Anaerobic membrane bioreactor and its efficacy in removing microbial contaminants

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Water scarcity is a global concern

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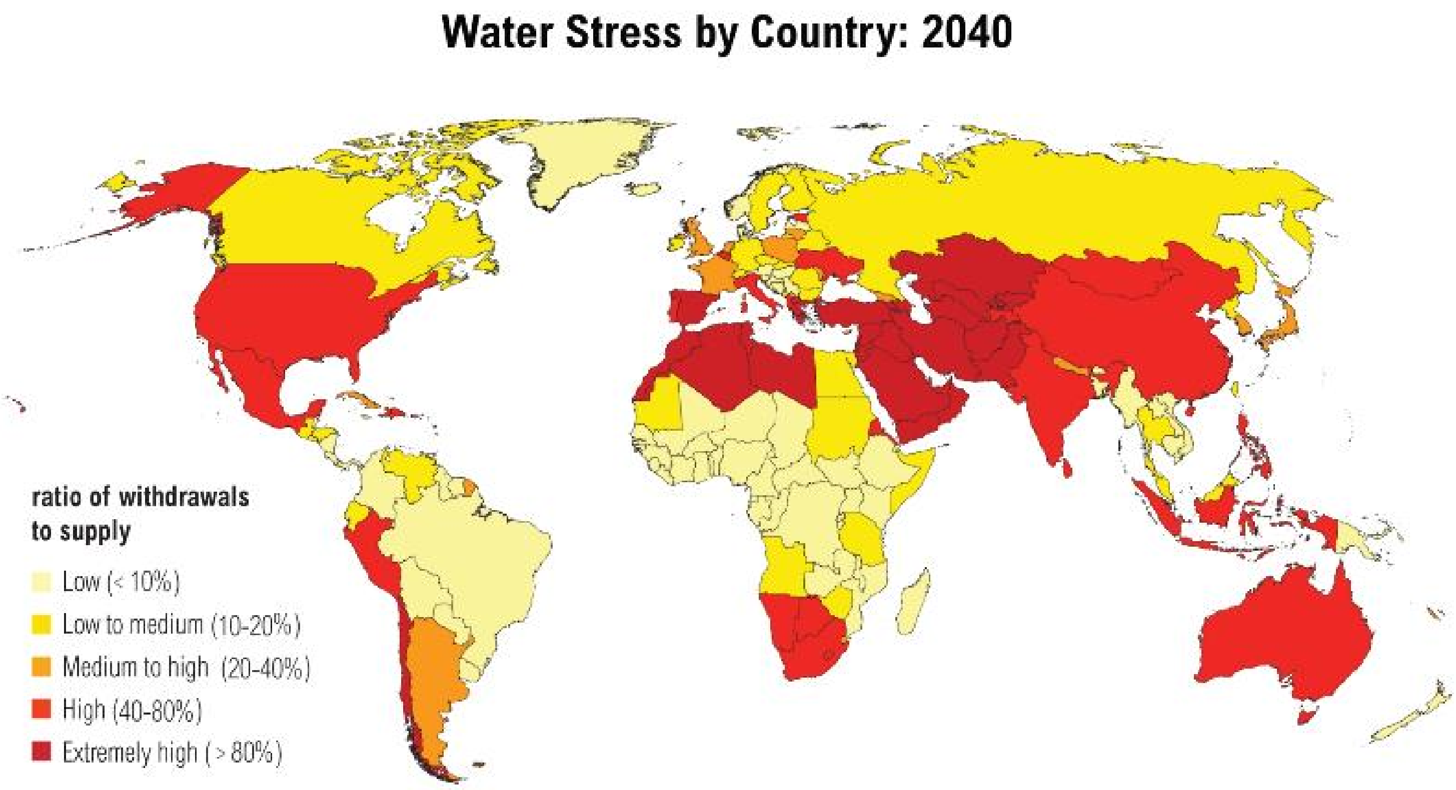

NOTE: Projections are based on a business-as-usual scenario using SSP2 and RCP8.5.

For more: ow.ly/RiWop

WORLD RESOURCES INSTITUTE

Water scarcity in Saudi Arabia and possible alternatives

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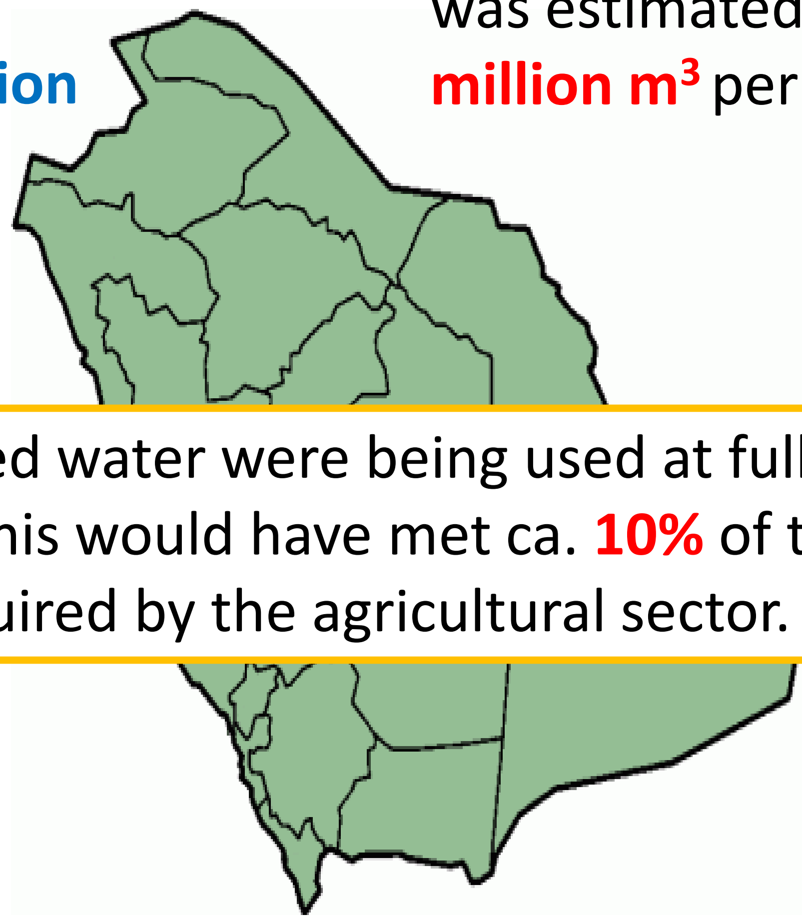
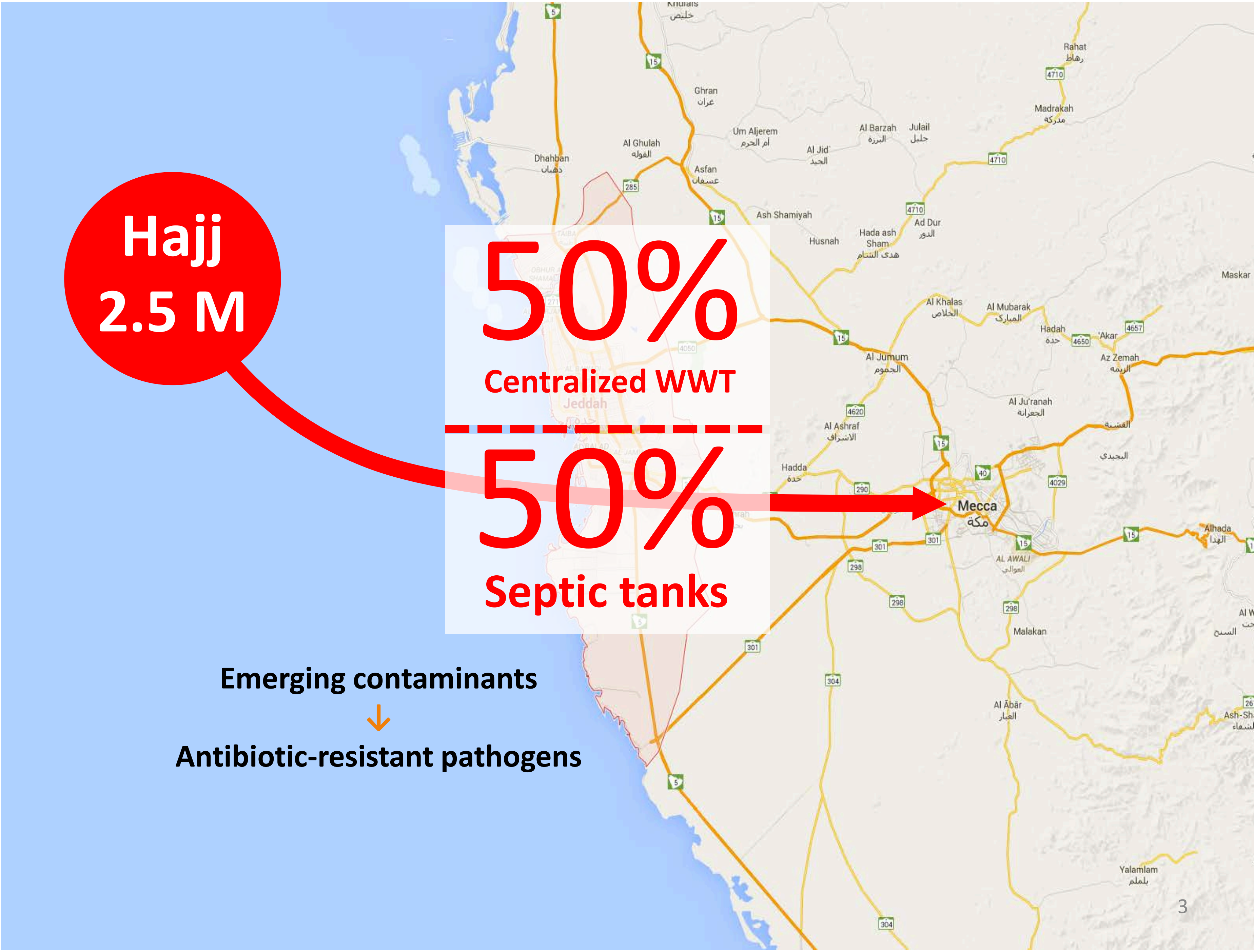
Amount of water used for food production was reported to be **57.1 million m^3** per day*.

