CFD在环境工程领域的应用

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Menu

- Background and Why
- What
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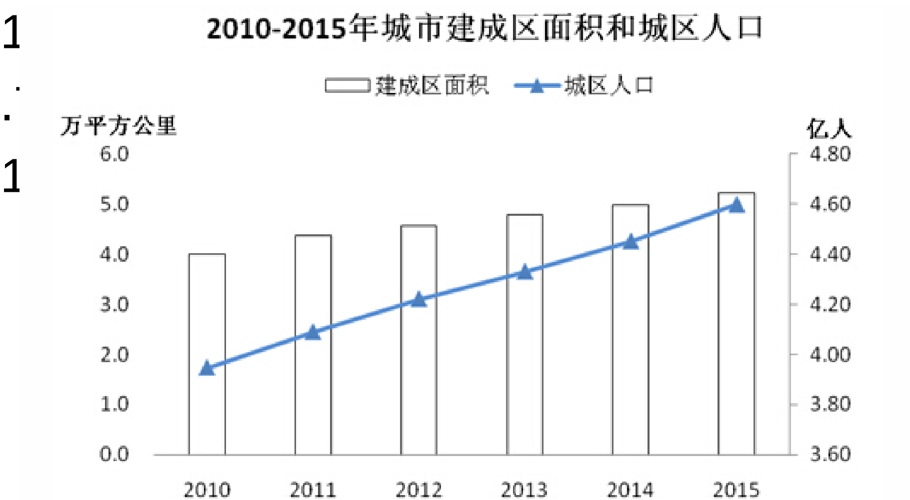
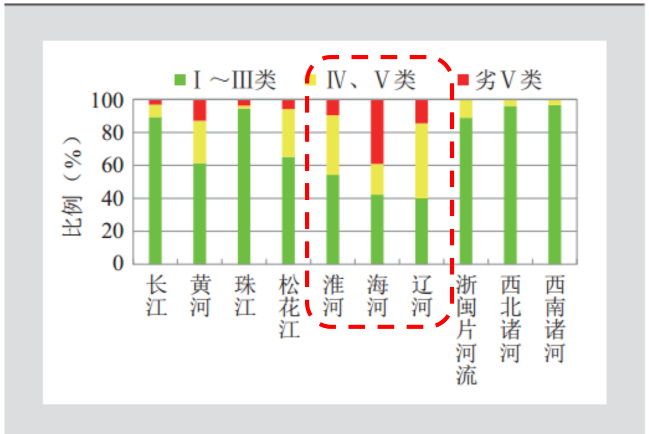
Background & Why

- The second water resource (China State Council, 2016):
  - 10.8 million m^3/d wastewater were reclaimed in 201
  - 23.   n 201

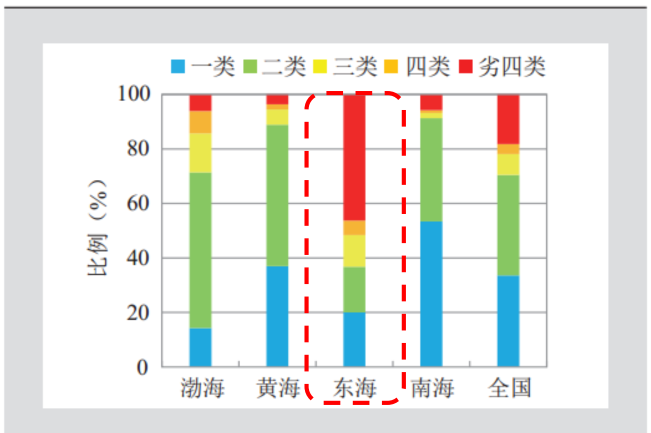


- Higher ratio of wastewater reuse can be

Country	Treated	Reclaimed	Reused	Reuse ratio
China	140	23	12	8.6%
America	132	40	14	10.6%
EU	116	-	2.78	2.4%
Israel	0.92	-	0.76	82.5%
Japan	40	-	0.52	1.3%



2015年七大流域和浙闽片河流、西北诸河、西南诸河水质状况

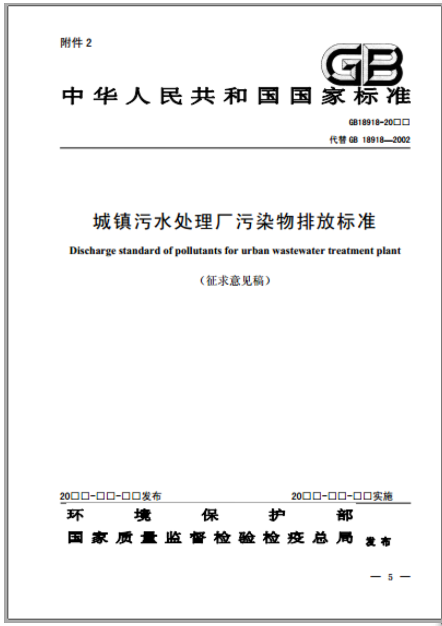


2015年全国及四大海区近岸海域水质状况

China's Ministry of Environmental Protection, 2016. China environmental state bulletin of 2015

Background & Why

- More restrict discharge standard is going to be issued (China State Council, 2016):


附件 2

GB

中华人民共和国国家标准

GB18918-20□□

代替 GB 18918—2002

城镇污水处理厂污染物排放标准

Discharge standard of pollutants for urban wastewater treatment plant

（征求意见稿）

20□□-□□-□□发布　　20□□-□□-□□实施

环境保护部

国家质量监督检验检疫总局 发布

— 5 —

Discharge standard of pollutants for urban wastewater treatment plant

Pollutants	Special grade standard	First grade Standard A	First grade Standard B	Second grade standard
COD_{Cr}	30	50	60	80
BOD_5	6	10	20	30
Ammonia	1.5(3)/3(5)	5/8	8/15	15/20
TN	10/15	15	20	25
TP	0.3	0.5	1.0	1.0
SS	5	10	20	30
Color	15	30	30	40
Oil	1.0	1.0	3.0	5.0
Petroleum	0.5	1.0	3.0	5.0
LAS	0.3	0.5	1.0	2.0

- Available treatment technologies (Ozgun, 2013; Zhang, 2016):
  - **Membrane bioreactors**
  - Conventional activated sludge
  - Emerging technologies: anammox, aerobic granular sludge, MBfR

Background & Why

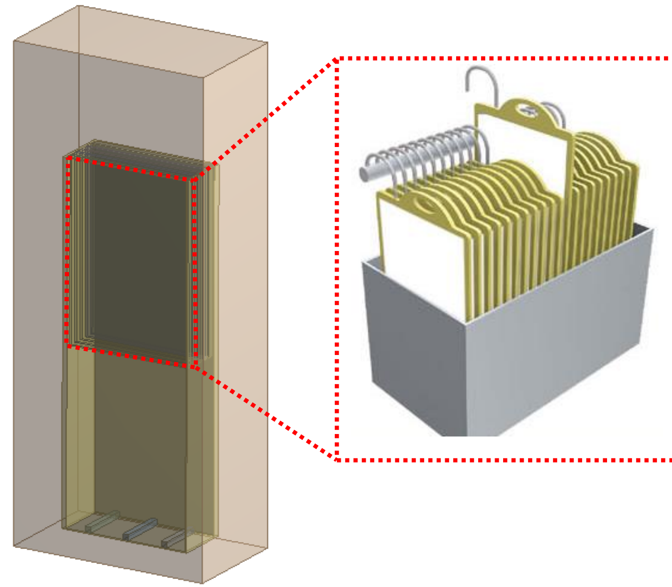
- **Strengthens of MBR**
  - **Small footprint**
  - **Higher biomass concentration**
  - **Highly-improved effluent quality**

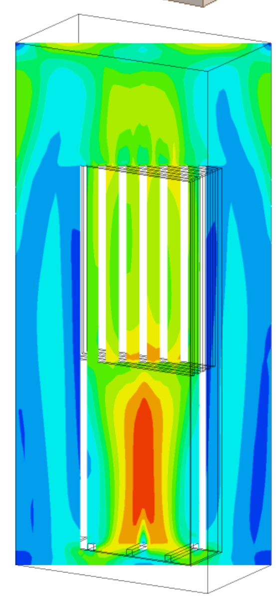
- **Weaknesses of MBR**
  - **Higher operation cost**
  - **Lower efficiency of nutrients removal**

A case in Beijing

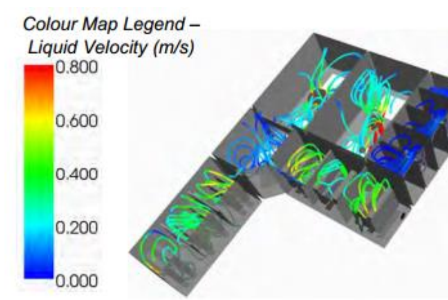
Capacity of MBR > 800,000 m³/d by 2015,

Reclaimed water 39,700,000 m³/d by 2015.

