




University of
Massachusetts
Amherst

VOC Emission Reduction and Water Reuse in Chemical Manufacturing Using MBR

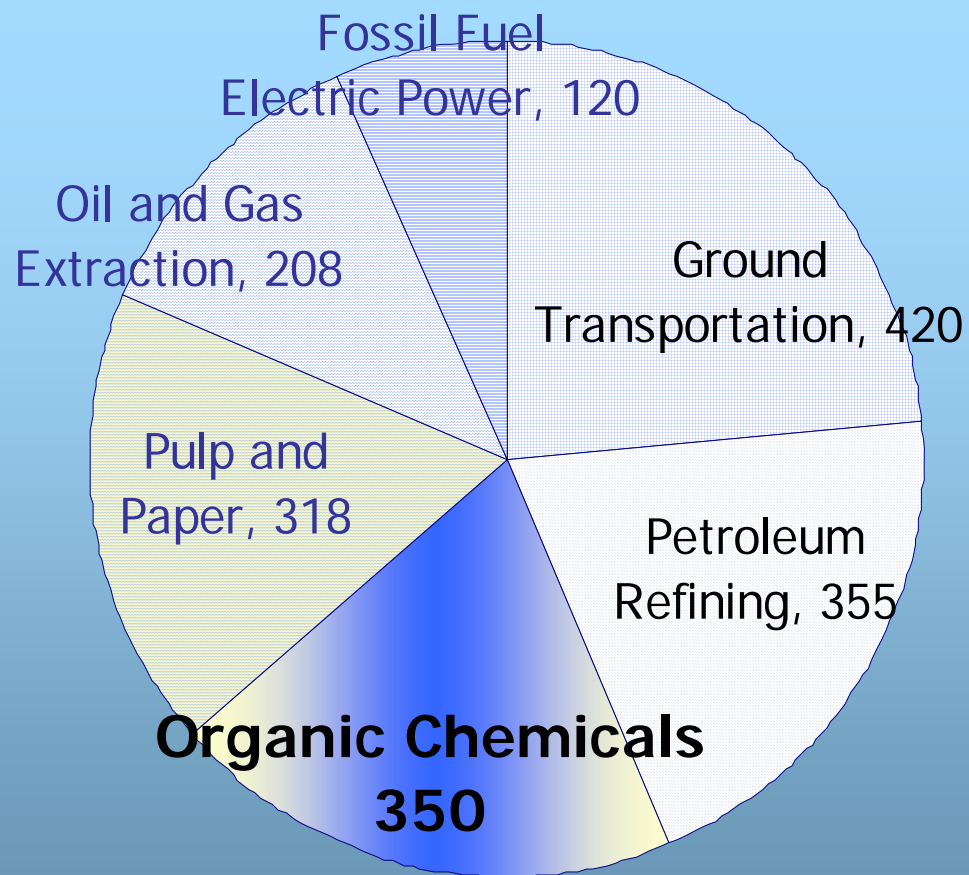
Item Type	Article;article
Authors	Ergas, Sarina J.;Min, Kyungnan
Download date	2026-06-14 00:14:57
Link to Item	https://hdl.handle.net/20.500.14394/50643



VOC Emission Reduction and Water Reuse in Chemical Manufacturing Using MBR

Sarina J. Ergas and Kyungnan Min
Dept. Civil & Environmental Engineering
University of Massachusetts, Amherst

VOC Releases by Industry (million pounds per year)



Ref. EPA (2002), Profile of the organic chemical industry, 2nd Ed.
Washington D.C., EPA-310-R-02-001

