



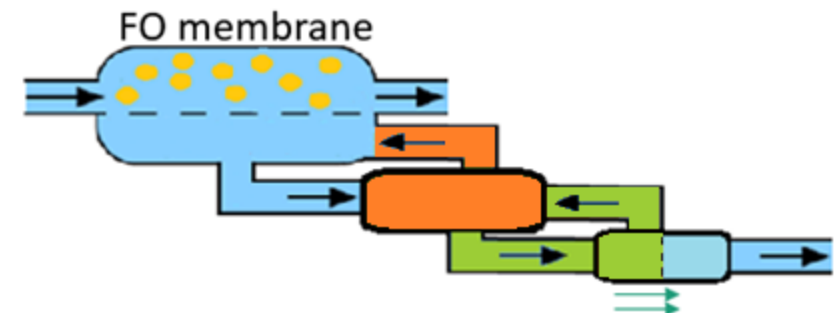
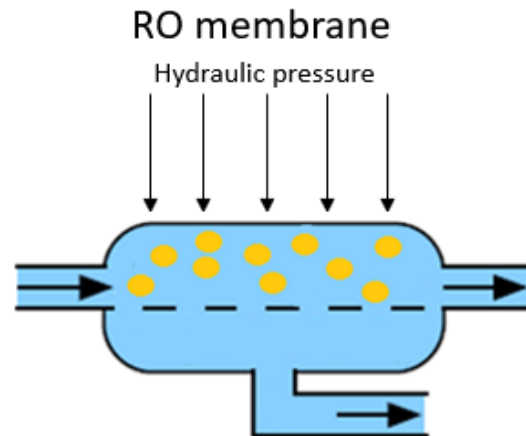
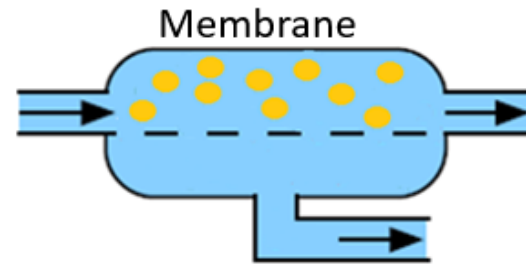
Modelling of a Forward Osmosis Process Using Experimental Data

Matej Ružička

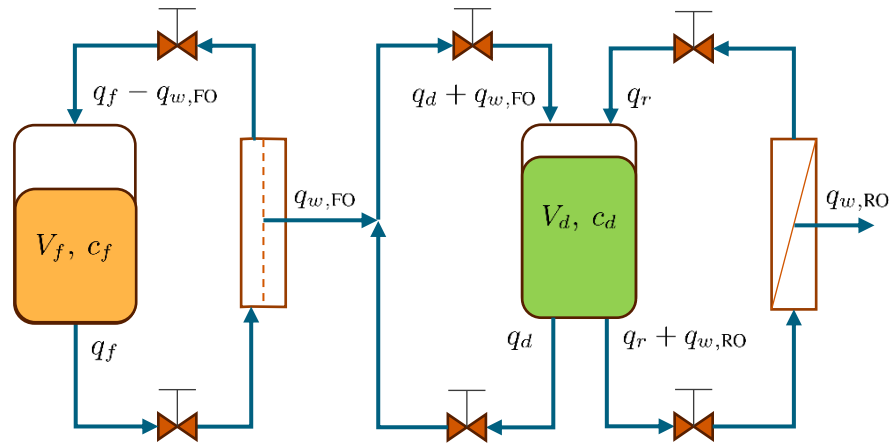
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Motivation

- Membrane processes
 - Water separation
- Forward (FO) vs reverse (RO) osmosis
 - Driving force
- Forward osmosis
 - **Osmotic pressure of draw solution**
 - Wastewater purification
 - **Concentration increase of pressure sensitive aqueous solutions**
- Why model?
 - Process behaviour
 - Dynamics
 - I/O relations
 - Process optimisation