Amount of wastewater flows was estimated to be **4.23 million m^3** per day.



If all treated water were being used at full capacity, this would have met ca. **10%** of the needs required by the agricultural sector.

* Figures reported in 2006 by http://www.fao.org/nr/water/aquastat/countries_regions/SAU/


Hajj
2.5 M
50%
Centralized WWT
50%
Septic tanks
Emerging contaminants
↓
Antibiotic-resistant pathogens
Jeddah
Mecca
مكة

Conventional WWTP enrich antibiotic-resistant bacteria

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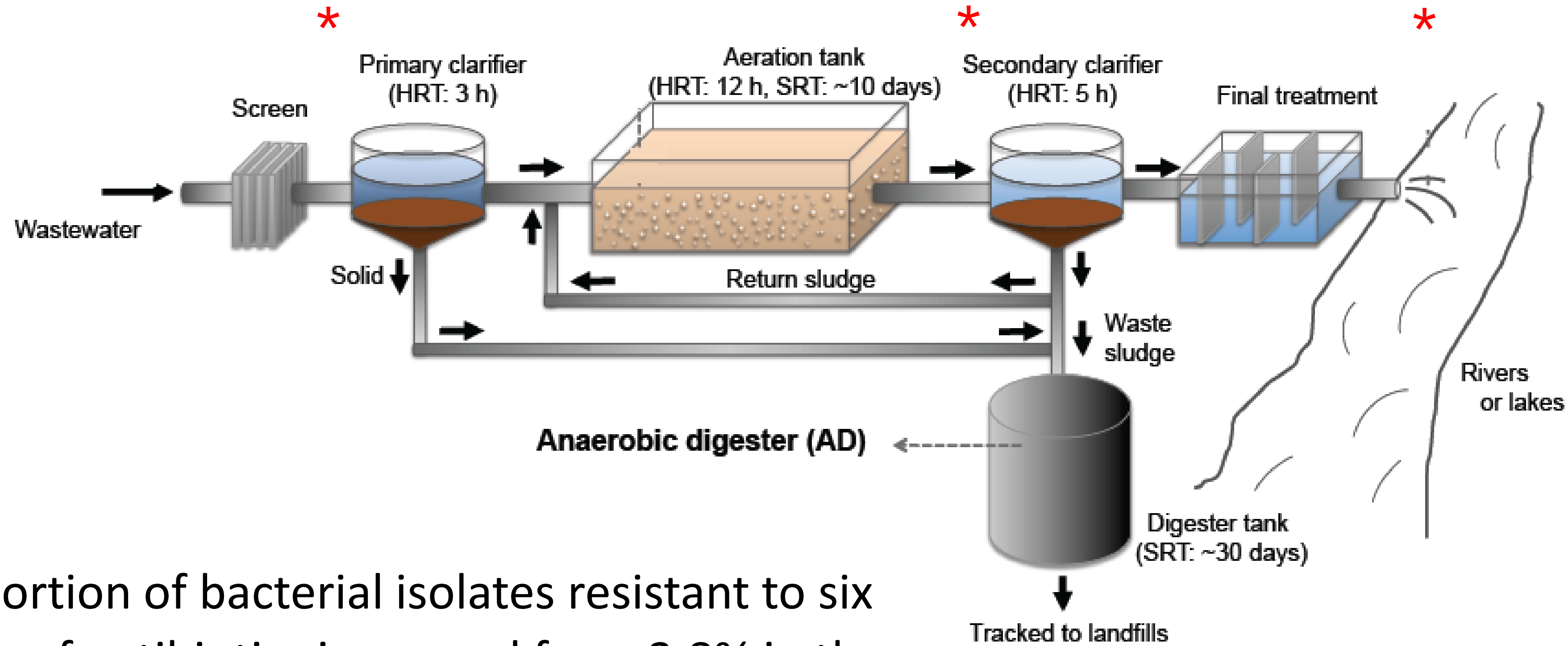
Primary treatment

Secondary treatment

Tertiary treatment

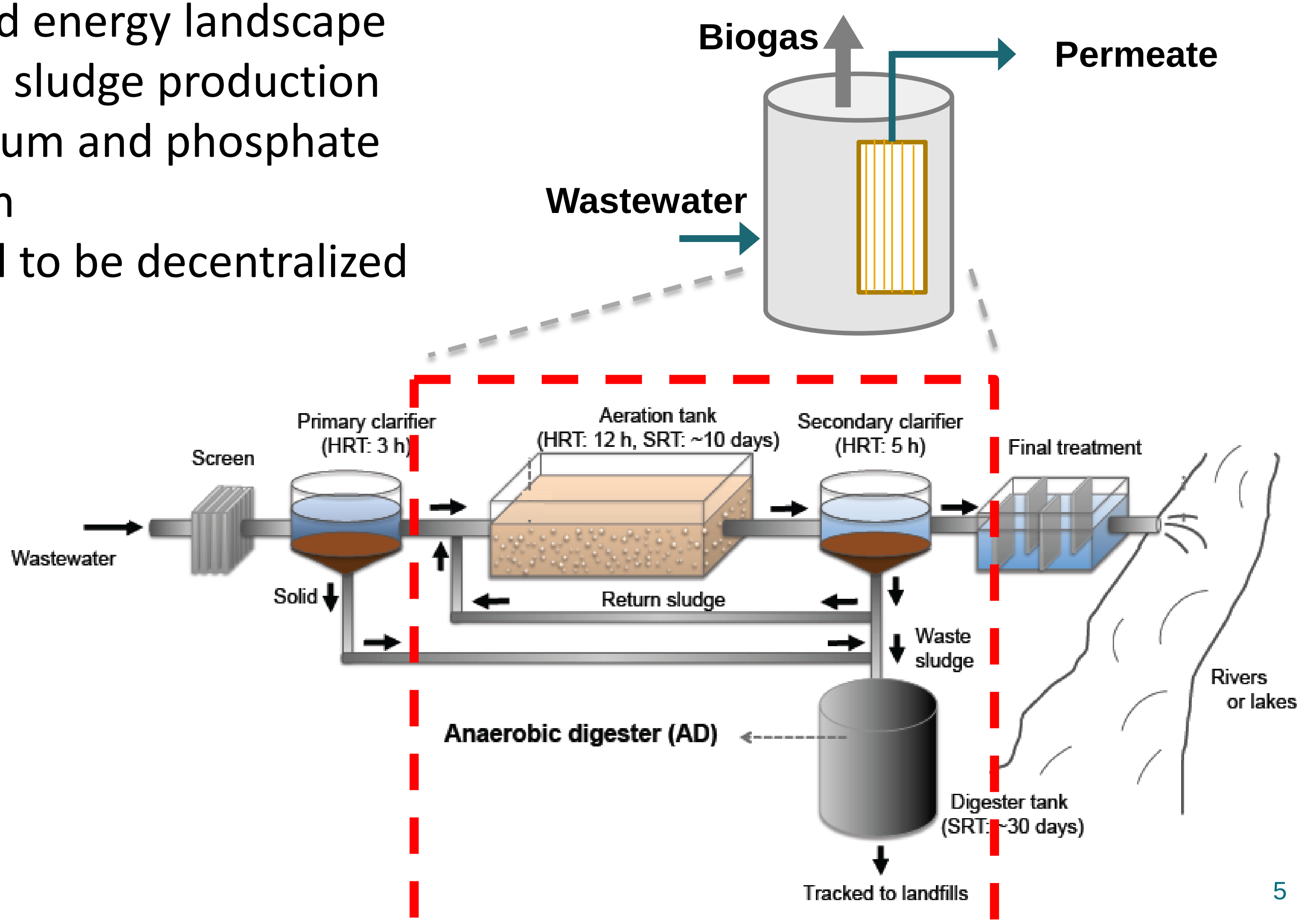


Proportion of bacterial isolates resistant to six types of antibiotics increased from 3.8% in the influent to 6.9% in the chlorinated effluent.

