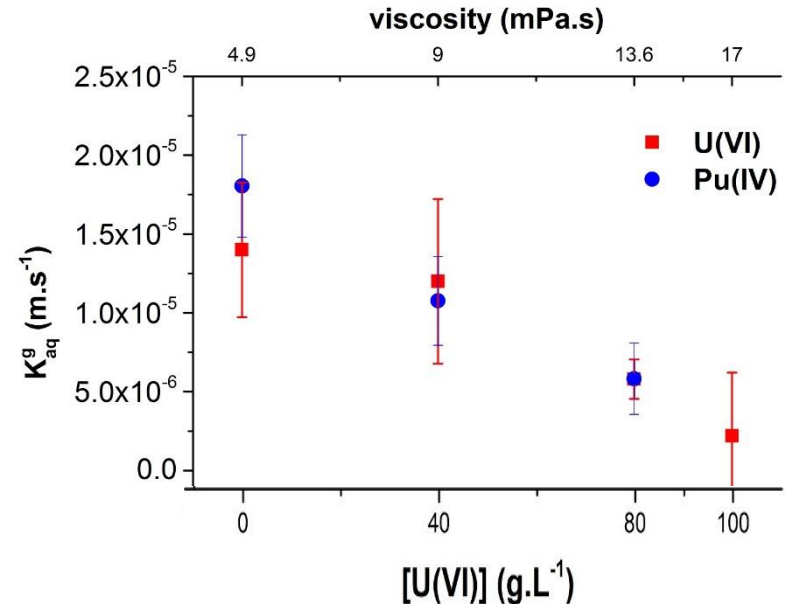
- Solvent loaded with [U(VI)] in macro-concentration (40, 80 and 100g.L<sup>-1</sup>)

**Continuous organic phase (Falling drop) at 25°C**

Aqueous drop 1: 40 g.L<sup>-1</sup> U(VI) HNO<sub>3</sub> 5M

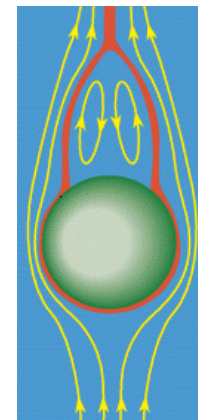
Aqueous drop 2: 50 mg.L<sup>-1</sup> Pu(IV) HNO<sub>3</sub> 5M

Drop size : 2.3 ± 0.1mm



- ✓ Similar trend of the mass transfer constants: the higher the organic uranium concentration, the lower the K<sup>g</sup> of U(VI) and Pu(IV)
- Increase of the boundary layer of the organic phase (drop interface) with the organic phase viscosity (7 to 33 μm)

⇒ **diffusional transfer**

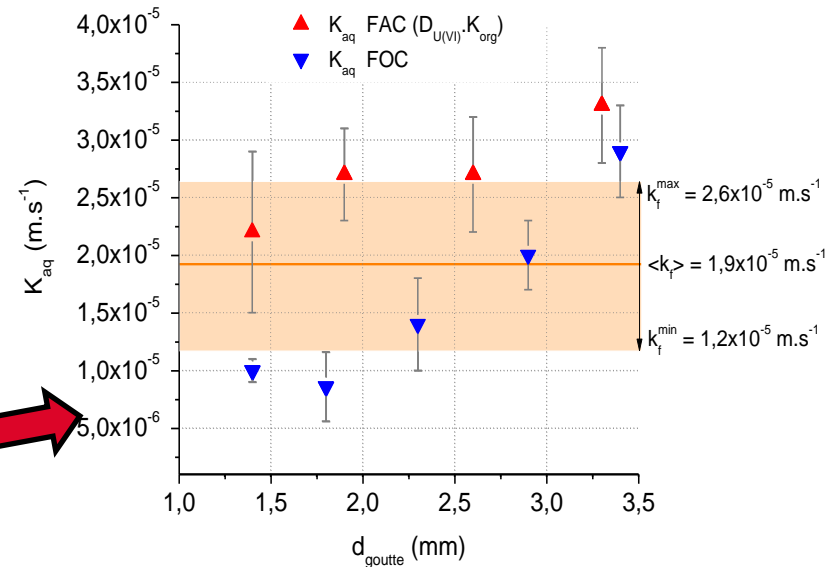


- 3 times slower than TBP/TPH but reliable data to implement the model



## COMPARISON OF THE 3 TECHNIQS

U(VI)	Nitsch cell	RMC	Single drop
$K_g^{Aq}$ ( $m.s^{-1}$ )	$1.3 \pm 0.6, 5 \times 10^{-6}$	/	$1.0 - 2.9 \times 10^{-5}$
$k_f$ ( $m.s^{-1}$ )		$1.9 \pm 0.1 \times 10^{-5}$	