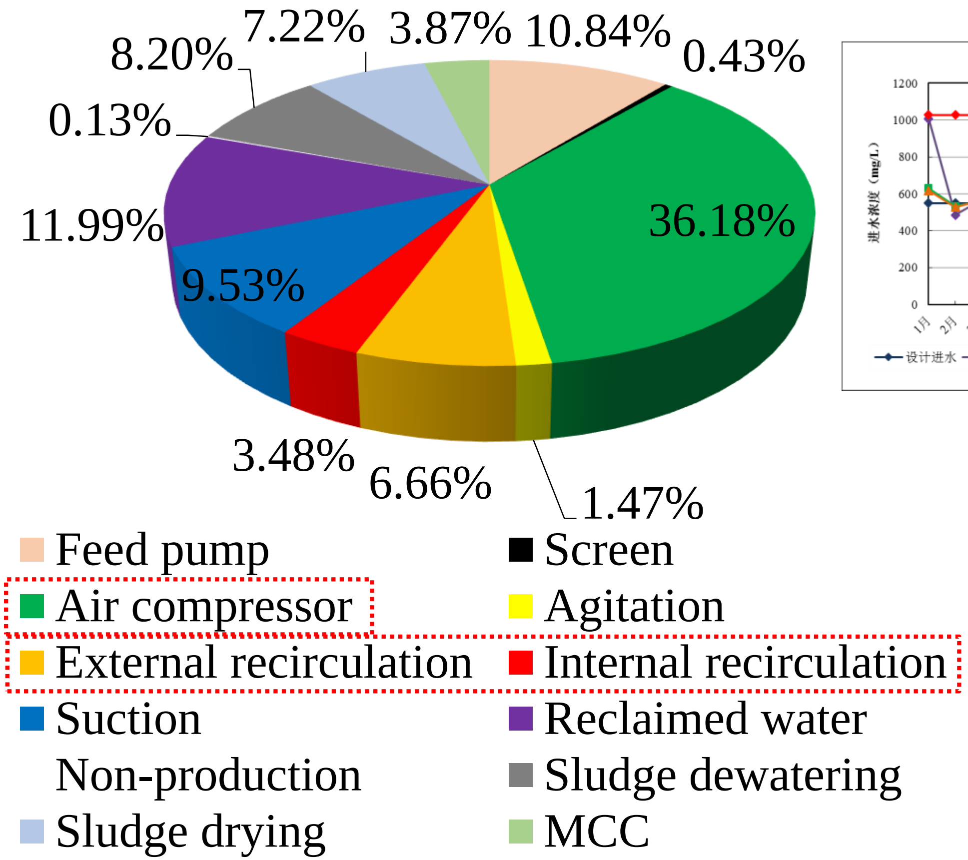




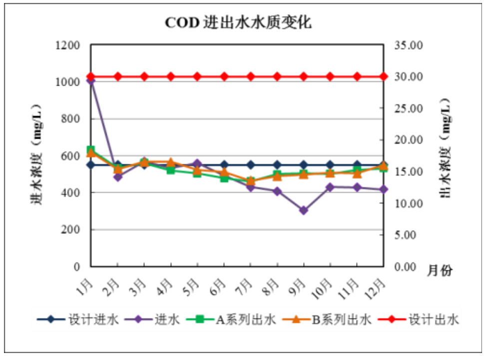
CFD modelling & simulation

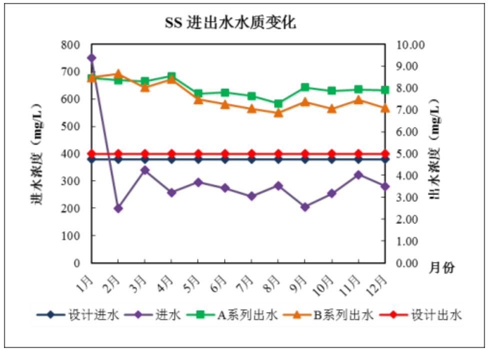


Background & Why



Composition of energy consumption of an A^2/O-MBR in Qinghe reclaim water plant

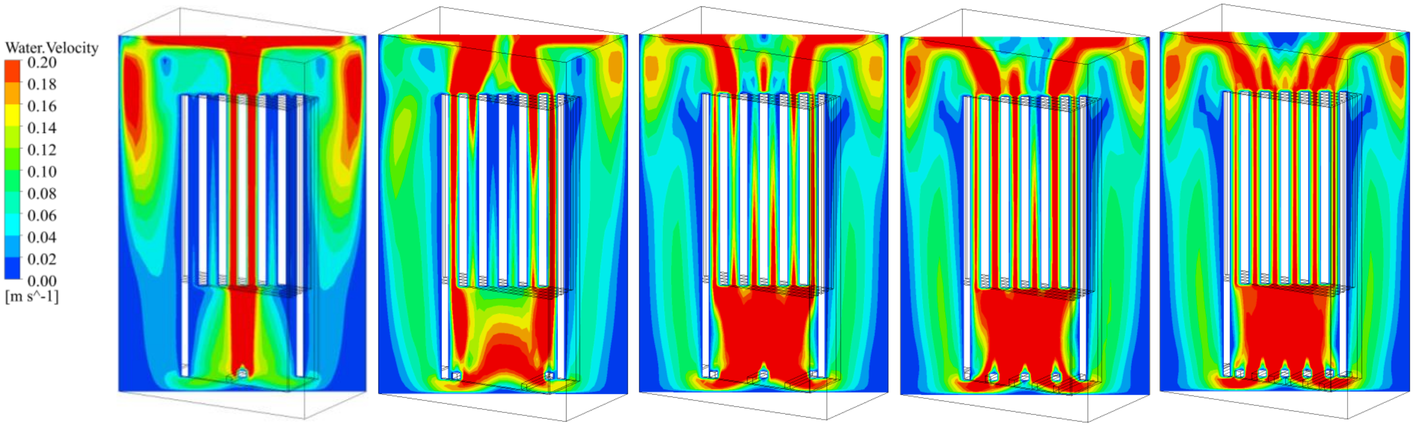


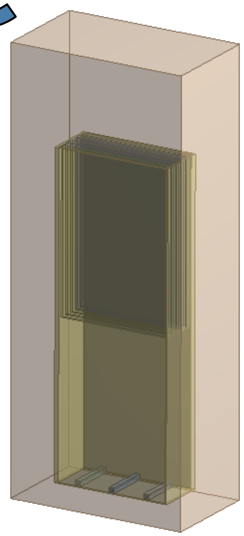


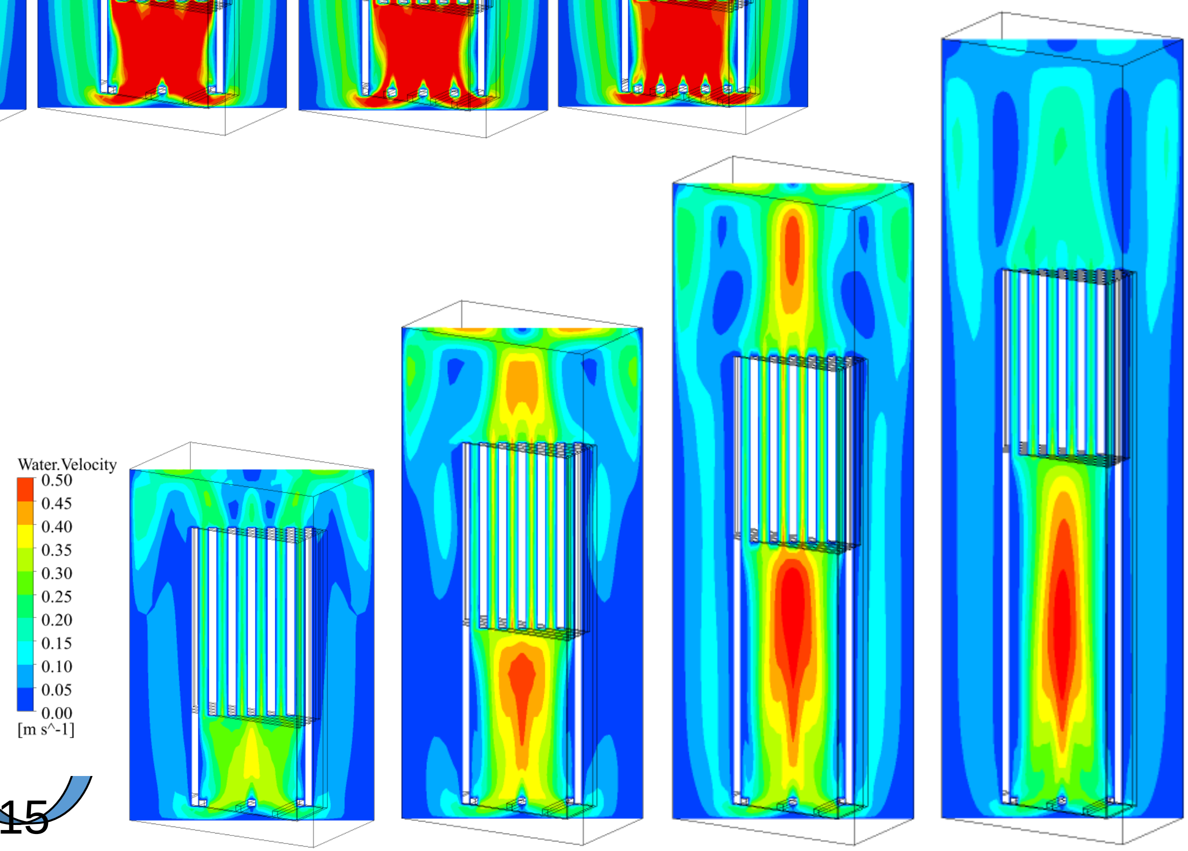
CFD approaches for energy saving & better water quality

- **Configuration modification**
- **Process adjustment**
- **Bio-kinetics integration**

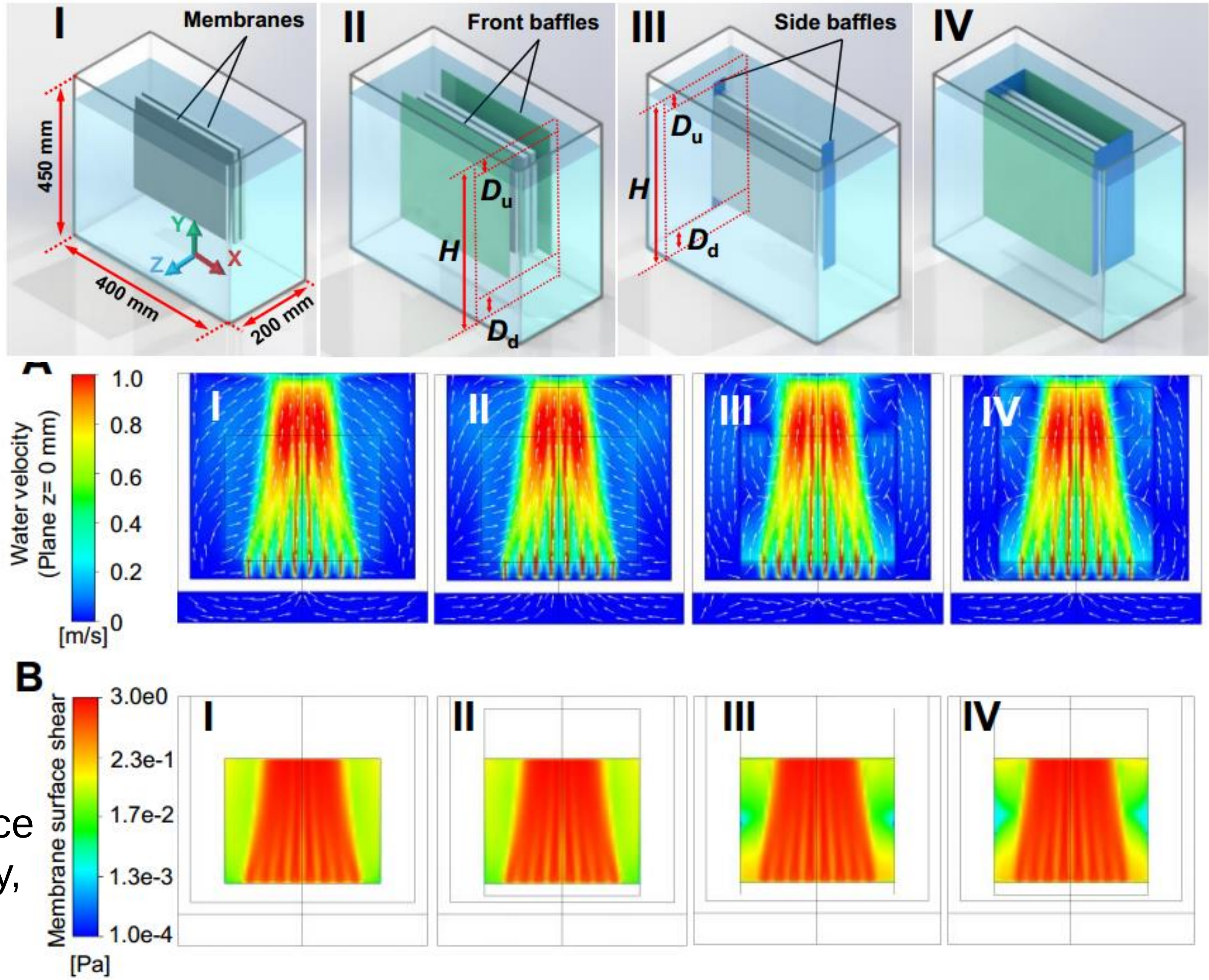
What— MBR configuration modification







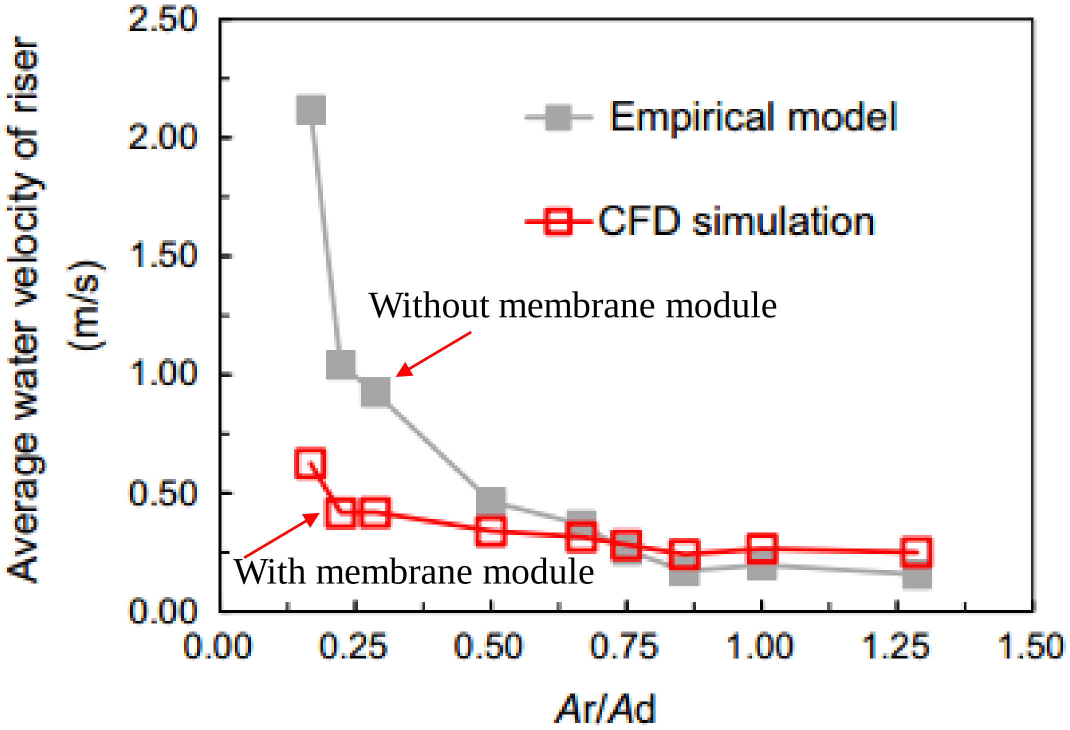
Yang, et al, watermatex IWA, 2015

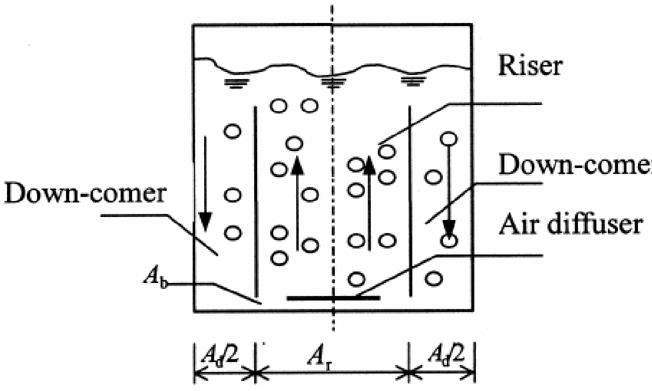


Yan, et al, Bioresource technology, 2015

What— MBR configuration modification

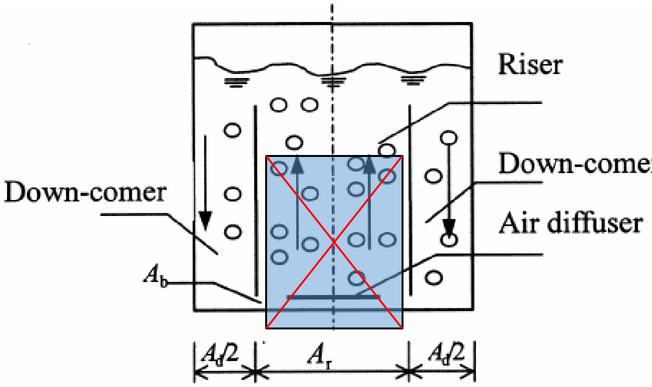
$$U_{Lr} = \sqrt{\frac{2gh_d(\varepsilon_r - \varepsilon_d)}{11.402\left(\frac{A_d}{2A_b}\right)^{0.789}\left(\frac{A_r}{A_d}\right)^2 \cdot \frac{1}{(1-\varepsilon_d)^2}}}$$