Al-Jassim et al. (2015) Water Research 73: 277-290

Advantages of anaerobic membrane bioreactor (anMBR)

- Improved energy landscape
- Reduced sludge production
- Ammonium and phosphate retention
- Potential to be decentralized



Aerobic vs. anaerobic cake layers

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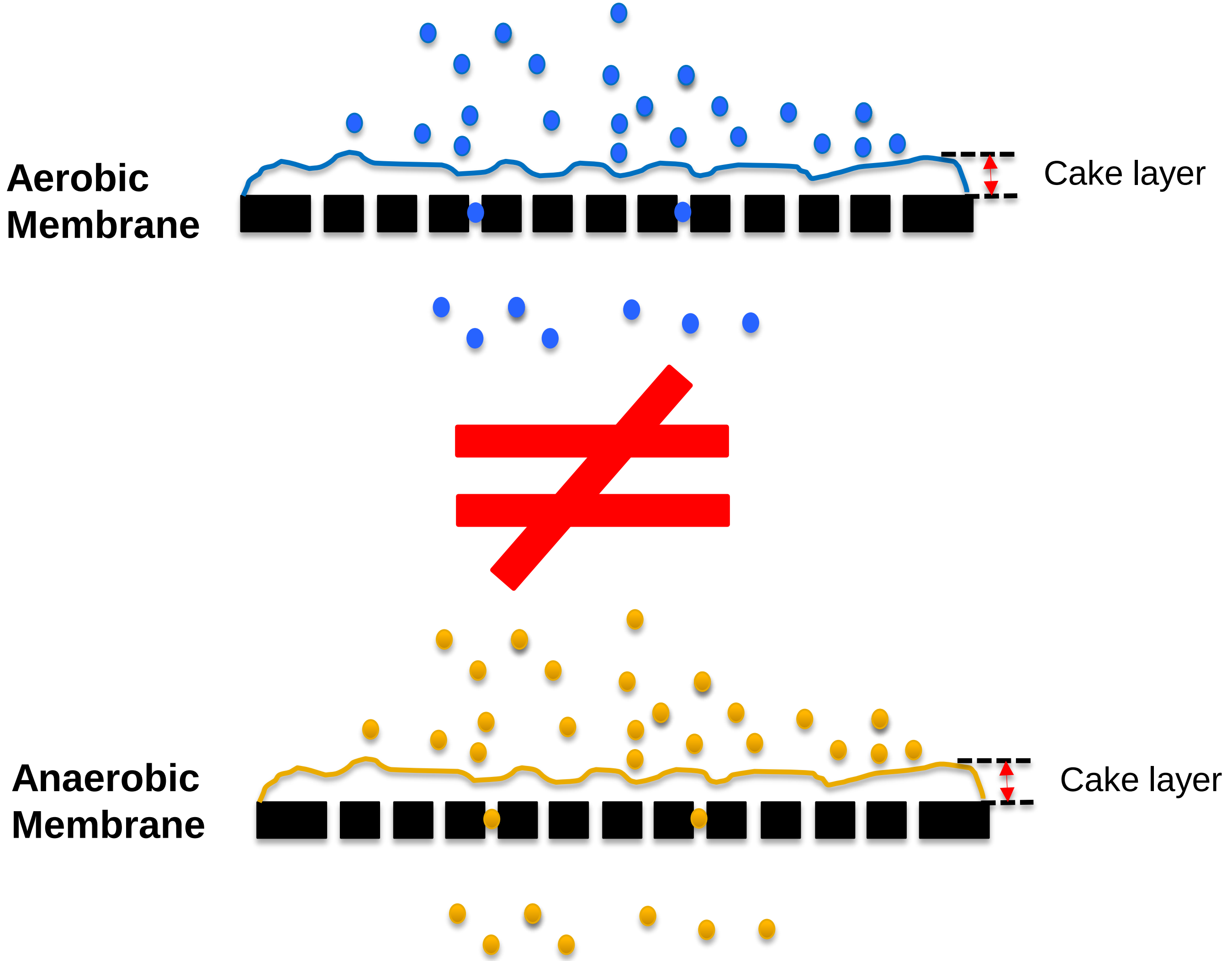

Xiong et al. (2016) Separation and Purification Technology 157: 192-202

Aims

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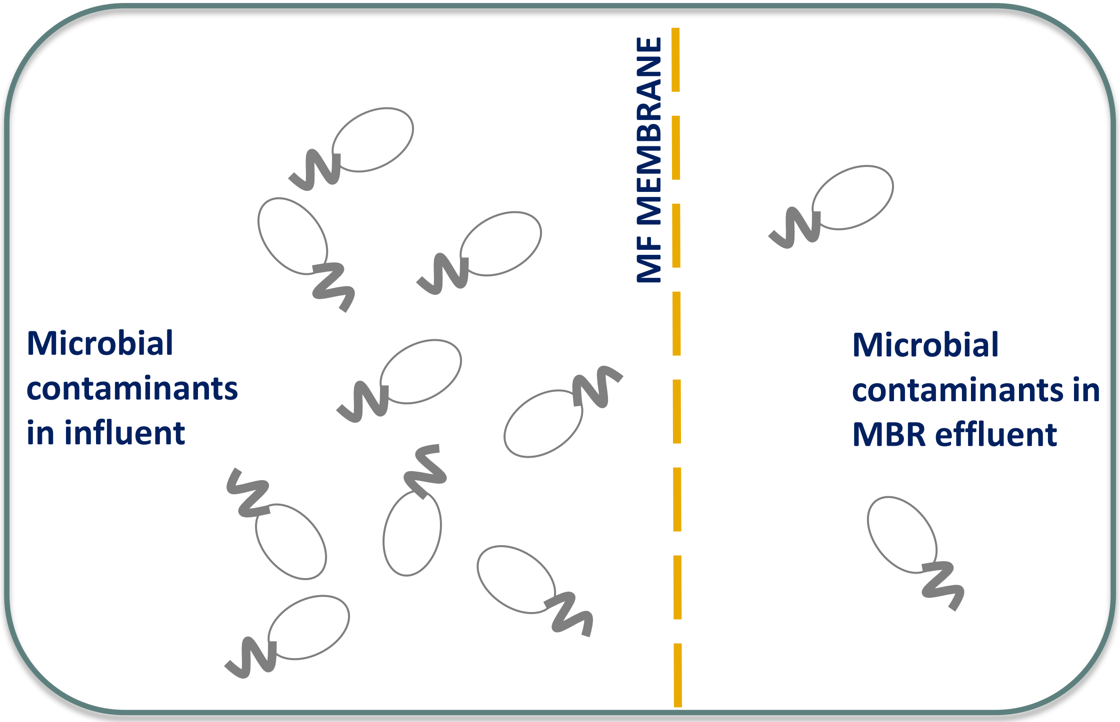
MEMBRANE-BASED WASTEWATER TREATMENT



- **Case study 1:** Molecular-based detection of opportunistic pathogens: removal achieved by aerobic vs. anaerobic MF-based MBR
- **Case study 2:** Removal of antibiotic-resistant bacteria and antibiotic resistance genes by varying degrees of fouling on anaerobic microfiltration membranes