Process



Goal

1. Model design

- Water fluxes
 - FO, RO
- Whole process

2. Model implementation

- Black box
- Grey box

3. Simulation

Problem solution

Black box approach

$$J_{w,FO} = ac_d + bc_d^2 + cc_f + dc_f^2 + e$$

Draw concentration [%]	Draw concentration**2 [%**2]	Feed concentration [brix]	Feed concentration**2 [brix**2]	Water flux [LMH]	Water flux estimated [LMH]
20	400	11.20	125.44	9.89	9.53
20	400	12.35	152.45	9.09	9.09
40	1600	50.99	2600.36	0.59	0.94
40	1600	51.83	2686.37	0.59	0.75
60	3600	53.98	2914.03	1.18	1.52
60	3600	56.09	3145.96	1.18	1.07

Experimental data used for flux model derivation (whole training dataset consists of 1240 measurements)

$$J_{w,FO} = 0.350c_d + 0.00288c_d^2 - 0.426c_f - 0.00194c_f^2 + 8.20$$

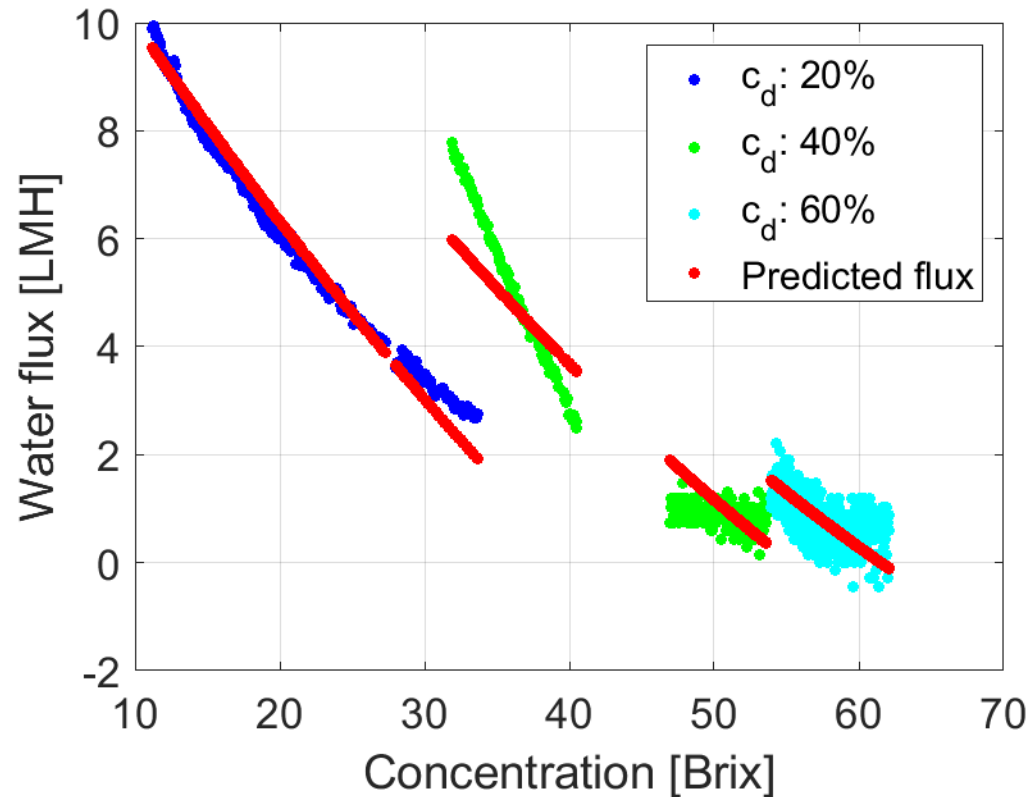
$J_{wFO} = a \cdot c_d + b \cdot c_d^2 + c \cdot c_f + d \cdot c_f^2 + e$

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	8.202337	0.122931	66.72289	0	7.96116	8.443514
X Variable 1	0.350258	0.008873	39.47626	3.5E-221	0.332851	0.367665
X Variable 2	0.00288	9.67E-05	29.8112	1.4E-147	0.00307	0.00269
X Variable 3	-0.42568	0.007416	-57.4033	0	-0.44022	-0.41113
X Variable 4	-0.001942	9.7E-05	-20.01389	2.08E-77	-0.001751	-0.002132