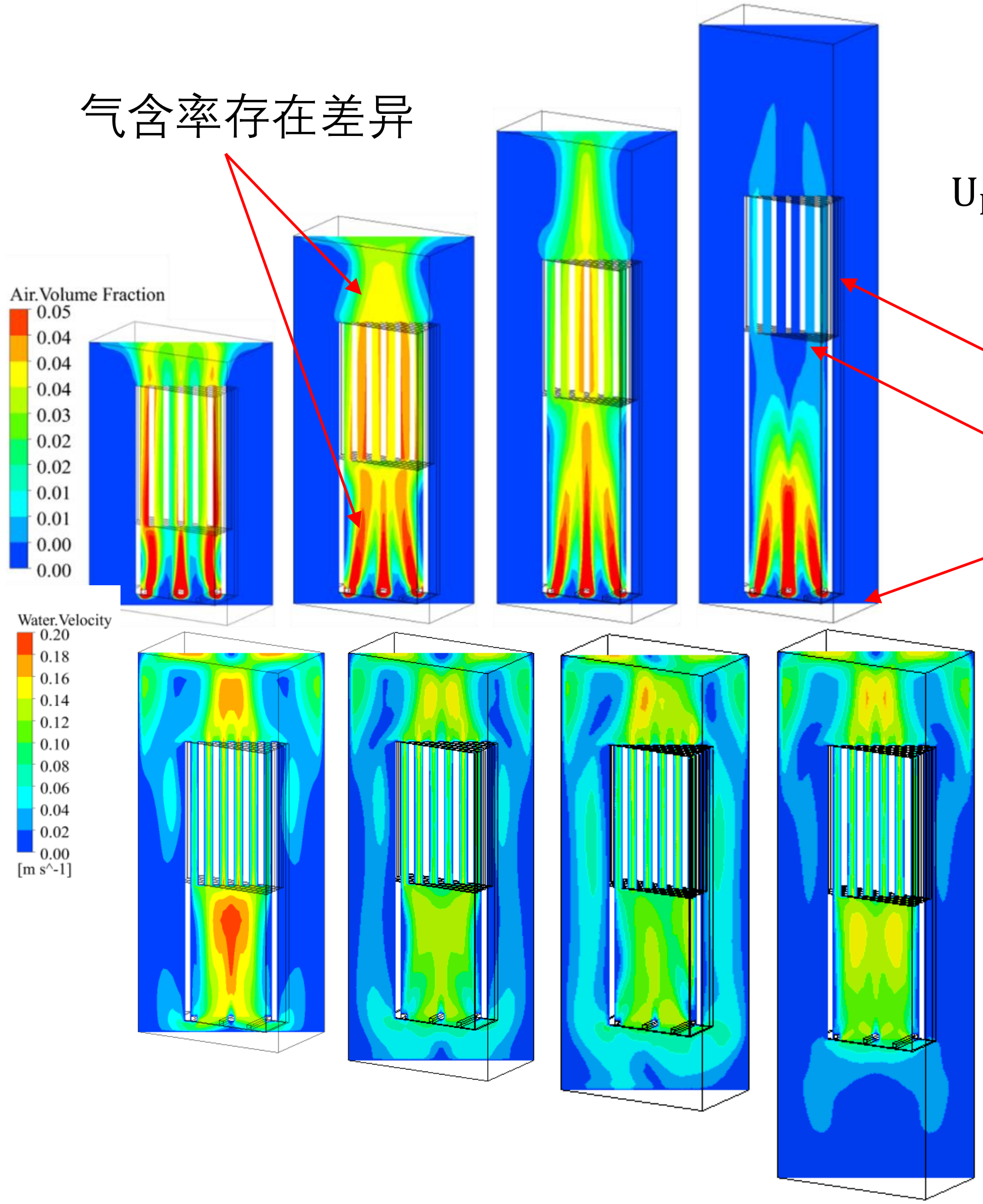
Without membrane module

VS



With membrane module

What— MBR configuration modification



$$U_{Lr} = \left[2gh_L\varepsilon_r/(1-\varepsilon)K_{BR}K_{BM}K_{AM}\left(\frac{A_r}{A_d}\right)^2 \right]^{0.5}$$

$$K_{AM} = c\frac{l}{d_c} \quad 0 < c < 1$$

$$K_{BM} = d\left(\frac{A_r}{A_c}\right)^e \quad 1 < d < 10,\ 0 < e < 1$$

$$K_{BR} = a\left(\frac{A_d}{A_b}\right)^b \quad 1 < a < 10,\ 0 < b < 1$$

Pearson correlation analysis

Different scenarios:

1. Module height
2. Membrane height
3. Bioreactor height h_L
4. Membrane space……

Yang, et al, IWA water conference, 2016

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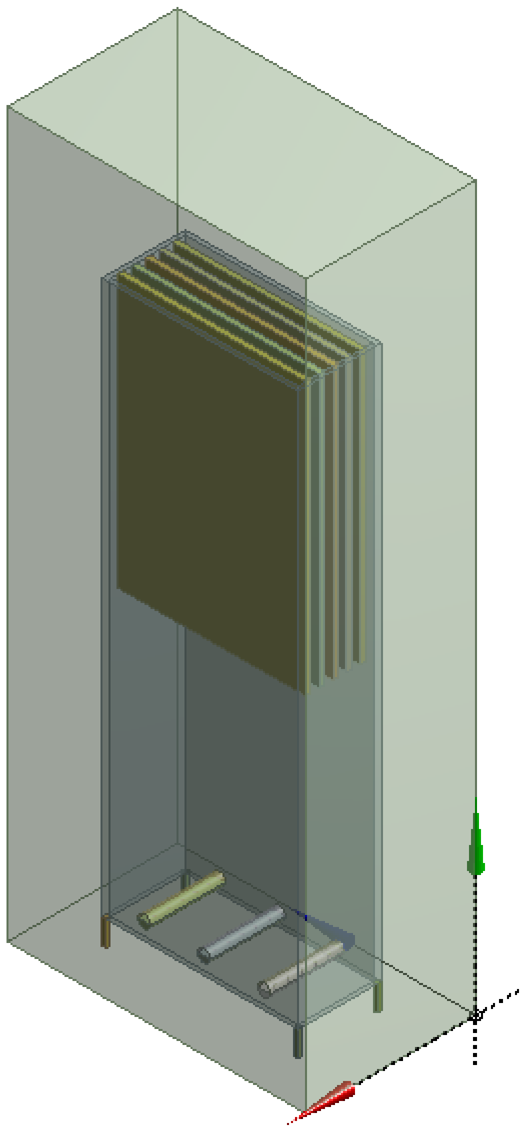
What— MBR configuration modification

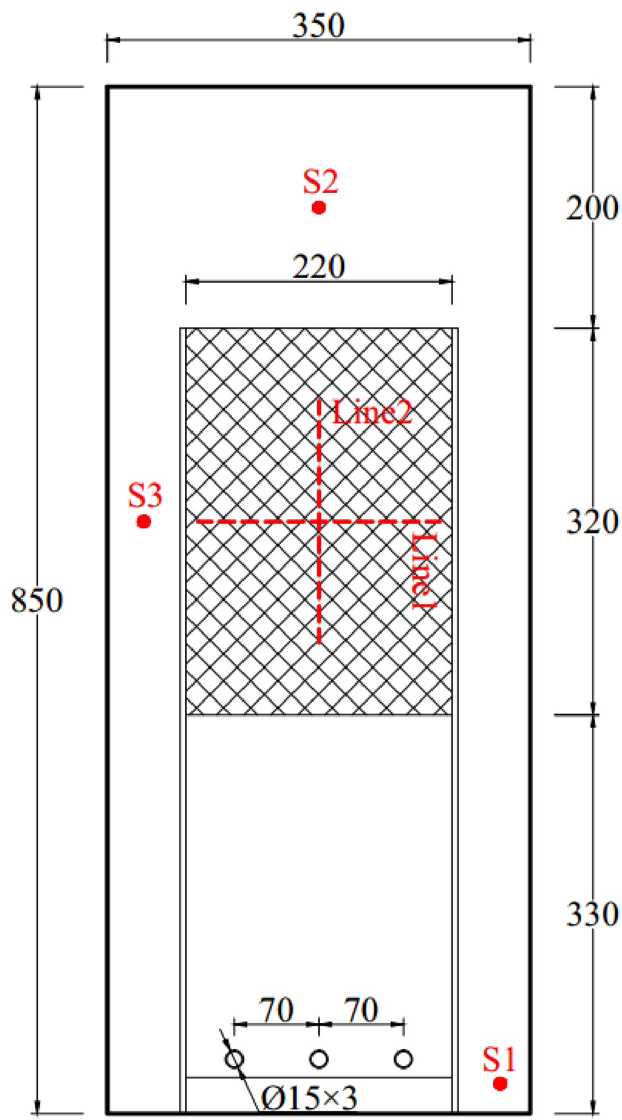
Pearson correlation analysis for liquid velocity in the riser and membrane shear s

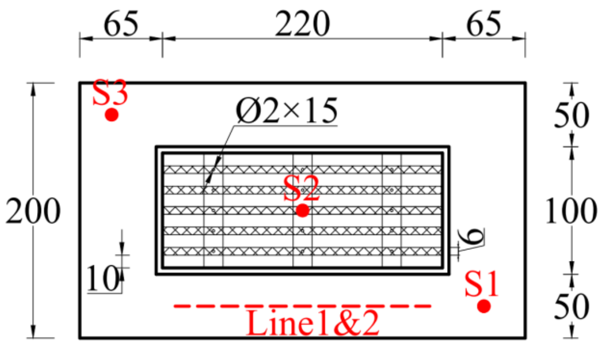
	viscosity	TKE	VOF_r	V_w	Strain_rate	Shear_Stress	Ar	Ad	Ac	Ab	d_c	h_L	h_D	h_E	Ad_Ab	Ar_Ac	Ar_Ad
viscosity	1																
TKE	-.864**	1															
VOF_r	-.389	.562*	1														
V_w	.686**	-.706**	-.097	1													
Strain_rate	-.833**	.623**	.323	-.486*	1												
Shear_Stress	-.806**	.962**	.632**	-.672**	.500*	1											
Ar	-.853**	.957**	.503*	-.777**	.677**	.877**	1										
Ad	-.459	.582*	.350	-.233	.445	.551*	.557*	1									
Ac	-.640**	.685**	.244	-.737**	.421	.611**	.741**	-.045	1								
Ab	-.206	.143	.128	-.274	.301	.157	.165	.026	.227	1							
L/d_c	-.890**	.967**	.488*	-.785**	.701**	.889**	.996**	.543*	.747**	.161	1						
h_L	-.283	.181	-.314	-.521*	.393	.087	.294	.045	.404	.711**	.286	1					
h_D	-.093	.046	-.706**	-.371	.094	-.132	.188	.029	.258	-.166	.183	.485*	1				
h_E	-.093	.046	-.706**	-.371	.094	-.132	.188	.029	.258	-.166	.183	.485*	1.000**	1			
Ad/Ab	-.263	.412	.212	-.035	.185	.371	.380	.848**	-.179	-.457	.370	-.365	.128	.128	1		
Ar/Ac	.263	-.199	.083	.414	-.065	-.166	-.231	.532*	-.819**	-.182	-.251	-.324	-.207	-.207	.572*	1	
Ar/Ad	.304	-.488*	-.185	.198	-.262	-.465	-.463	-.791**	-.075	-.126	-.434	-.225	-.144	-.144	-.605**	-.297	1

- The parameters which are considered to be significantly correlated to liquid velocity in the riser are Ad/Ab, Ar/Ad, Ar/Ac, L/d_c, h_L for Newtonian fluid.
- However, only A_r, A_c, L/d_c, h_L were found to be correlated to liquid velocity for Non-Newtonian.
- Further study is needed to address the discrepancy.

What— Operation optimization







What— Operation optimization

Table 1 Operating conditions and corresponding ranges used for the design of experiments

Operating conditions	Operating range
MLSS (g/L)	6.0-18.0
Air flowrate (m^3/h)	1.0-2.0
Bubble diameter (mm)	1.0-5.0