Case study 1: Sampling

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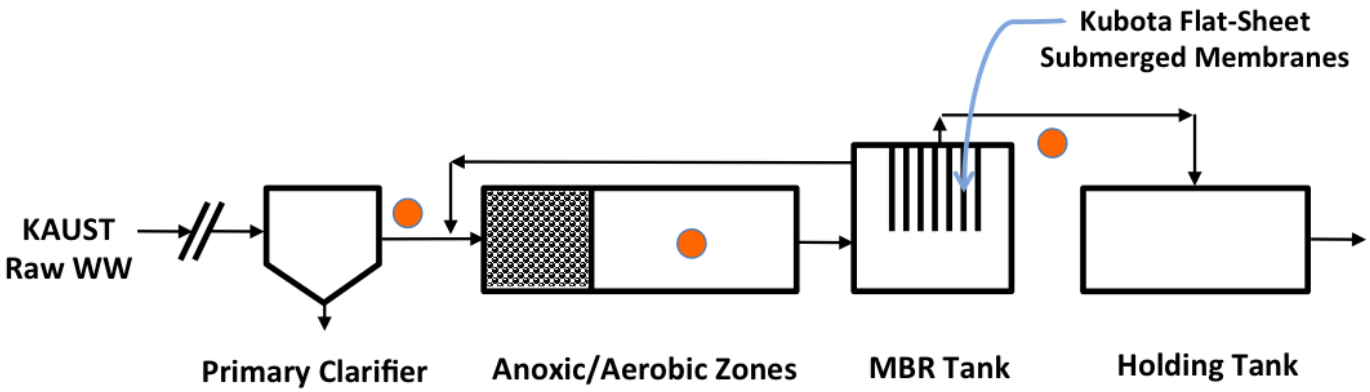
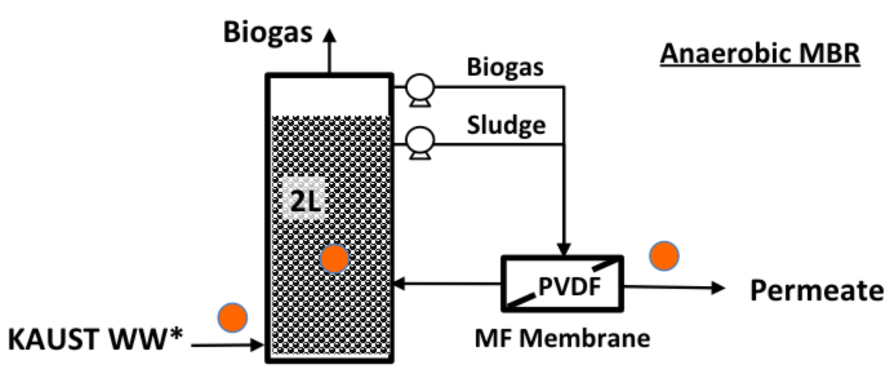
1. KAUST Wastewater Treatment Plant (Full-scale MBR)



2. Lab-scale anaerobic MBR



● indicates sampling point

Harb et al. (2016) Environ. Science and Pollution Research 24: 5370-5380

Molecular-based measurements and analyses

- Microbial Community Analysis
  - 16S rRNA gene-based Illumina MiSeq Sequencing
  - Influent, Aerobic reactor Sludge and effluents

- Pathogen Detection
  - Quantitative digital PCR (dPCR) targeting pathogenic species

Occurrence of pathogenic genera and their log removal values

Genera
Mycobacterium
Treponema
Arcobacter
Neisseria
Acinetobacter *
Pseudomonas *
Legionella
Unclassified *Enterobacteriaceae* *
Escherichia
Stenotrophomonas
Aeromonas
Streptococcus
Enterococcus
Dialister

ND denotes not detected

Harb et al. (2016) Environ. Science and Pollution Research 24: 5370-5380

Abundance of specific pathogenic species

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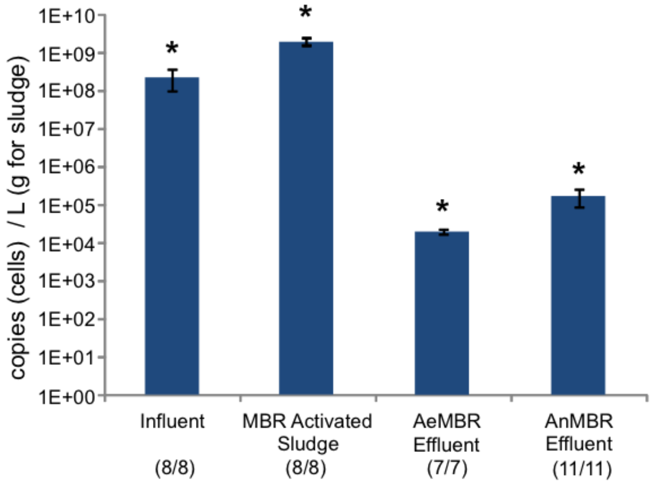
Total Bacteria (*rpoB*)



Harb et al. (2016) Environ. Science and Pollution Research 24: 5370-5380

What're the risks?

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- Quantitative microbial risk assessment
- Estimate risk of exposure by specific pathogen detected by dPCR
- Event 1: using the effluent for agricultural irrigation
- Event 2: using the sludge for land application
- Bacterial concentrations from dPCR results
- Exposure assessment, infection probability obtained from qmrawiki.canr.msu.edu
- Annual risk

Exposure dosage	Influent WW irrigation exposure	AeMBR effluent irrigation exposure	AnMBR effluent irrigation exposure	AeMBR sludge land application dermal exposure	AeMBR sludge land application ingestion exposure
Annual risk					
Acinetobacter baumannii	1.0×10^{0}	6.0×10^{-3}	4.3×10^{-5}	5.0×10^{-3}	2.6×10^{-2}
Pseudomonas aeruginosa	1.0×10^{0}	3.2×10^{-1}	6.3×10^{-2}	-	-
Klebsiella pneumoniae	1.0×10^{0}	4.2×10^{-3}	7.3×10^{-4}	4.9×10^{-3}	2.6×10^{-2}

- Acceptable microbial risk ≤ 1×10^{-4}

high risk | moderate risk | low risk

Harb et al. (2016) Environ. Science and Pollution Research 24: 5370-5380

Case study 1: conclusions

- Targeting of specific pathogens by both high-throughput sequencing and dPCR showed higher removal rates by the lab-scale anaerobic MBR.
- Compared to aeMBR, anMBR treatment of municipal wastewater could be a viable means for improving effluent reuse and sludge disposal pathogen risks.

Case study 2

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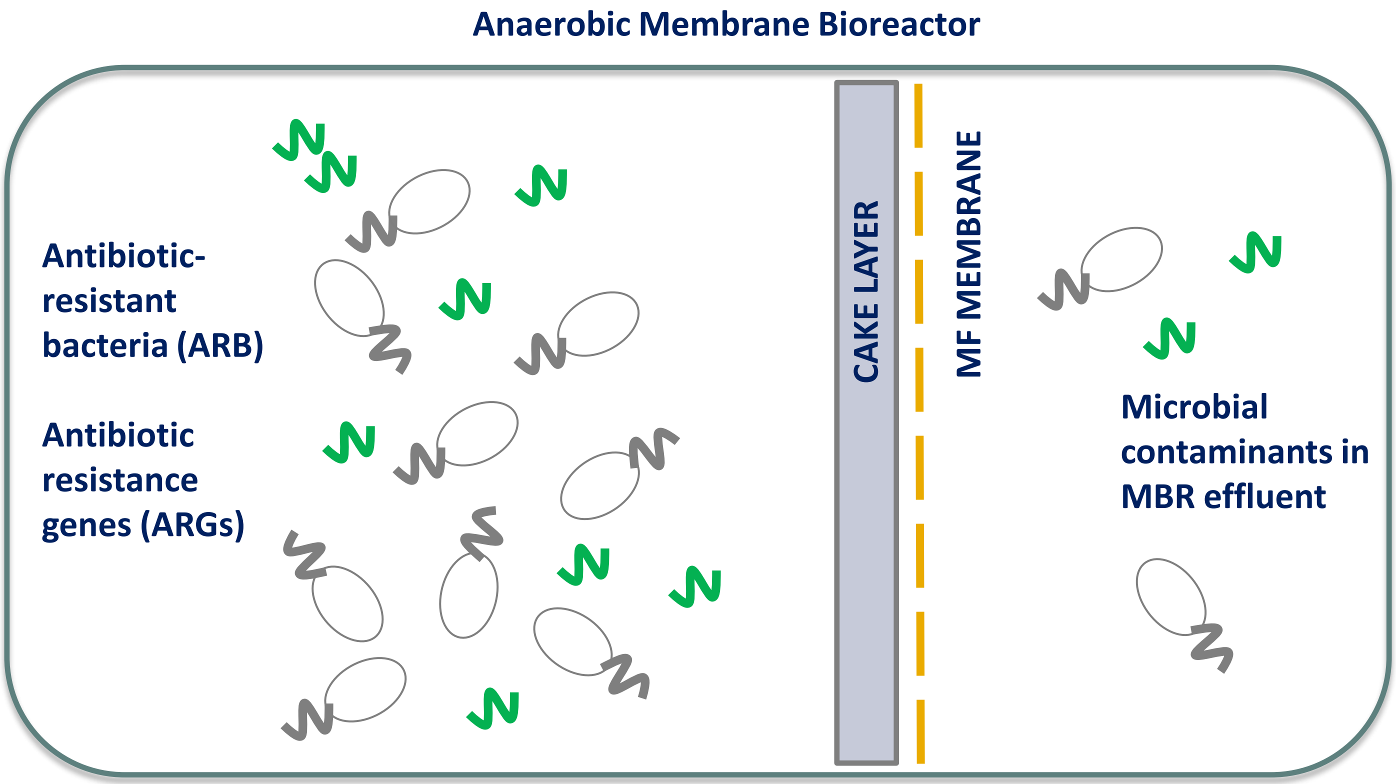