- ❑ Transfer resistance located in the organic phase
  - Nitsch cell unsuitable technique for the monoamide solvent
- ❑ Molecular diffusion seems to control the transfer
- ❑ Value of  $k_f$  of U(VI) on the same order of magnitude than the Single drop one
  - Mixed regime or data to be confirmed?
- ❑ Values in agreement with the extraction model

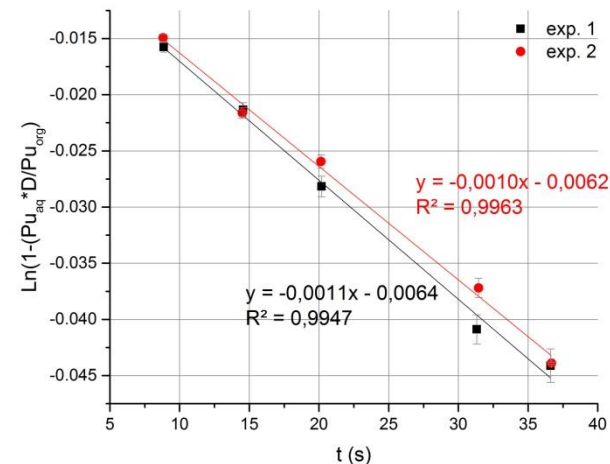
- ❑ Pulsed column + mixer-settler tests in stripping conditions: U(VI) faster than Pu(IV)

## Continuous organic phase (Falling drop) at 25°C

80 g.L<sup>-1</sup> U(VI), 40 mg.L<sup>-1</sup> Pu(IV)  $HNO_3$  0.15M

Aqueous drop:  $HNO_3$  0.1M;  $d=3.4 \pm 0.1$ mm

	U(VI)	Pu(IV)	$H^+$
$K_g^{Aq}$ (m.s <sup>-1</sup> )	6.2 x10 <sup>-6</sup>	5.8 x10 <sup>-7</sup>	6.8x10 <sup>-7</sup>

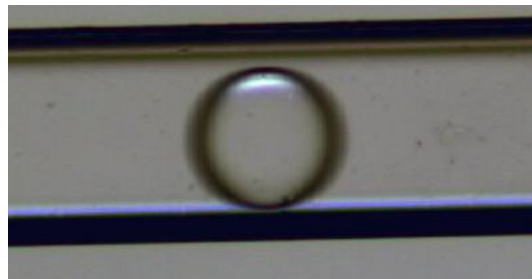
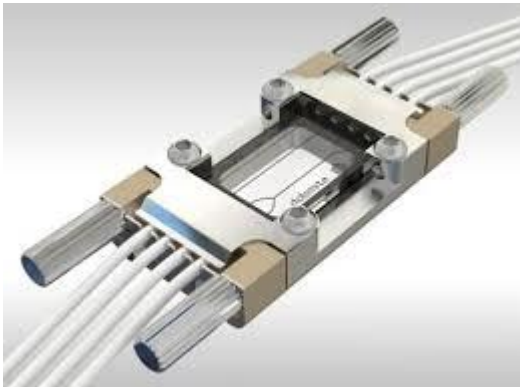


- ✓ U(VI) transfer 10 times faster

- ❑ Consistency with counter-current test observations (CBP facility)

- More information with the Atal2016 – 236 and 241 presentations

- ❑ **Single drop method: most complete study**
- ❑ U(VI) and Pu(IV) seem to have **similar behavior** during the extraction process but new experiments have to confirm that trend
- ❑ Mass **transfer probably controlled by the diffusional resistance** in organic phase
- ❑ Data reliable enough to implement the **model**
  - Determination of the mass transfer constants by **micro devices**



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