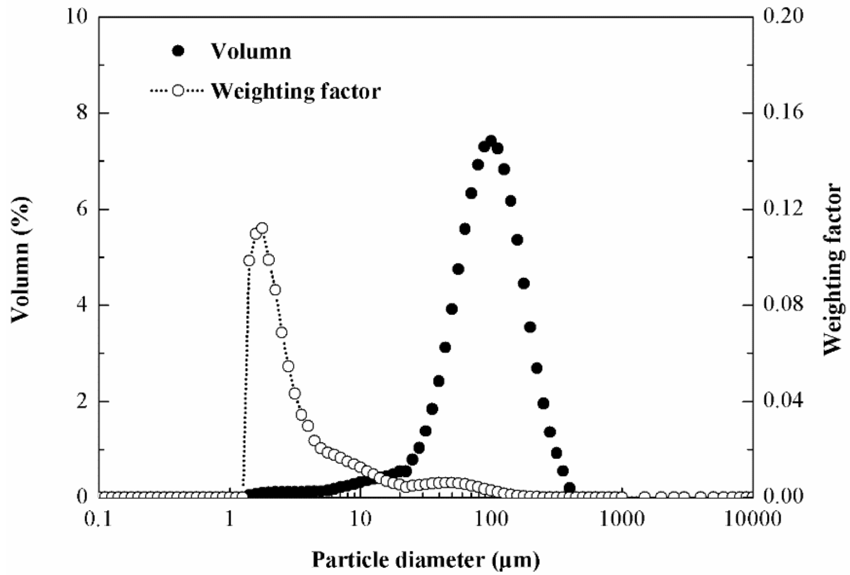


Fig. 3 PSD and PSW factor

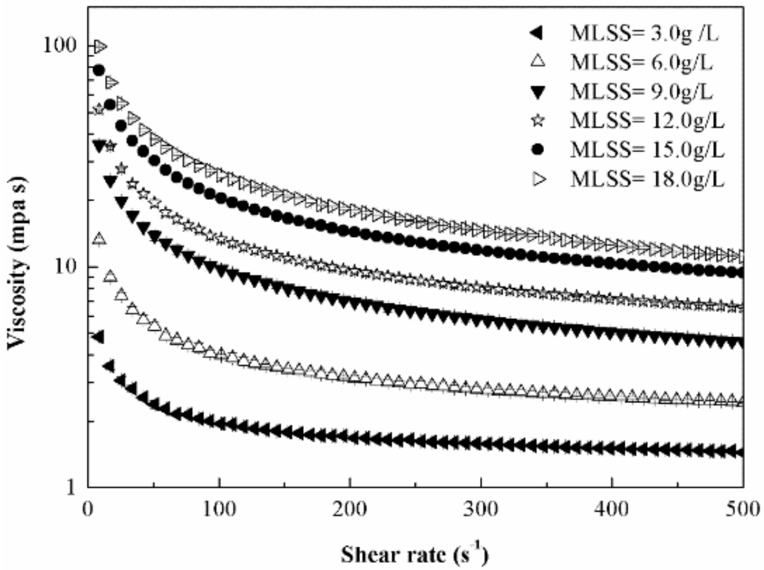
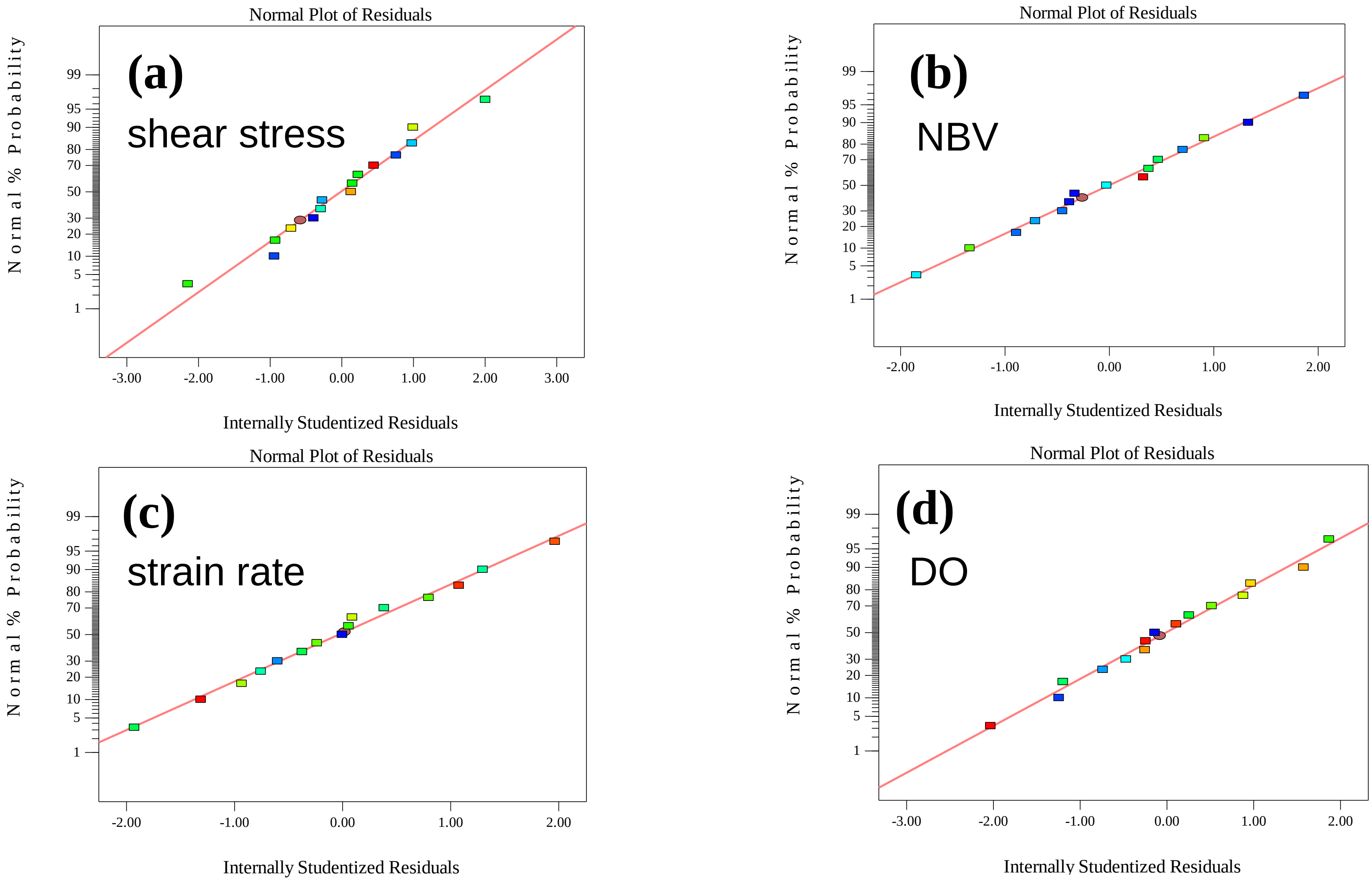


Fig. 4 Viscosity-shear rate rheology

What— Operation optimization

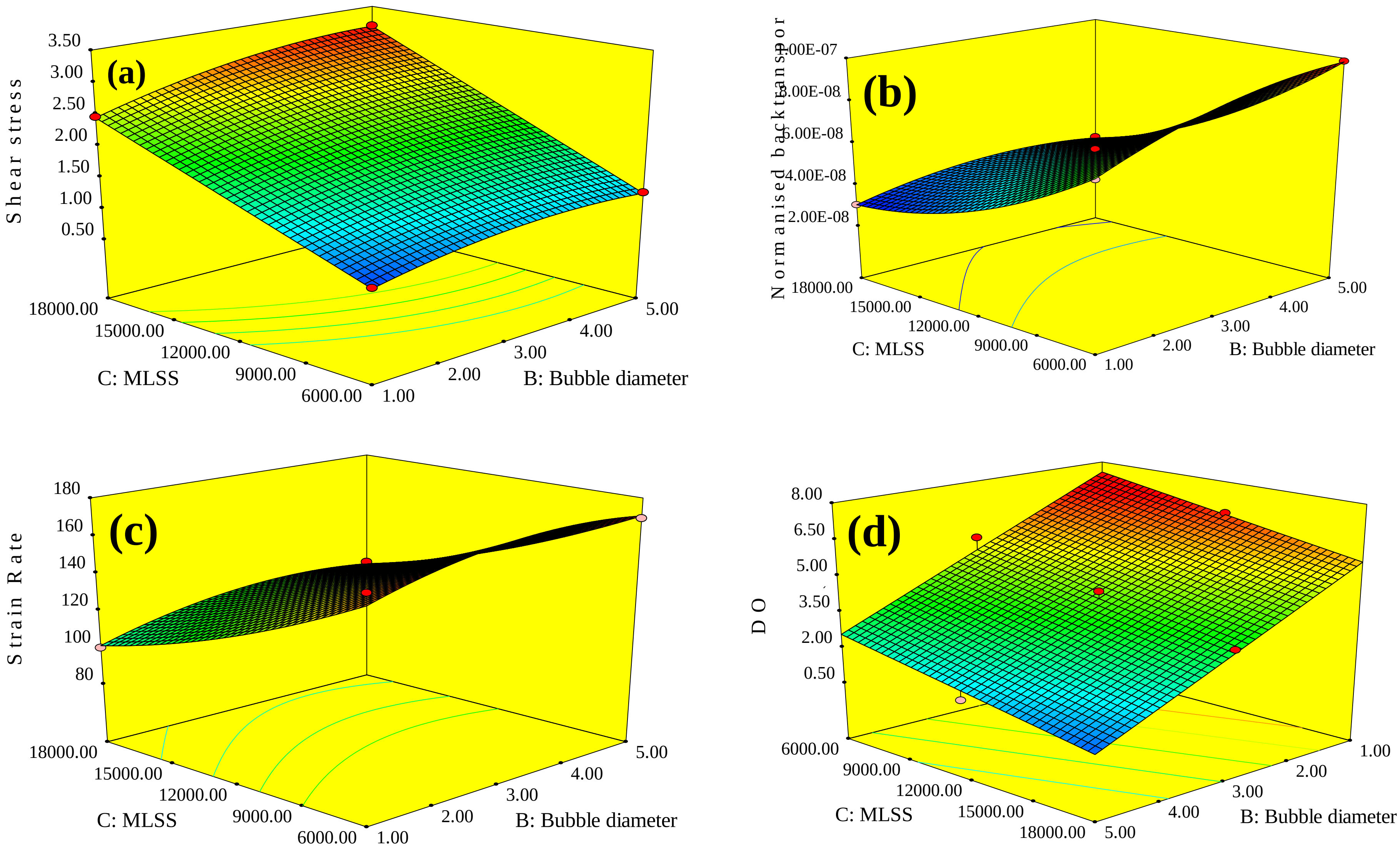


What— Operation optimization

Table 3 Optimal operating conditions and response values for each one of the membrane scouring indices

Optimal targets		Shear stress (Pa)	NBV(m $s^{-1}J^{-1}$)	Strain rate (s^{-1})
Aeration intensity		2.00	1.00	2.00
Bubble diameter		4.32	4.97	4.97
MLSS		18000.00	3000.00	3000.00
Response	Shear stress	3.14	0.55	0.78
	NBV	$3.21e^{-8}$	$1.24e^{-7}$	$7.79e^{-8}$
	Strain rate	118.17	152.50	191.37
	DO(mg L^{-1})	2.00	2.63	3.55

What— Operation optimization

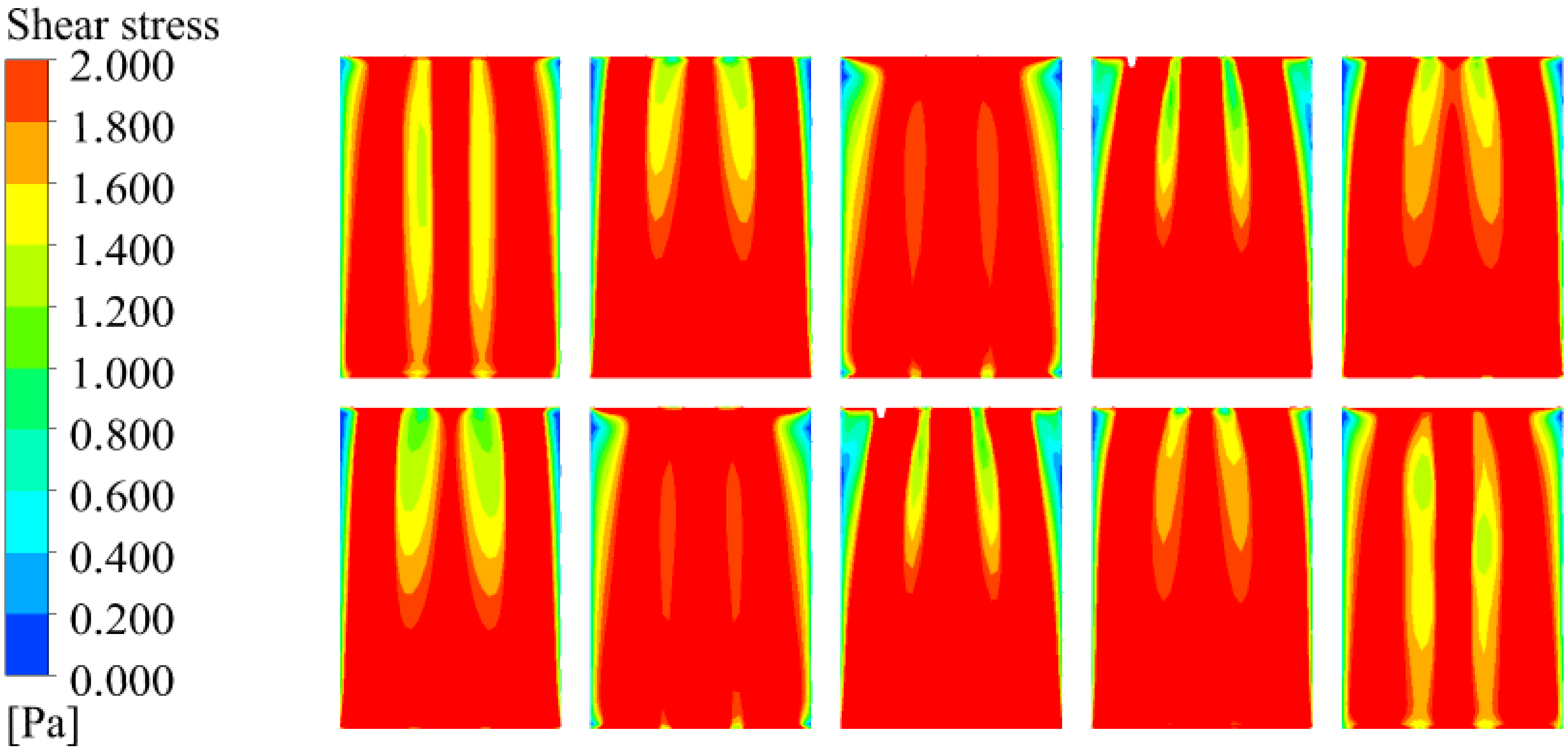


What— Operation optimization

Table 4 Optimal operating conditions and response values considering the maximization of multiple responses

Propensity		Shear stress=NBV	Shear stress＞NBV	NBV＞Shear stress
Optimal targets		Shear stress NBV	Shear stress NBV	Shear stress NBV
Aeration intensity		1.28	2.00	1.00
Bubble diameter		4.27	3.45	4.20
MLSS		10274.18	18000.00	5945.36
Response	Shear stress	1.69	3.05	1.03
	NBV	$6.11e^{-8}$	$3.46e^{-8}$	$9.70e^{-8}$
	Strain rate	125.93	118.14	134.75
	DO	2.62	3.08	3.16
Desirability		0.31	0.57	0.41