Hypothesis:

Removal of ARB and ARGs affected by varying degrees of fouling on anaerobic microfiltration membrane

Experimental design 1

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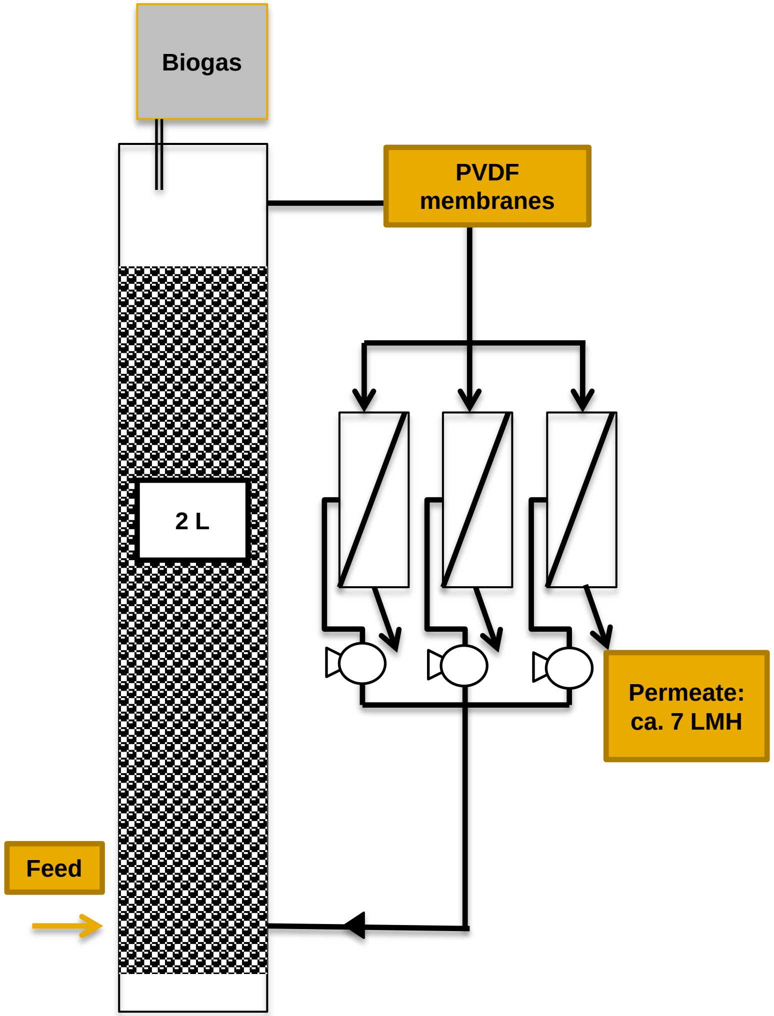

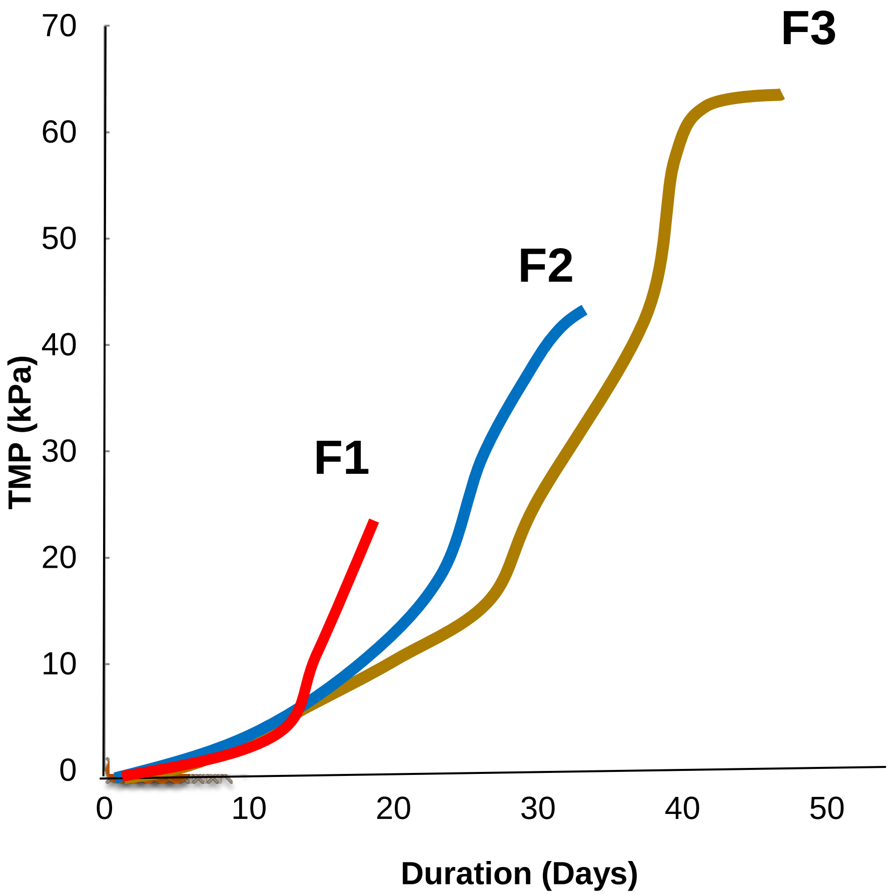

Cheng and Hong (just accepted) Environmental Science and Technology. DOI 10.1021/acs.est.7b03798

SEM images of fouled membranes

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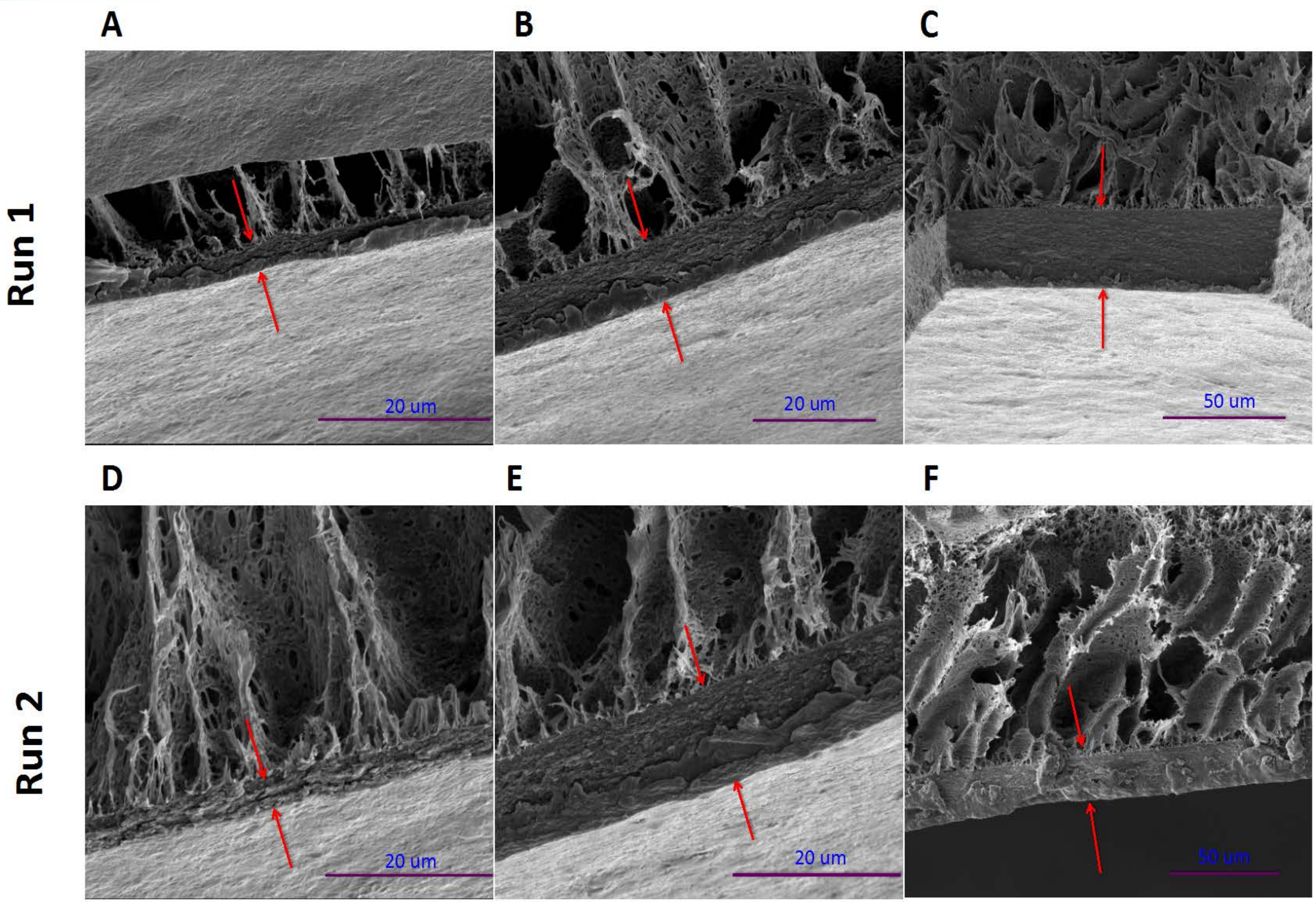