Output data table from Excel's data analysis solver

$$J_{wFO} = 0.350258 \cdot c_d + 0.00288 \cdot c_d^2 - 0.42568 \cdot c_f - 0.001942 \cdot c_f^2 + 8.202337$$

Estimated and measured FO flux



$$J_{wFO} = 0.350258 \cdot c_d + 0.00288 \cdot c_d^2 - 0.42568 \cdot c_f - 0.001942 \cdot c_f^2 + 8.202337$$

$$J_{w,FO} = 0.350c_d + 0.00288c_d^2 - 0.426c_f - 0.00194c_f^2 + 8.20$$

Grey Box

- **Total mass balance**

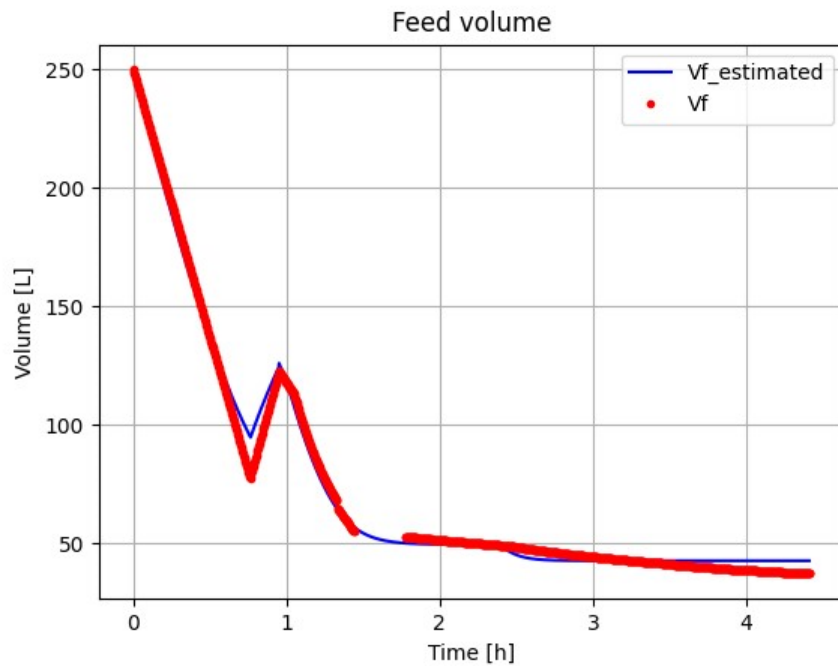
- {total mass accumulation} = {mass inflows} – {mass outflows}
- $\frac{dV_F(t)}{dt} = q_{IN}(t) - J_{wFO}(t) \cdot A$

- **Solute mass balance**

- {solute mass accumulation} = {solute inflows} – {mass outflows}
- $\frac{dc_F(t)}{dt} = \frac{c_F(t) \cdot (J_{wFO}(t) - q_{IN}(t))}{V_F(t)}$

- Estimation of process states by comparison with measured ones – **minimalization of loss function**
- Applying differential equations derived from MB to estimate flux, feed volume and feed concentration
- Water flux through FO membrane – calculated out of estimated variables
- Calculation of estimated states and **coefficients in flux equation**