What— Operation optimization



What— MBR process innovation

➢ **What's new ?**

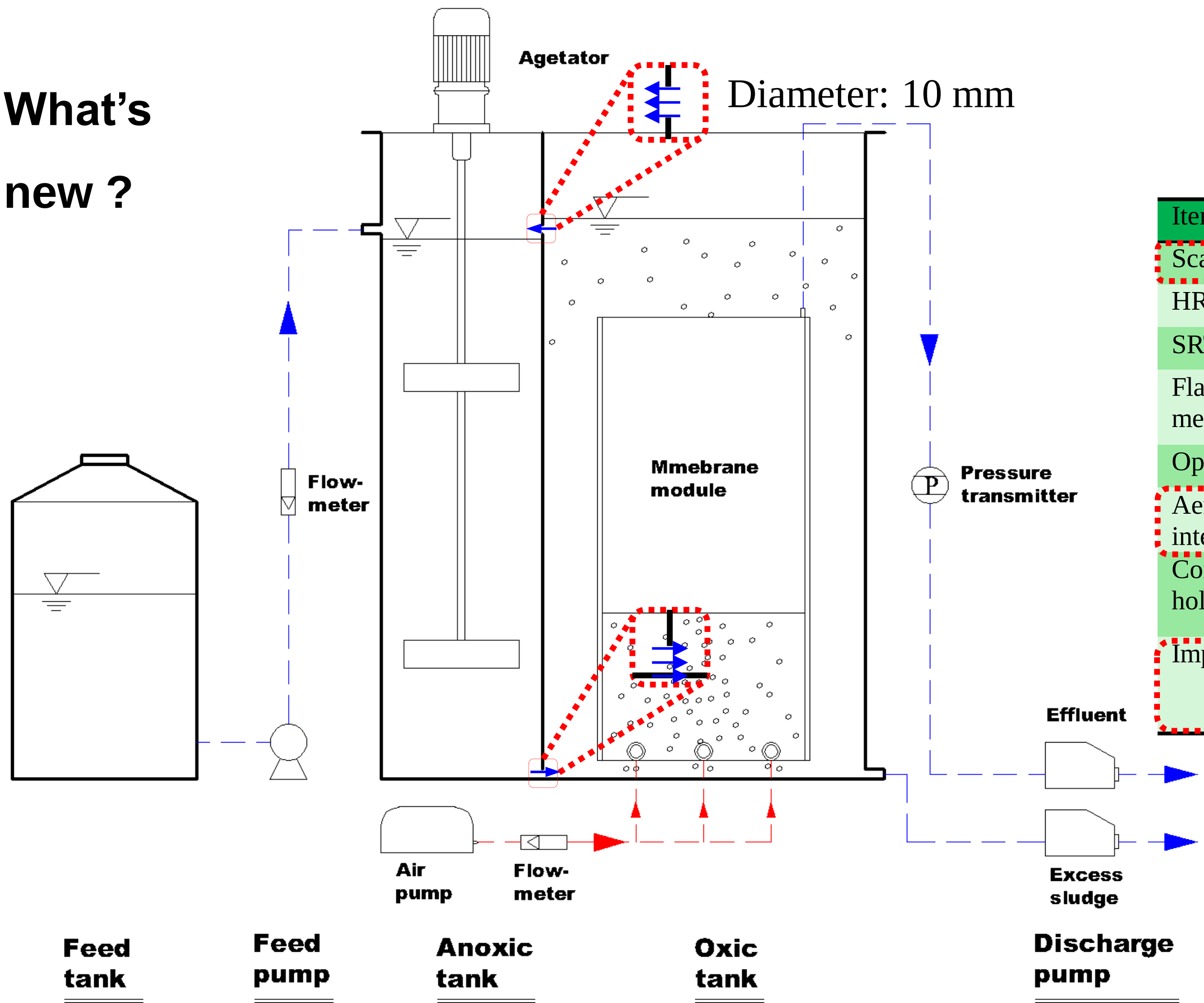


Diagram of the Integrated airlift A/O-MBR

Geometry and operation parameters

Items	Parameters
Scale	100.0 L/d
HRT	14.0h
SRT	20.0d
Flat sheet membrane	Sinap-25-PVDF, pore size≤0.1μm
Operation flux	10.5LMH
Aeration intensity	0.5 (SAD 25), 1.0 (SAD 50), 1.5 (SAD 75) m^3/h
Connecting hole diameter	10.0mm
Impellers	Double straight oar 60 rpm w: d: D= 0.25: 1.00: 1.25

➢ **Key concerns ?**

What— MBR process innovation

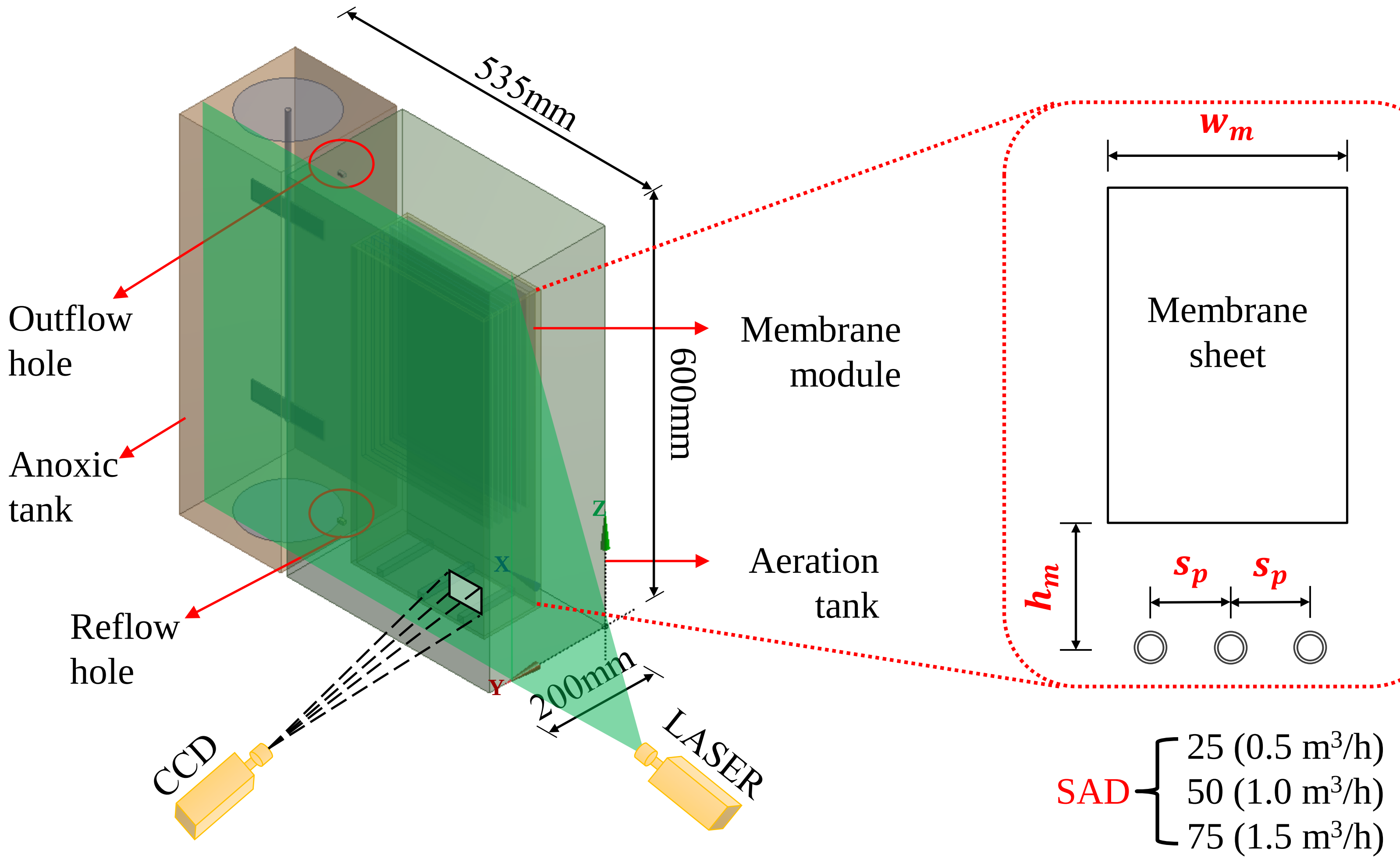
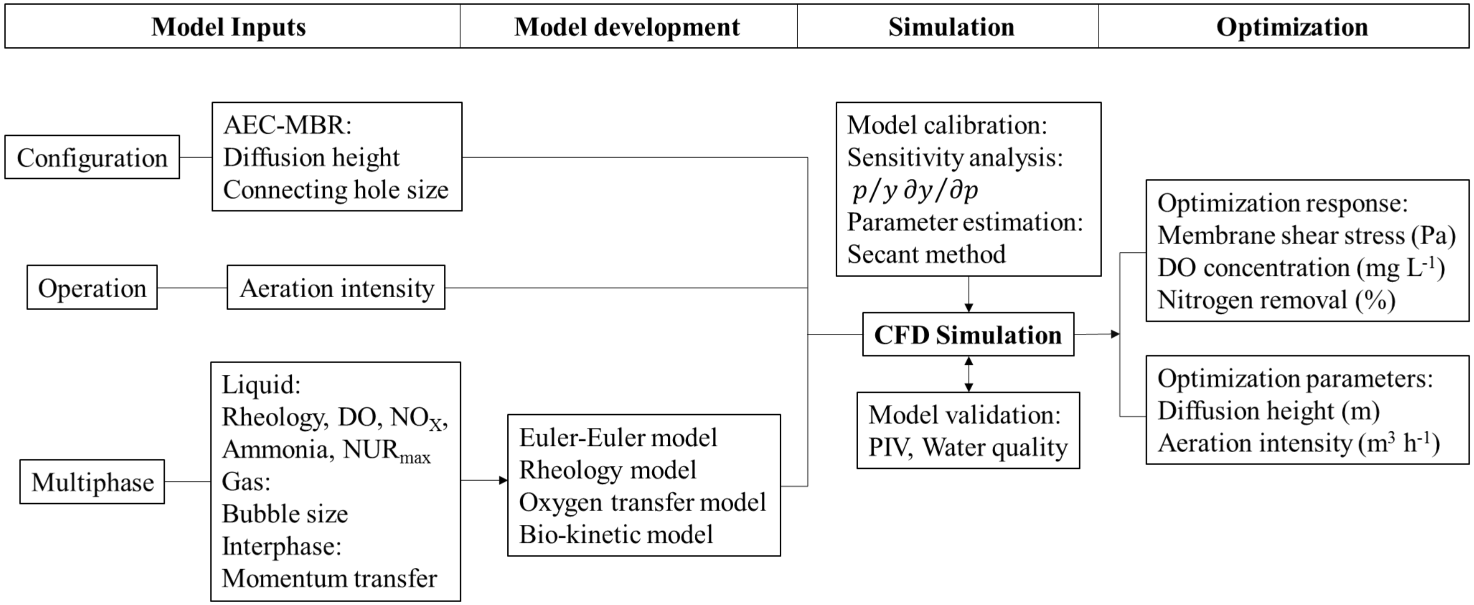
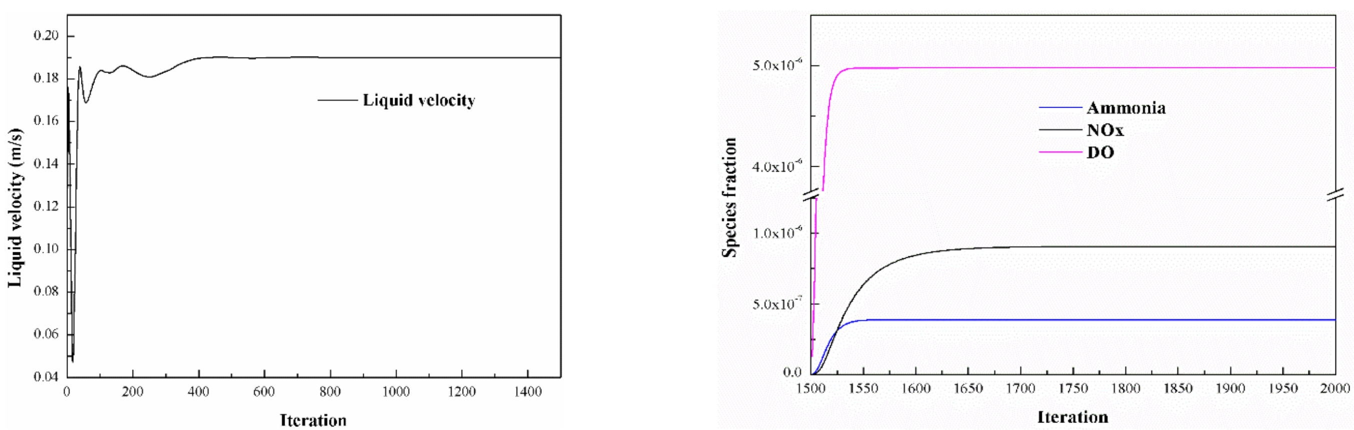