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Physical parameters of fouled membranes

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Membrane	Thickness (μm)		Estimated dried biovolume (mm^3)[a]		Roughness		Hydrophilicity	Surface zeta potential
	Run 1	Run 2	Run 1	Run 2	R_a (nm)[b]	R_q (nm)[c]	Contact angle (°)	(mV)
N0	N.A.	N.A.	N.A.	N.A.	118.3 ± 27.0	144.0 ± 36.0	78.7 ± 3.8	-44.3 ± 4.4
F1	2.99 ± 0.17	3.96 ± 0.26	15.0	19.8	79.2 ± 10.4	102.5 ± 17.5	90.2 ± 2.3	-17.3 ± 0.3
F2	8.80 ± 0.13	10.4 ± 0.48	44.0	52.2	61.7 ± 6.5	76.1 ± 7.6	95.5 ± 1.9	-19.2 ± 1.9
F3	26.9 ± 3.24	20.3 ± 0.43	134	102	51.1 ± 6.5	65.2 ± 8.6	107.4 ± 1.6	-25.8 ± 2.3

[a]Estimated dried biovolume was determined by multiplying the average thickness by the membrane surface area.

[b]R_a is the arithmetic average of the absolute values of the surface height deviations measured from the mean plane.

[c]R_q is the root mean square average for height deviation taken from the mean image data plane.

Cheng and Hong (just accepted) Environmental Science and Technology. DOI 10.1021/acs.est.7b03798

Chemical parameters of fouled membranes

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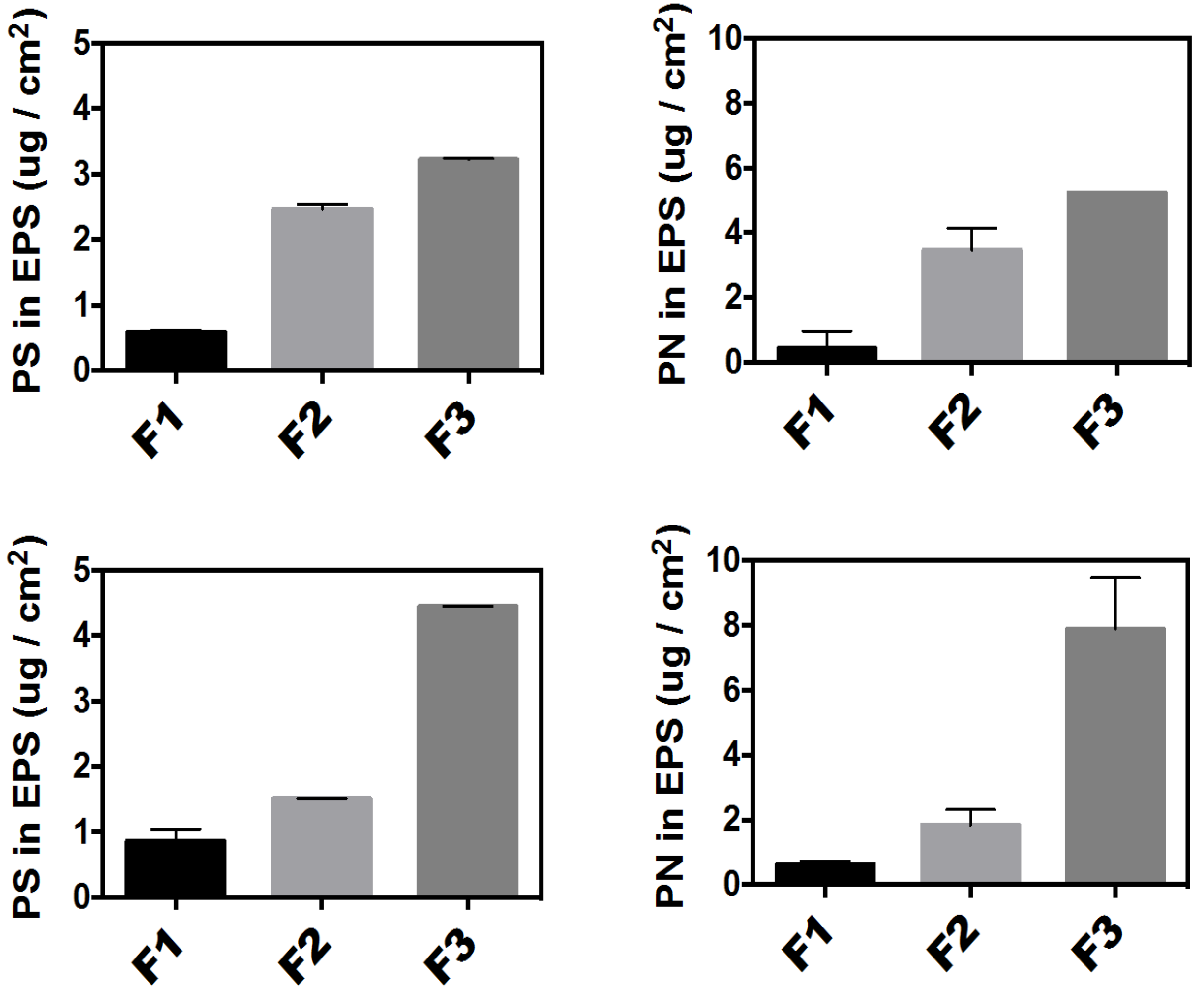
Run 1

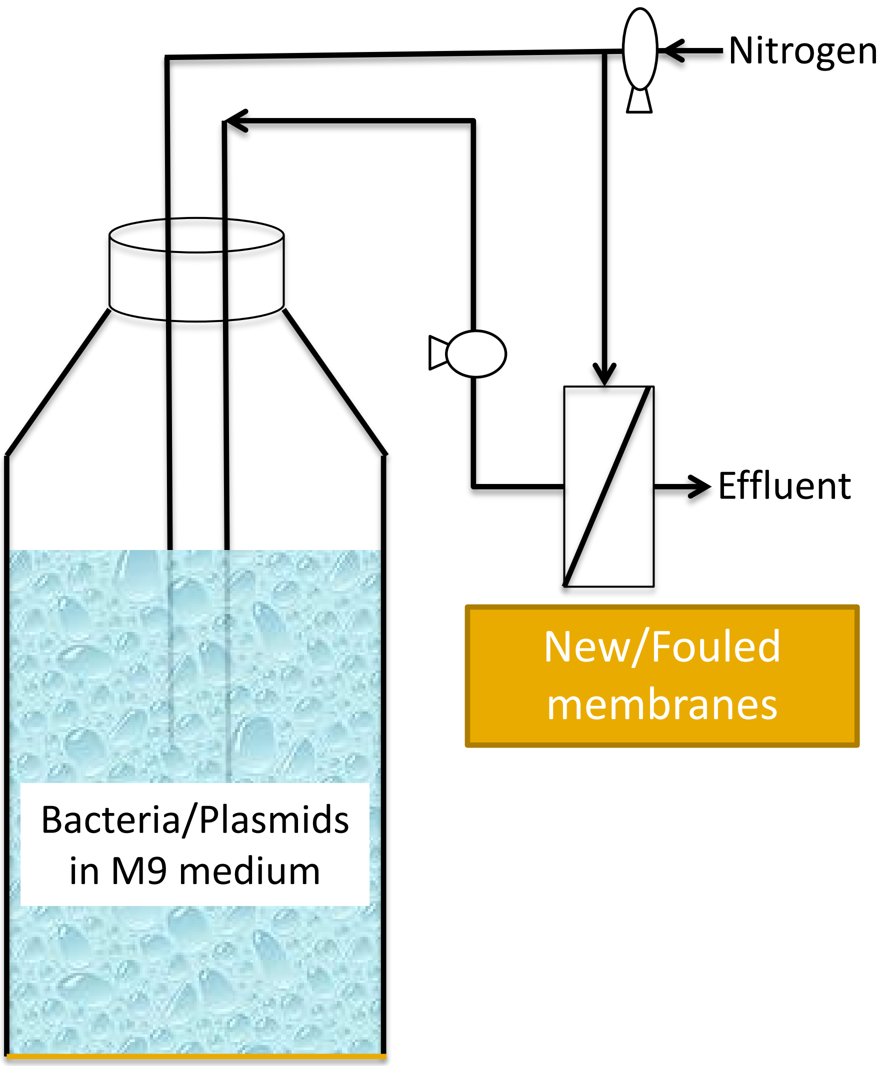
Run 2



Cheng and Hong (just accepted) Environmental Science and Technology. DOI 10.1021/acs.est.7b03798

- Surface characteristics of anaerobic membranes change with increasing fouling: more hydrophobic, lower surface roughness and lower negative charge
- Biofilm thickness increase with increase protein and polysaccharide contents
- Would these parameters result in differences when removing ARB and ARGs?