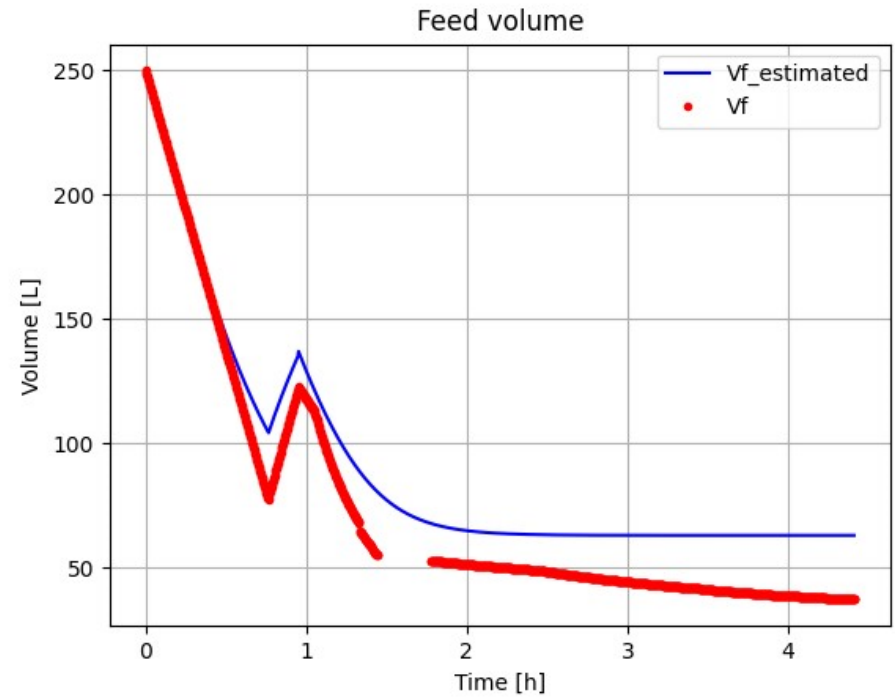
Grey Box



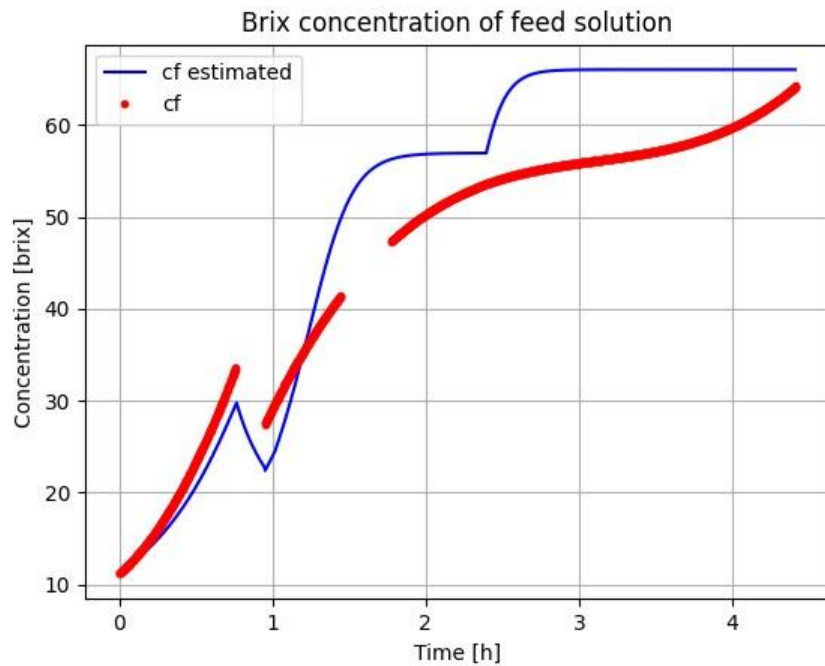
$$J_{wFO} = 11.37 \cdot c_d - 0.2507 \cdot c_f + 9.72$$