Fig. 3. Configuration of the airlift recirculation A/O-MBR

What— MBR process innovation

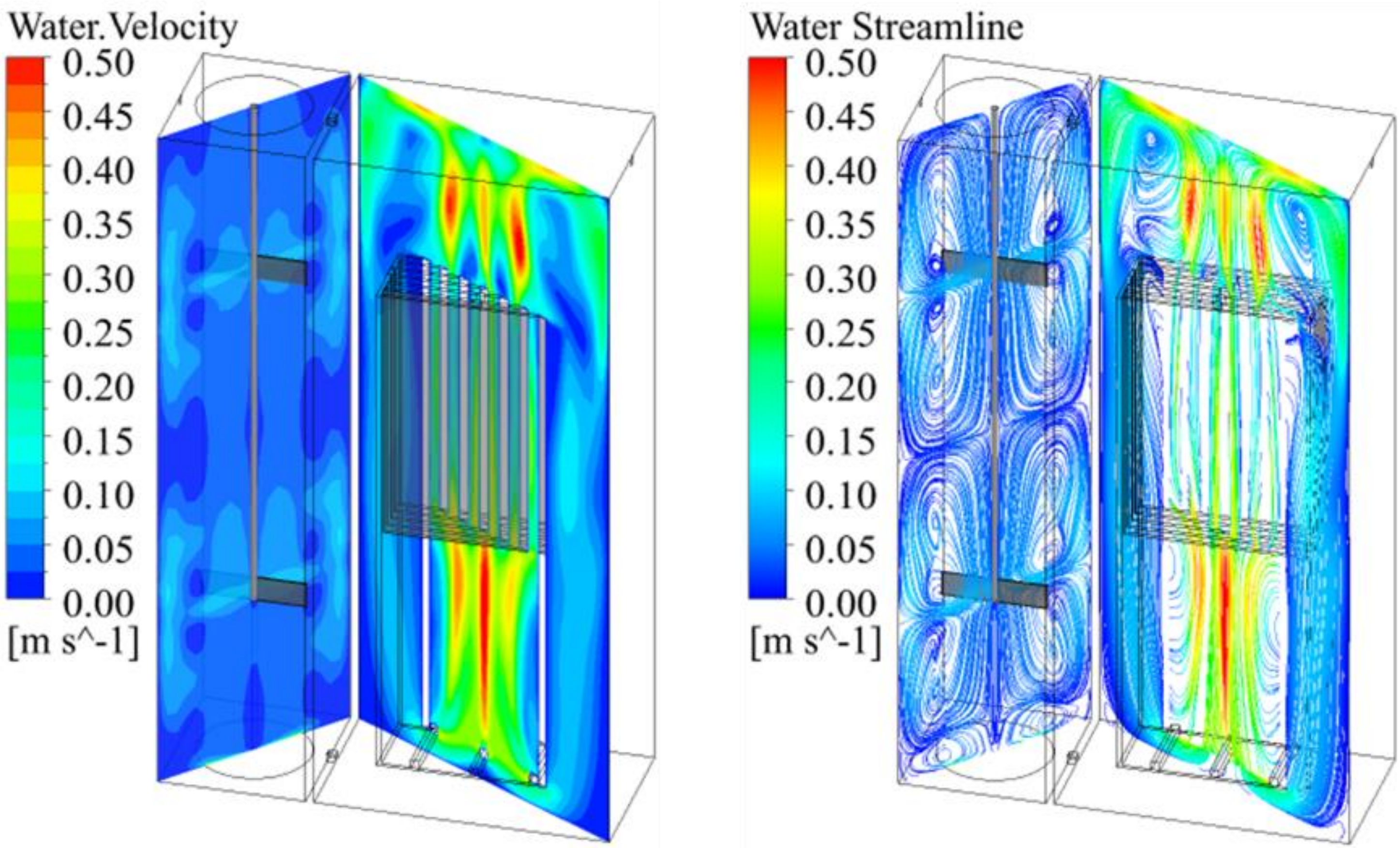


Work flow of CFD study for membrane bioreactor



Area-weighted average water velocity (left) and species concentration (right) at the cross section of reflow hole

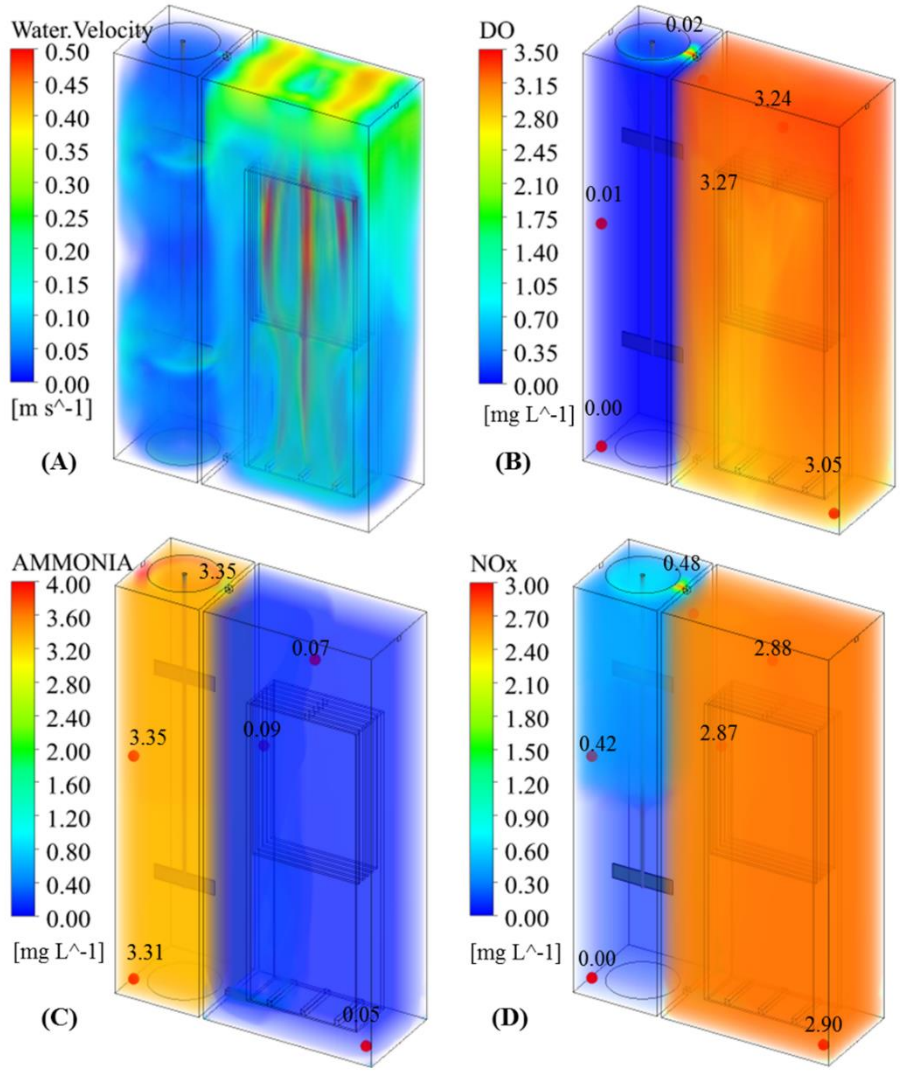
What— MBR process innovation



Local flow profile of water velocity (left) and water streamline (right) in the AEC-MBR at SAR50

Yang, Bioresource technology, 2016

What— MBR process innovation



Hydrodynamics and spatial distribution of species and scalars

Yang, Bioresource technology, 2016

What— MBR process innovation

Table 3 Performances of the AEC-MBR at different aeration intensities

Parameters	SAR 25	SAR 50	SAR 75
Average DO in oxic unit (mg L^{-1})	0.97±0.14[b]	3.10±0.24	4.98±0.30
Average DO in anoxic unit (mg L^{-1})	0.004±0.04	0.02±0.13	0.08±0.22
Average ammonia in oxic unit (mg L^{-1})	0.11±0.16	0.08±0.13	0.05±0.10
Average ammonia in anoxic unit (mg L^{-1})	4.36±1.13	3.41±1.19	1.96±1.08
Average NO_X in oxic unit (mg L^{-1})	2.72±0.18	2.87±0.17	2.36±0.11
Average NO_X in anoxic unit (mg L^{-1})	0.10±0.14	0.16±0.21	0.52±0.28
Removal ratio of total nitrogen (%)	94.8	94.6	95.6
Recirculation ratio (%)	1036	1306	1531
Average shear stress (Pa)	0.9±0.6[c]	1.2±0.8	1.4±0.8

Yang, Bioresource technology, 2016

What— MBR process innovation

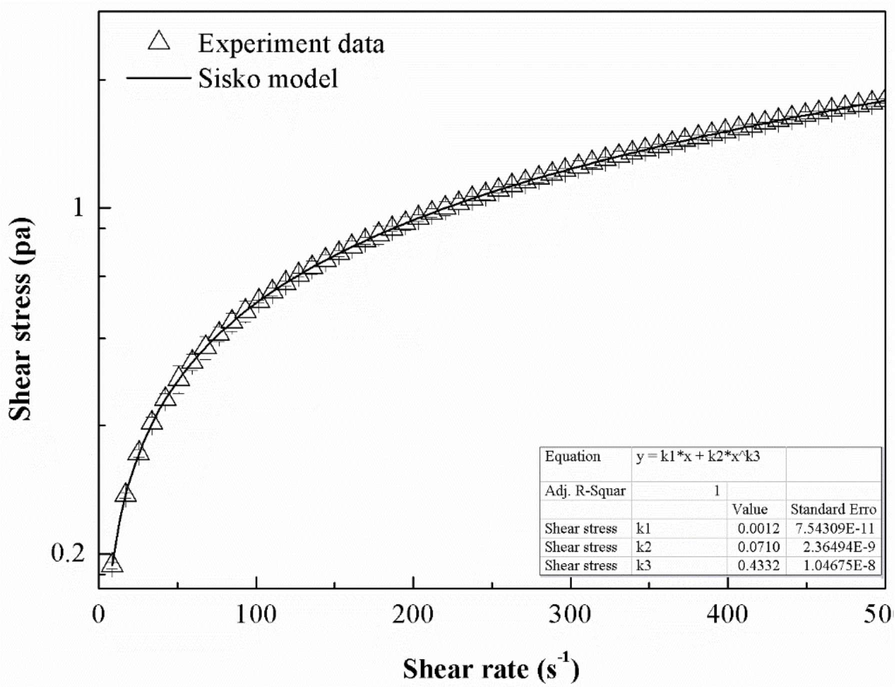


Fig. S1 Shear stress-shear rate nonlinear curve fitting for activated sludge (MLSS = 7.5 g/L, T=20℃) in the AEC-MBR

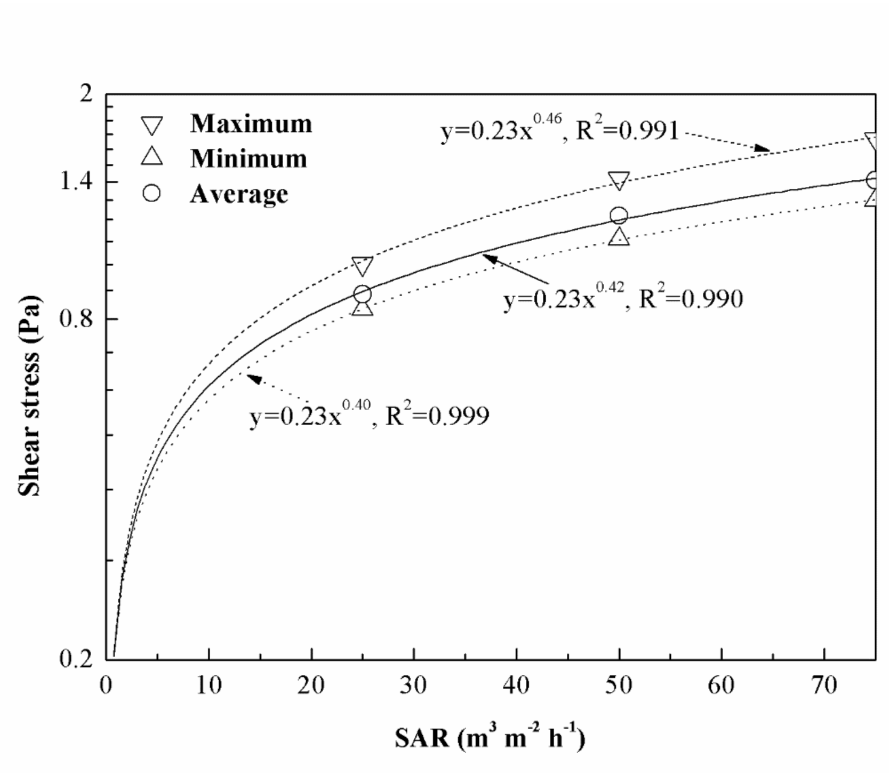
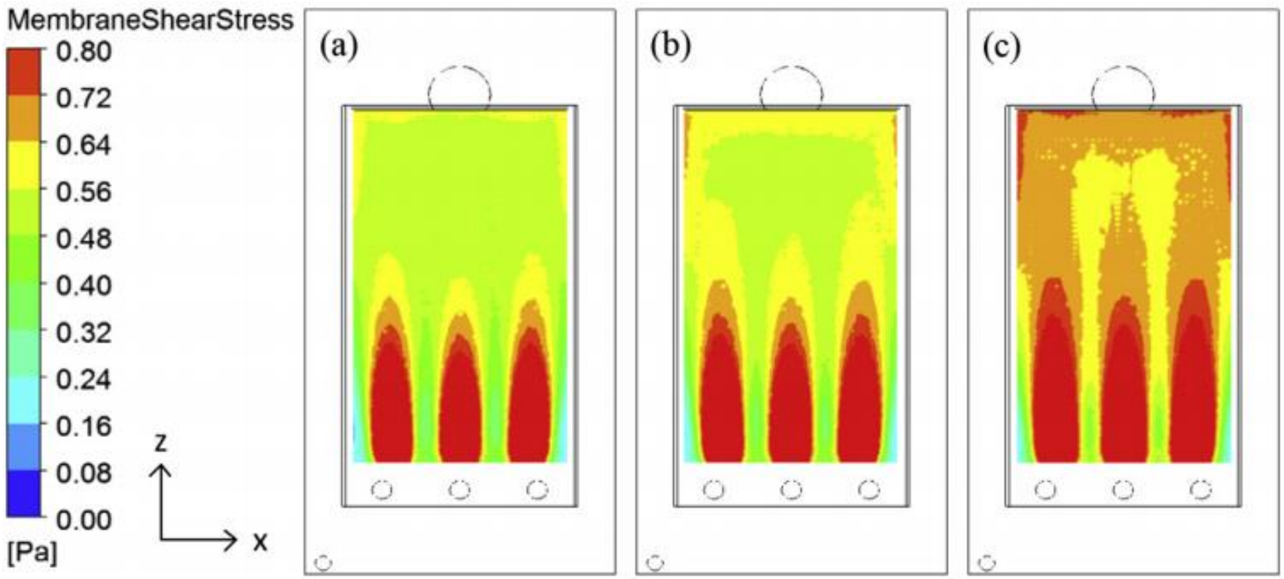
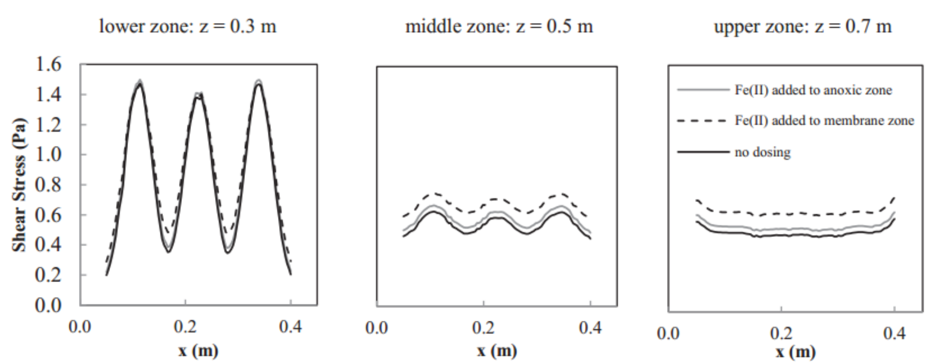


Fig. 6 Effects of aeration intensity on membrane surface shear stress with maximum on m1b, minimum on m5a and average of all membrane surfaces

What— MBR process innovation



Shear stress on the membrane surface for (a) no dosing, b) Fe(II) added to primary anoxic zone, c) Fe(II) added to membrane zone.