Experiment design 2



- F 1-1, F 1-2, F 1-3 and F 1-4: Fouled 1 membrane (20 kPa) sampled at 5, 10, 15 and 20 kPa;
- F 2-1, F 2-2, F 2-3 and F 2-4: Fouled 2 membrane (40 kPa) sampled at 10, 20, 30 and 40 kPa;
- F 3-1, F 3-2, F 3-3 and F 3-4: Fouled 3 membrane (60 kPa) sampled at 10, 20, 40 and 60 kPa;
- N 0-1, N 0-2, N 0-3, N 0-4: New membranes sampled at 0 kPa but different time.

Foulant enhance removal of ARGs

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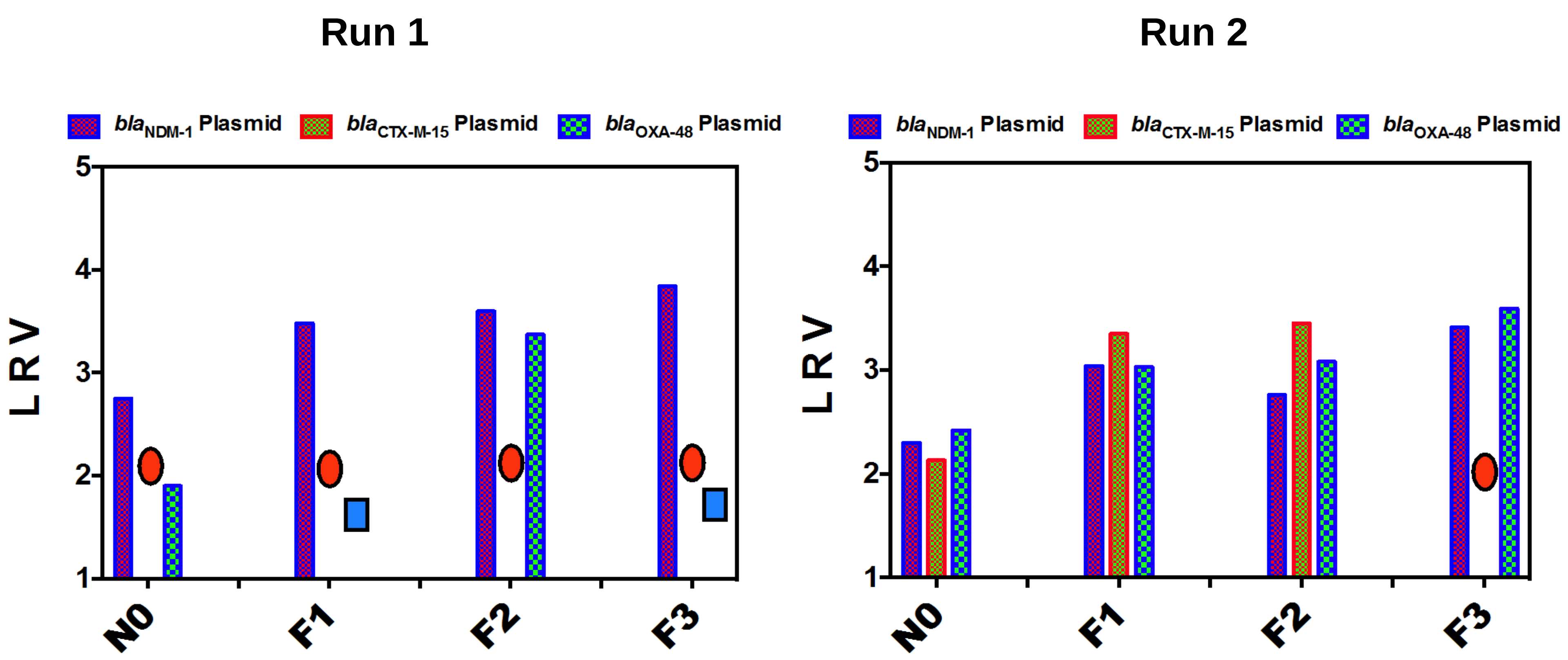

denote gene target cannot be detected in permeate and thus no LRV was determined

Higher adsorption of ARGs on fouled membranes

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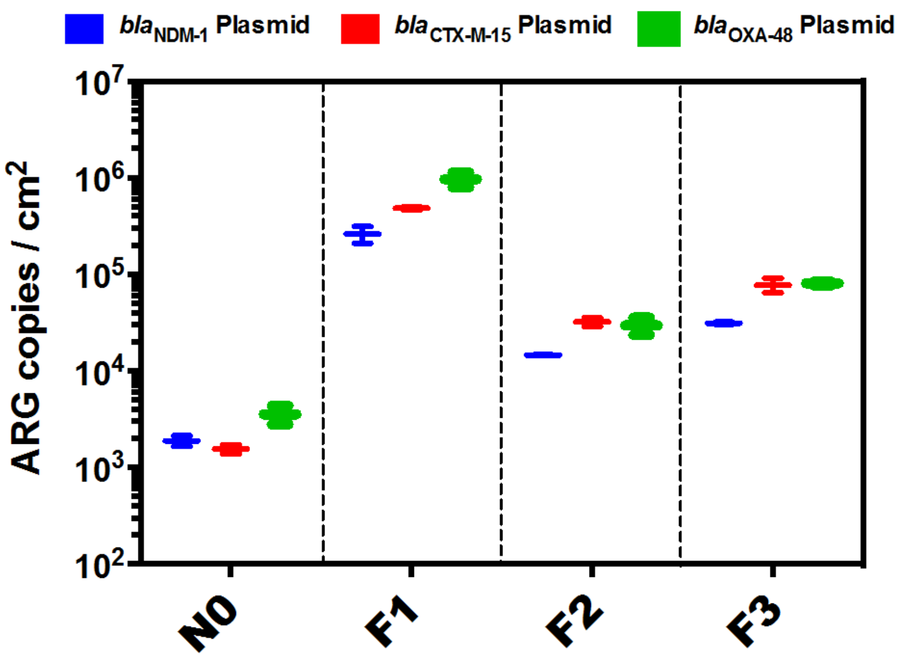
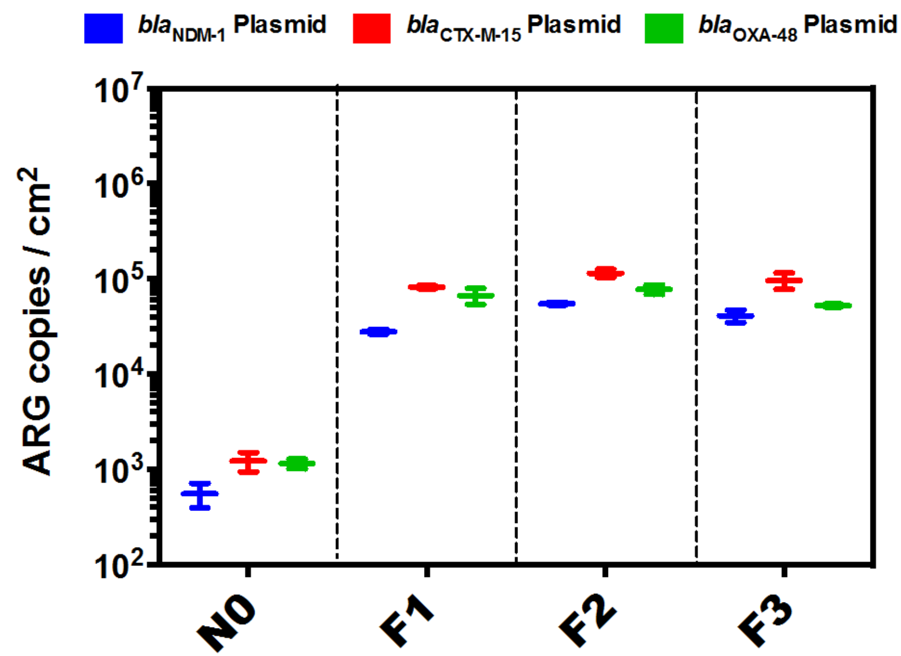
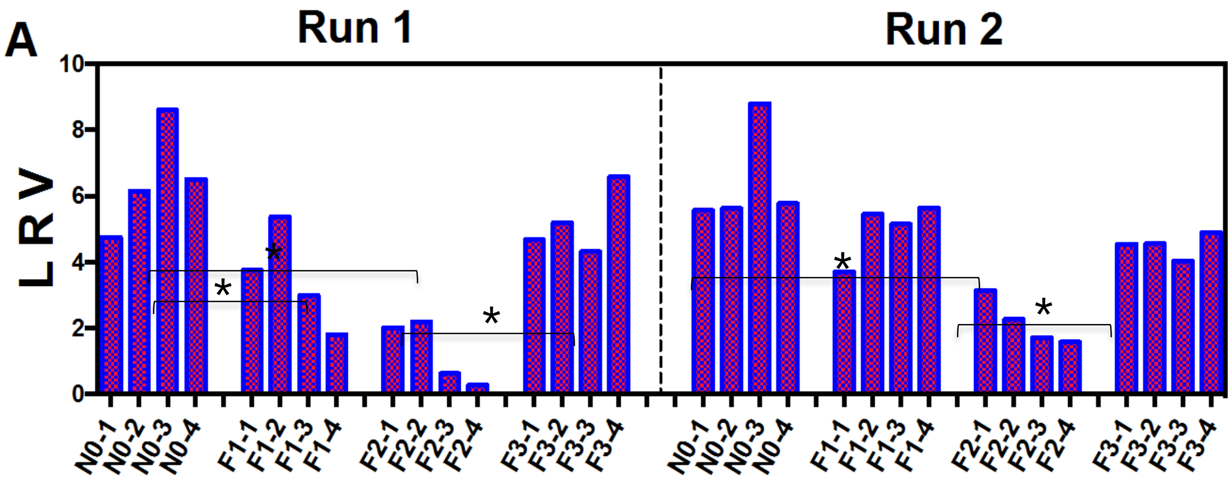
Run 1