$$J_{w,FO} = 11.37c_d - 0.25c_f + 9.72$$

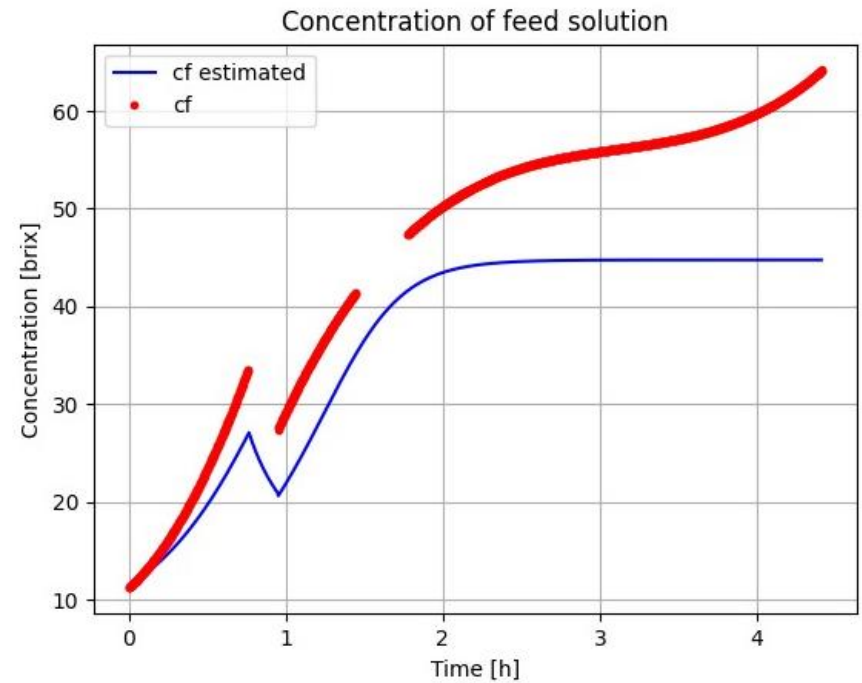
Black Box



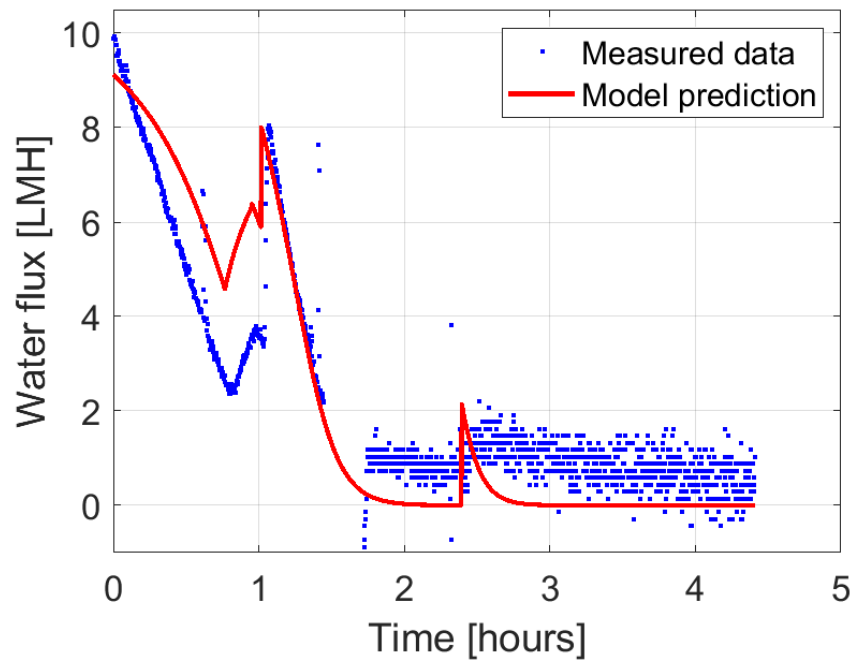
Grey Box



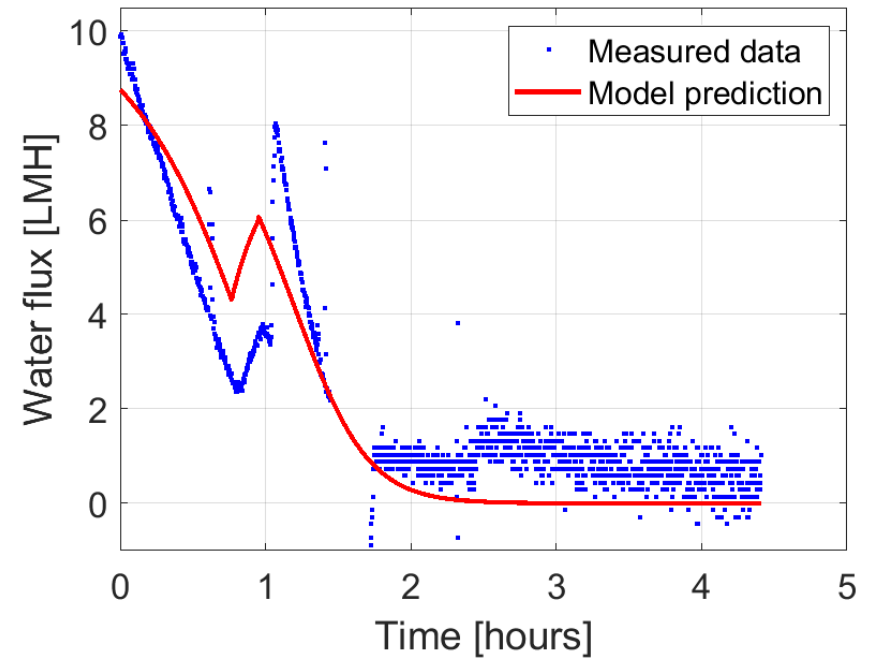
Black Box



Grey Box

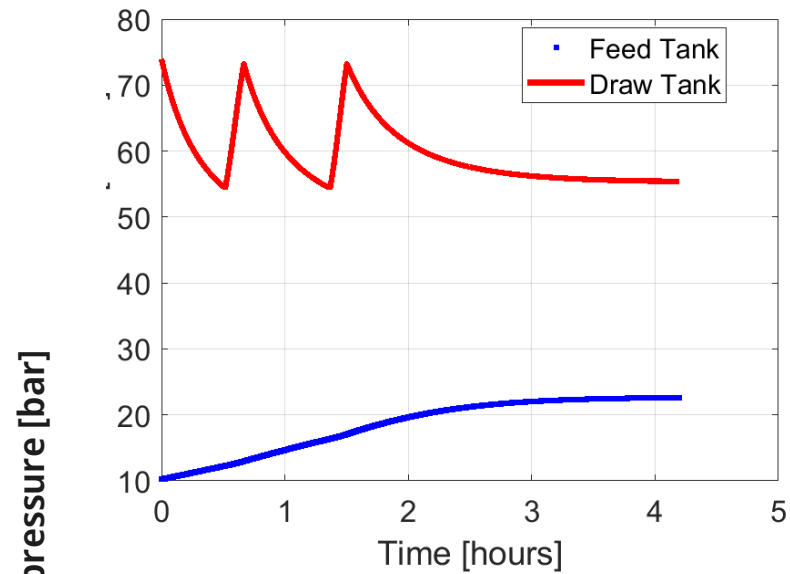


Black Box

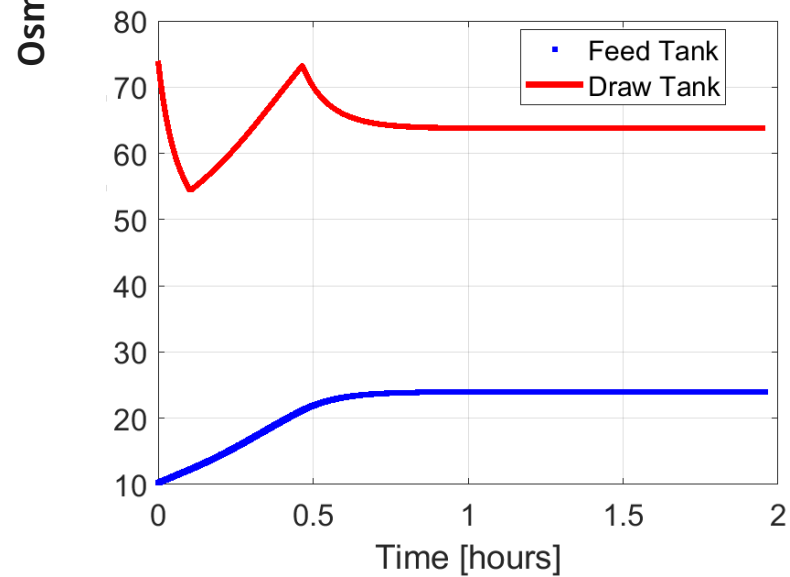


What is it all good for?

Osmotic pressure in time – 1 FO membranes



Osmotic pressure in time – 5 FO membranes



Conclusion

- Forward osmosis process
- Model derivation
 - Black box approach
 - Grey box approach
- Simulation design

Acknowledgements: This work is funded by the Slovak Research and Development Agency (project no. APVV-21-0019), by the Scientific Grant Agency of the Slovak Republic (grant no. 1/0691/21), and by the European Union under Horizon Europe Grant Agreement number 101079342 (Fostering Opportunities Towards Slovak Excellence in Advanced Control for Smart Industries).