Shear stress distribution on membrane surface along the membrane width (x) at different heights (z) for different dosing scenarios

Liu, Water Res., 2015

What— MBR process innovation

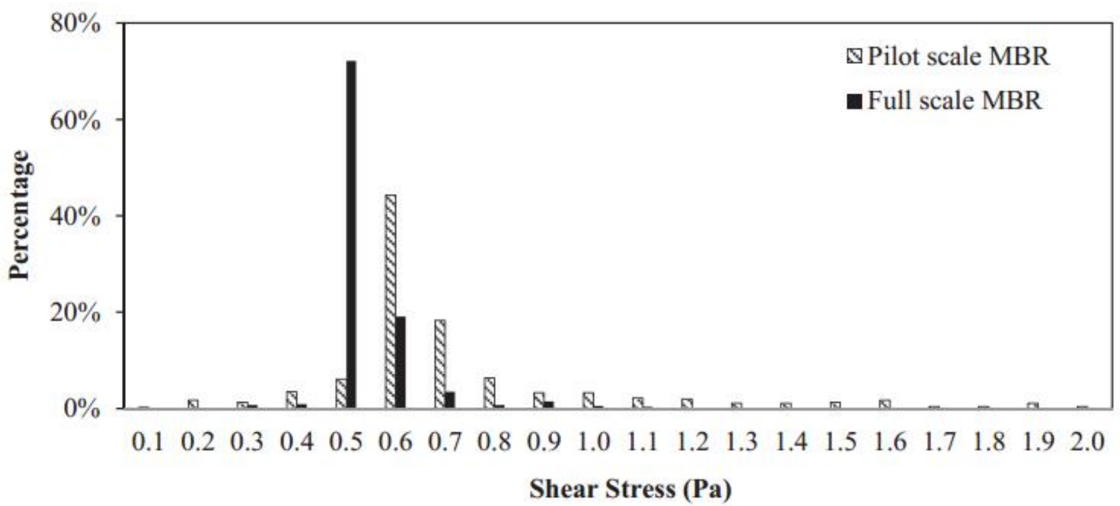
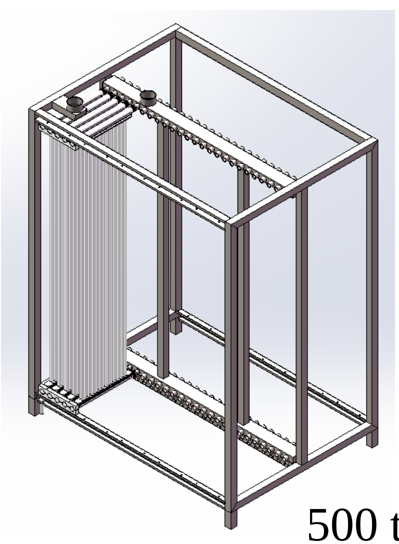
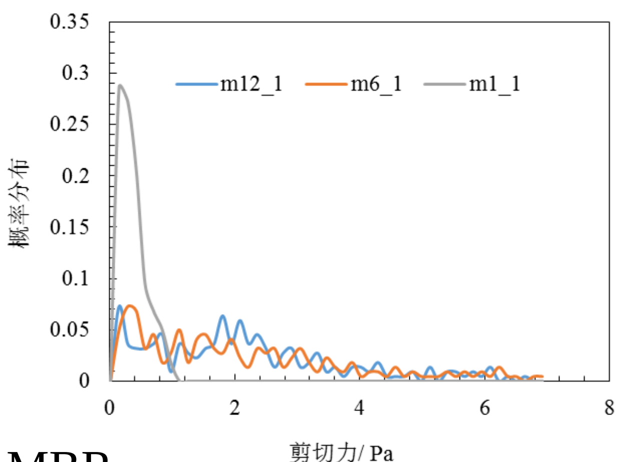
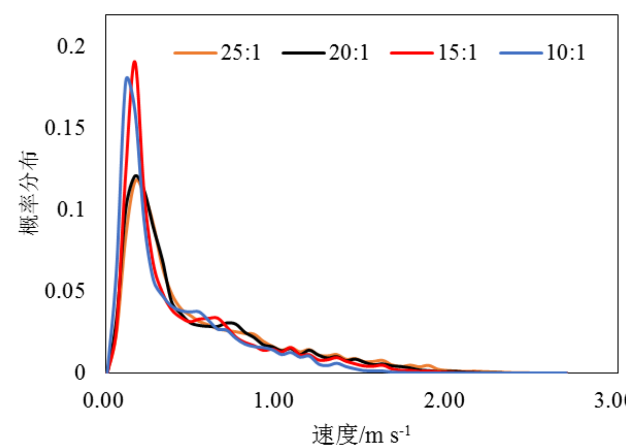


Fig. 14 – Comparison of membrane surface shear stress of pilot and full scale MBRs with Fe(II) dosed to membrane zone.



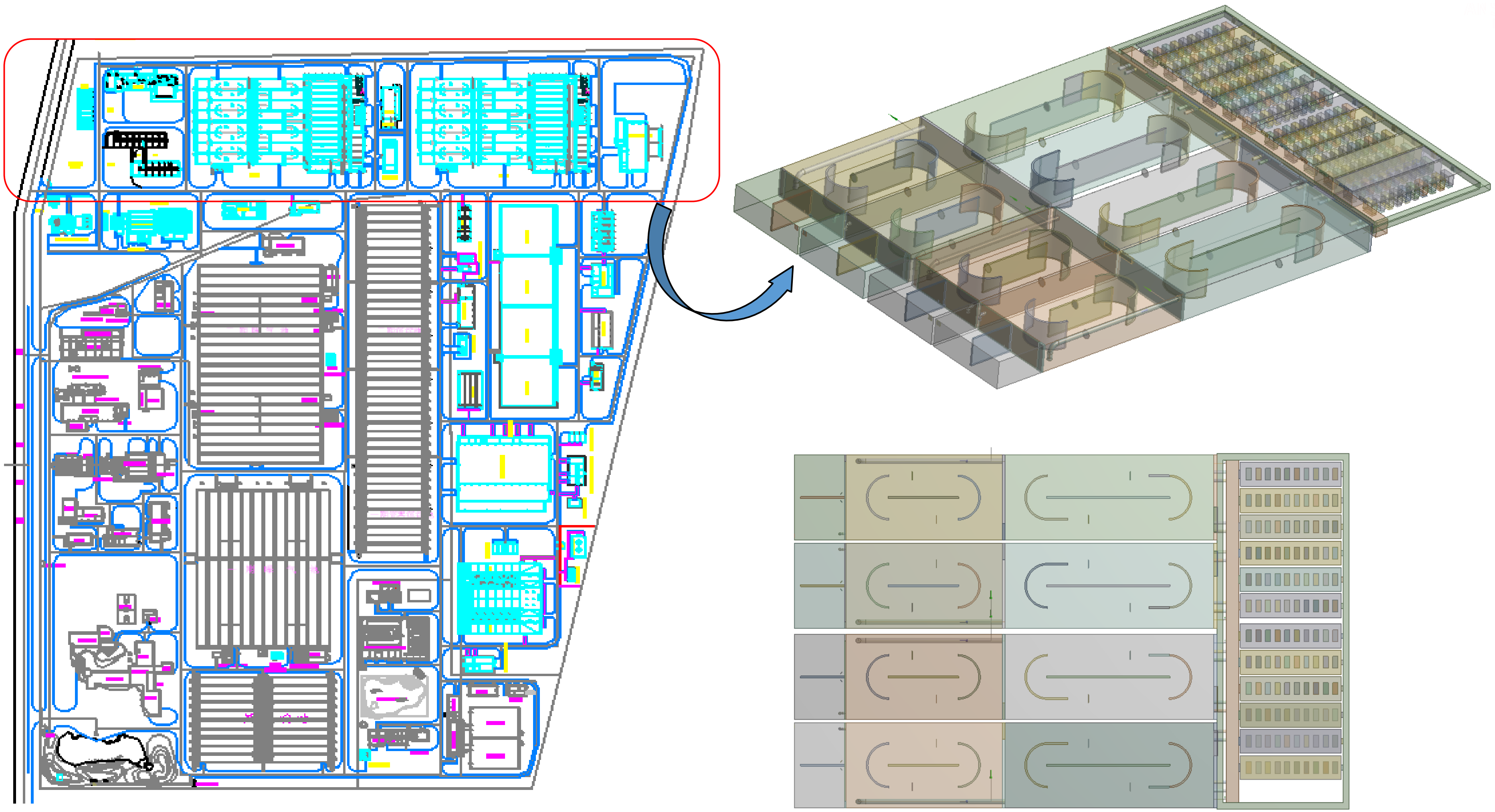
500 t/d MBR





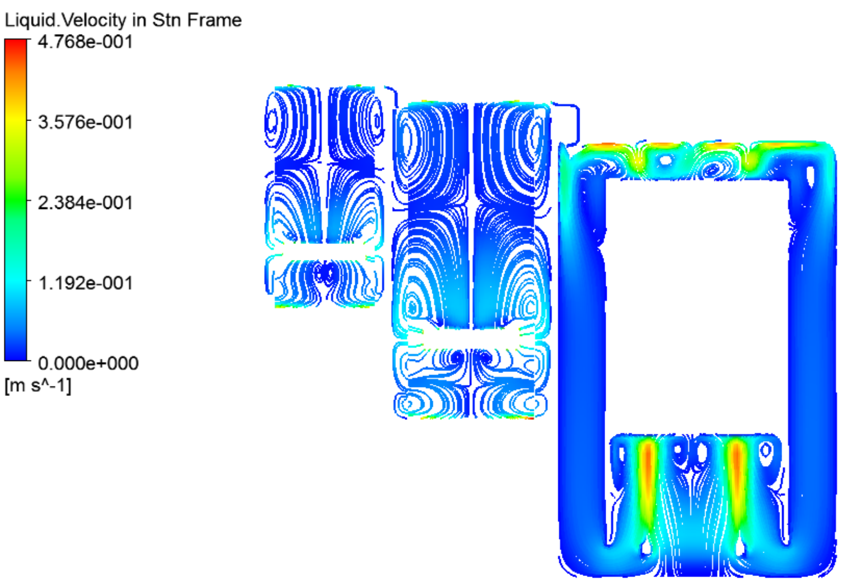
Liu, IWA Conf., 2016

What— Full-scale WWTP simulation

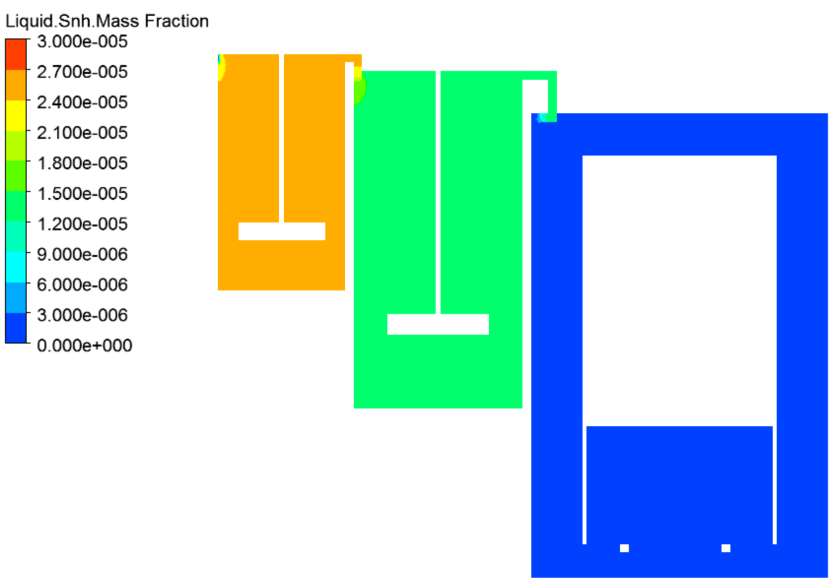


Plan view of full-scale A2/O-MBR and CFD modelling prospective

What— Full-scale WWTP simulation



Flow streamline in a pilot-scale A^2/O-MBR

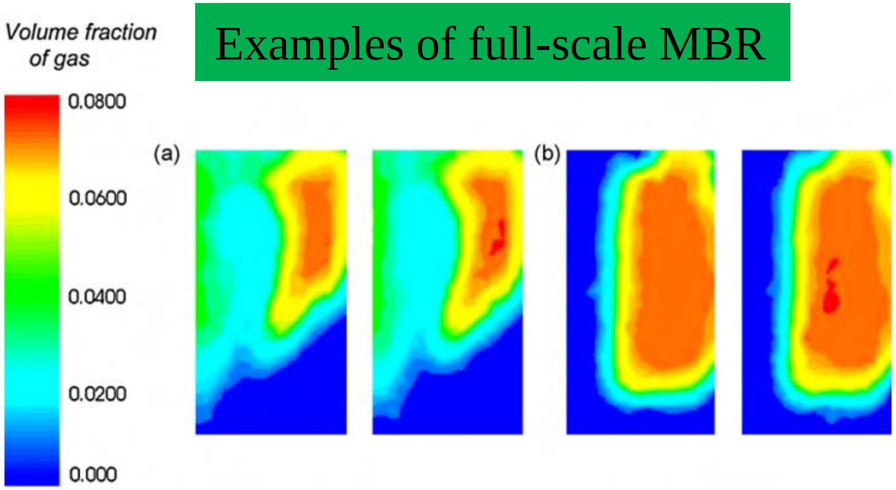


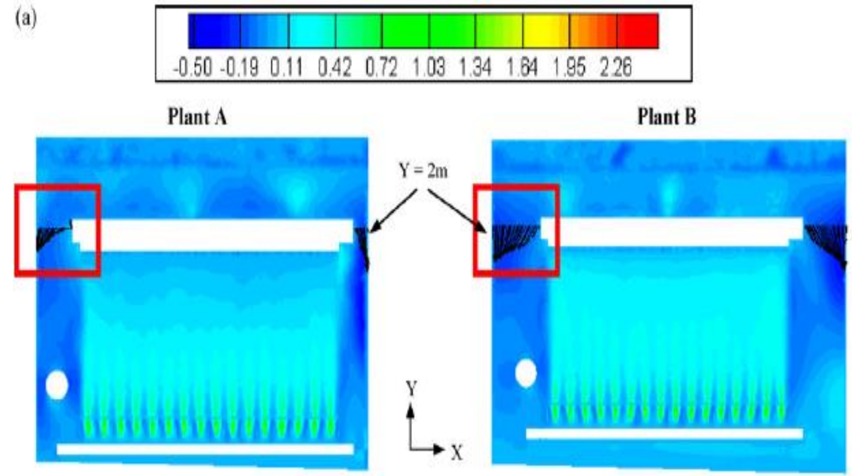
Species fraction distribution in a pilot-scale A^2/O-MBR