Run 2





E. coli **PI-7 with** ***bla***$_{\textbf{NDM-1}}$

Higher adsorption of ARB on fouled membranes

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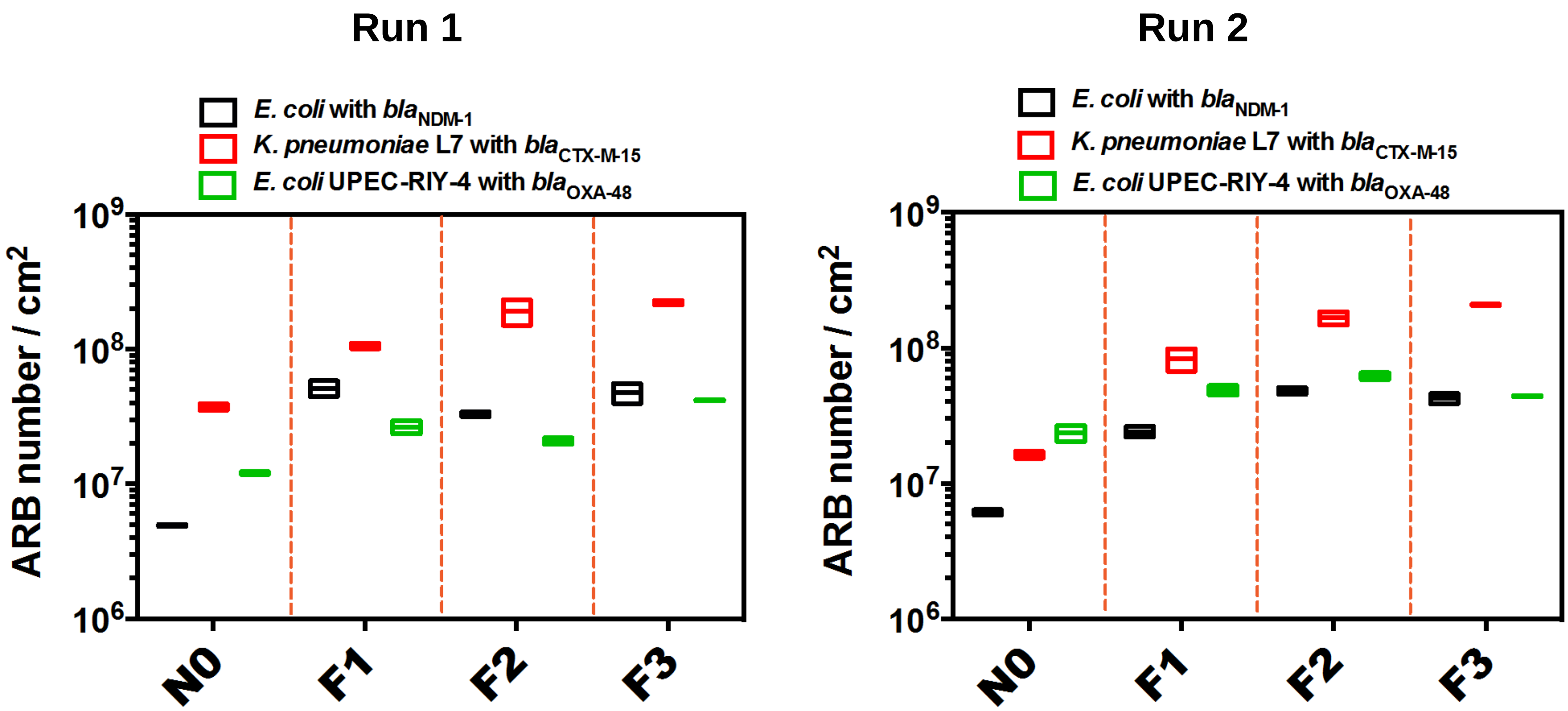

Conclusions

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- Total LRV of ARGs increased with the extent of fouling
- LRV of ARB decreased initially before stabilizing at a LRV similar to that of new microfiltration membranes
- Specifically, LRV of ARB decreased when membranes were sub-critically fouled
- Removal mechanisms in an anMBR is a combination of size exclusion and adsorption, as well as the filtration pressure/force
- Long term operation of anaerobic MBR favors the removal of emerging contaminants like ARB and ARGs

Conclusions

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- The advantages of anMBRs towards aeMBRs are

(i) a lower energy and costs required to operate;

(ii) the production of methane that can be harvested to become an energy source; and

(iii) less volume of antibiotic-laden sludge that needs to be disposed adequately (Shoener et al., 2016)

(iv) anMBR may provide treated effluent that is safer than that produced by aeMBR (Harb et al., 2016; Cheng and Hong, 2017)

Acknowledgements

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Dr. Moustapha Harb

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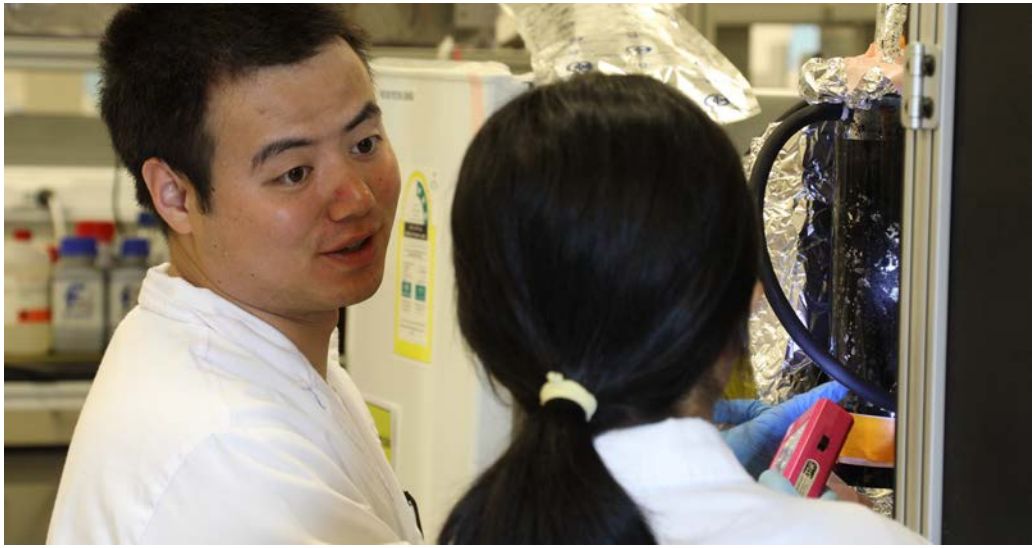

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