- A full model for pilot- and full-scale MBR will be done for the simulation of both of the hydrodynamics and water qualities

What— Full-scale WWTP simulation

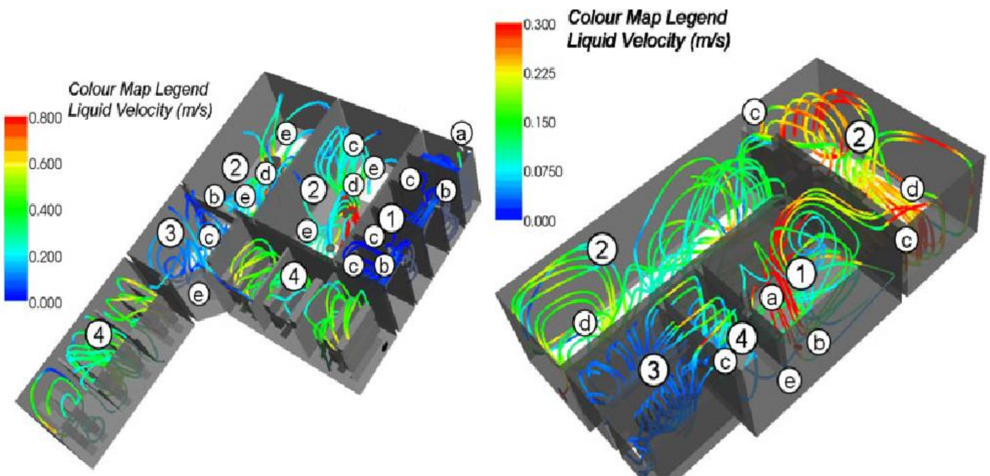
Examples of full-scale MBR



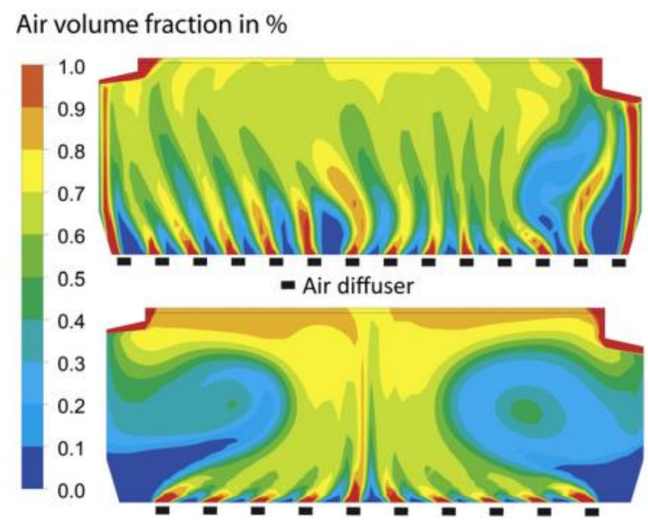


Bio-kinetics within the CFD framework for full-scale MBR kept silence.

ddapt

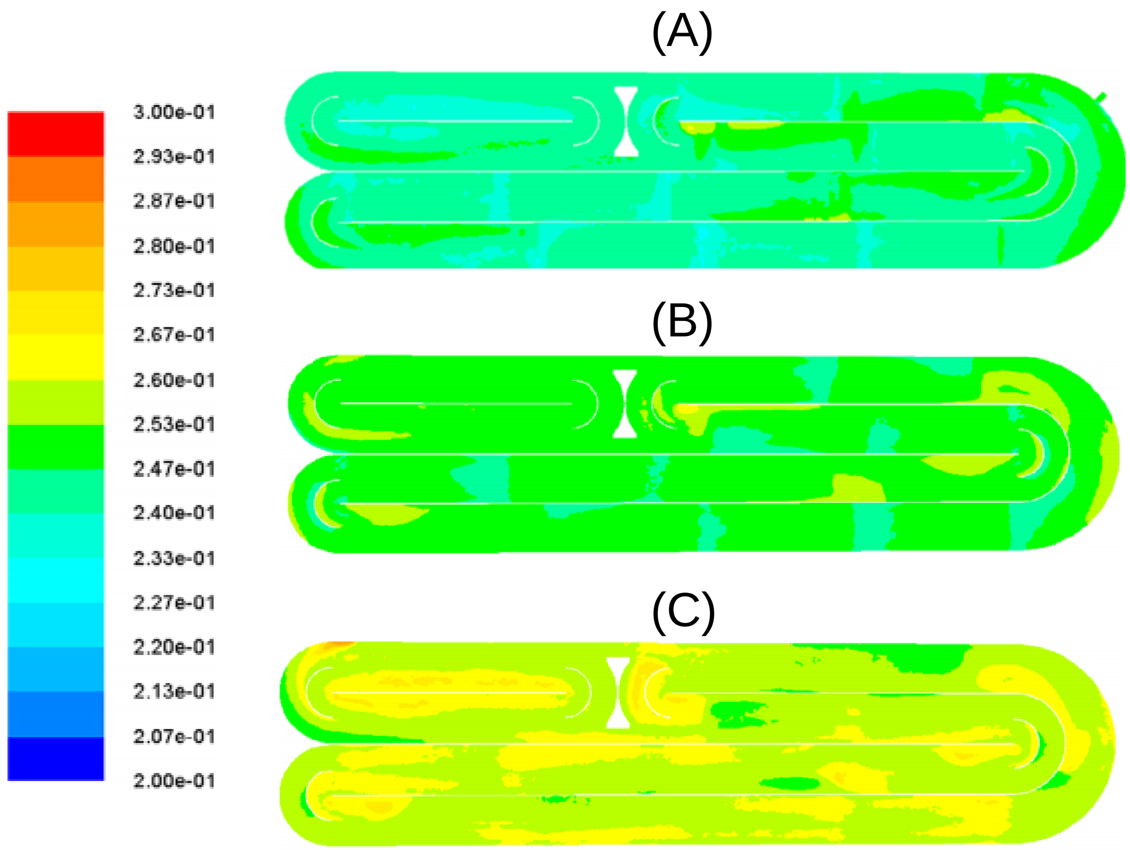


Mixing condition of different MBR WWPT, adapt from Wang, 2010.

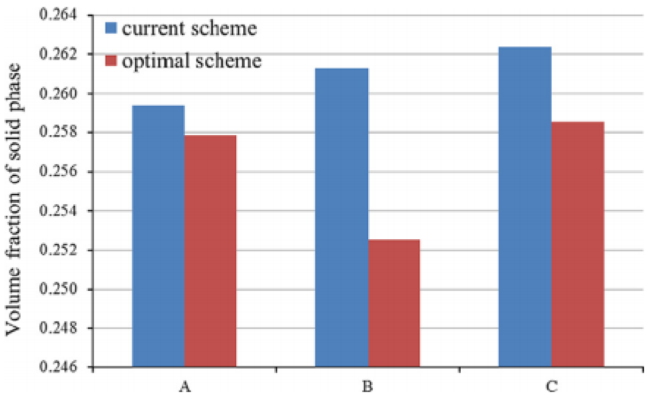


Different diffuser patterns' effect on flow field, adapt from Gresch, 2011.

What— Full-scale WWTP simulation



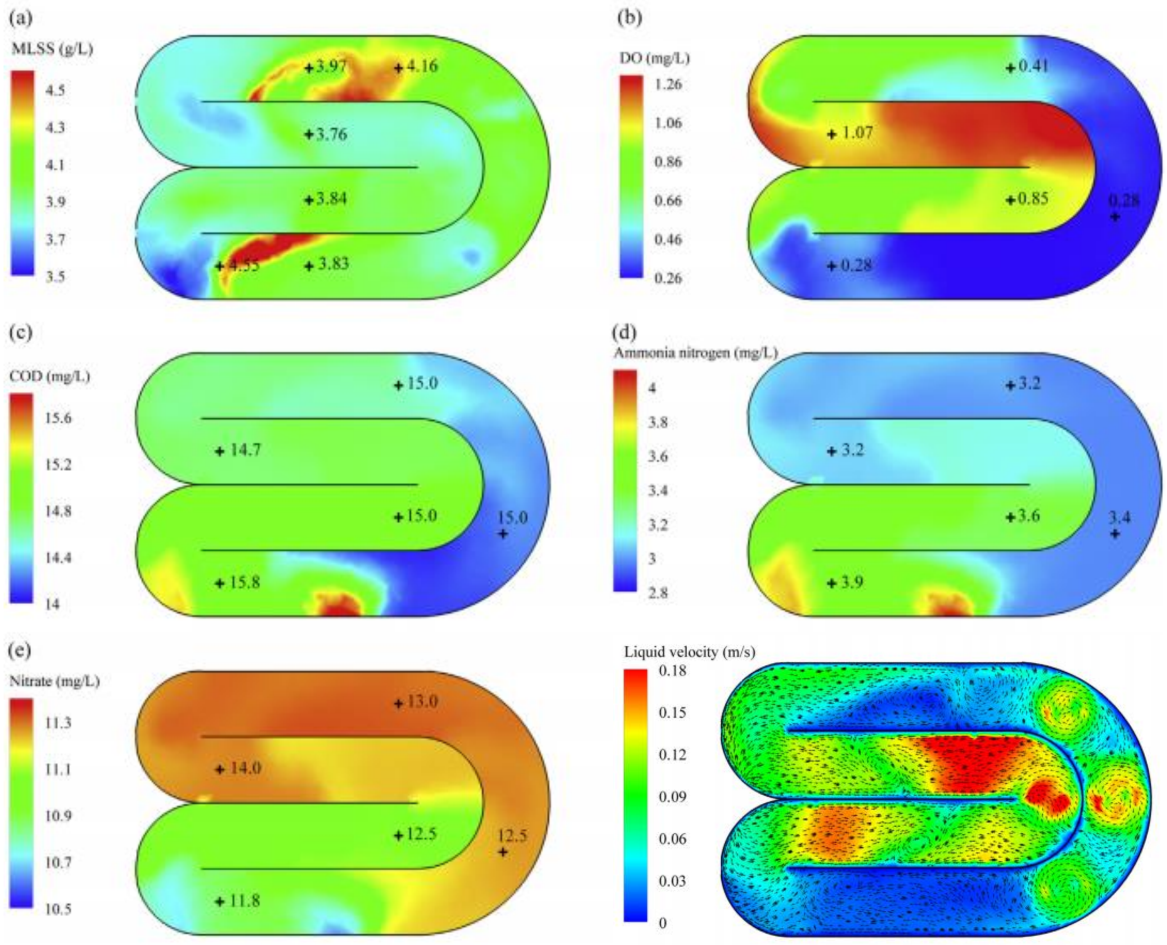
Contours of volume fraction of solid phase at different height: (A) top, (B) middle, and (C) bottom of the tank.



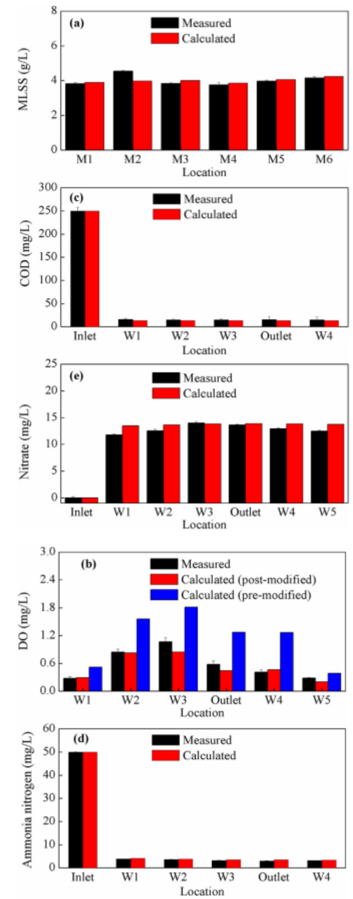
Proportion of the volume fraction of solid phase

Xie, Chem. Eng. J., 2014.

What— Full-scale WWTP simulation



Distribution of scalar and species 0.25 above the bed



Measurement vs simulatio

Lei, Water Res., 2014.

Conclusion

- Membrane bioreactors are available technology for wastewater treatment and reuse with the upgrade of discharge standard.
- Modification of bioreactors and operation can be handeled by the means of CFD.
- AEC-MBR was an example of MBR optimization via CFD approach in which the total nitogen removal can be higher than 90% with the higher membrane shear stress compared to others.
- Full-scale bioreactors modeling and simulation is just start, further work involved water quality prediction and operation modification are needed.

感谢聆听