Clean Air Act Amendments (CAAA) of 1990

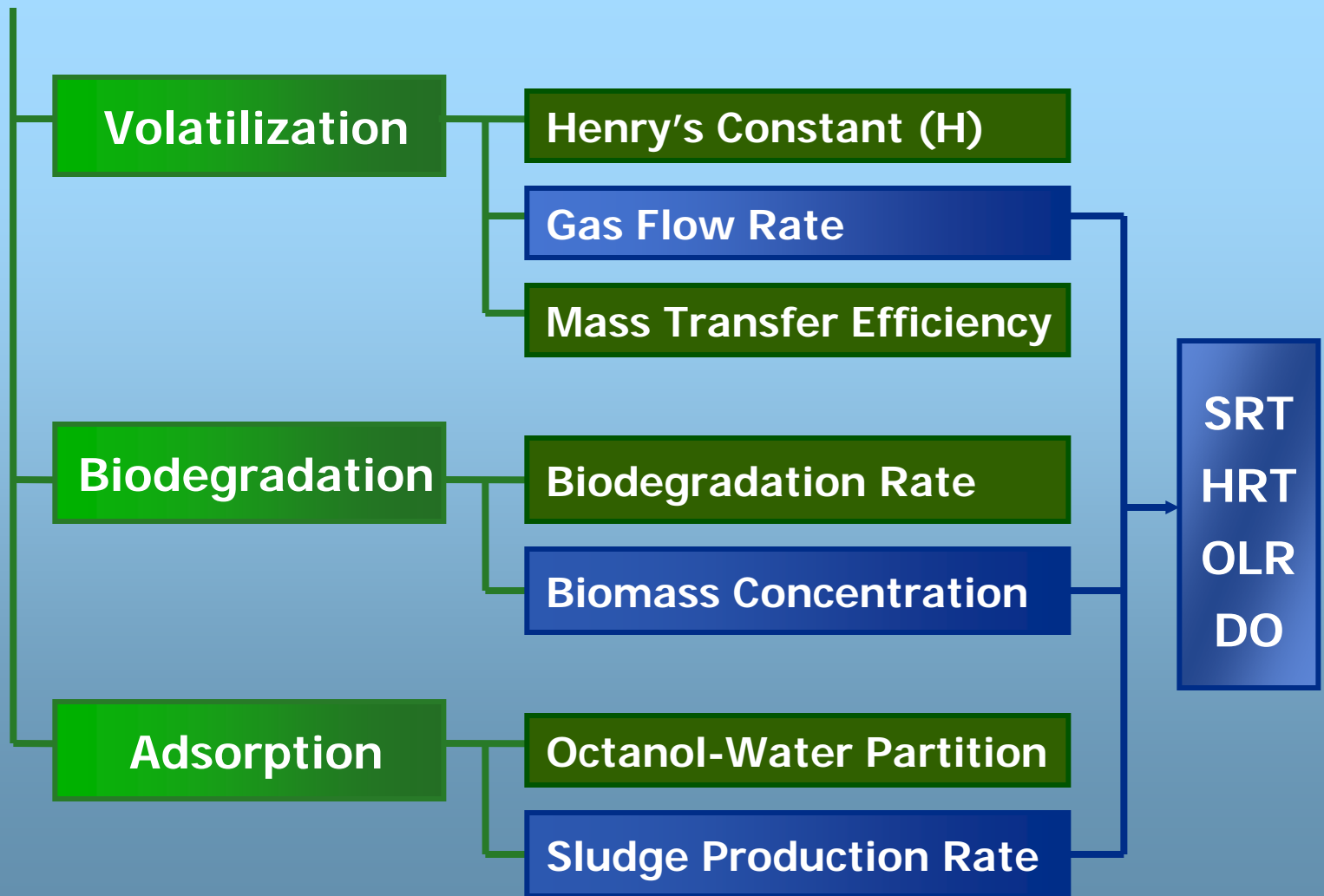
Title III. Air Toxics

National Emission Standards for Hazardous Air Pollutants (NESHAPs)

Maximum Achievable Control Technology (MACT) Standards

Miscellaneous Organic Chemical Manufacturing Process NESHAPs (MON)

VOC Removal Pathways in Wastewater



Objectives

Modeling of VOC Removal

Solids Residence Time (SRT)

Dissolved Oxygen (DO)

Organic Loading Rate (OLR)

Compare with Experimental Data Lab-scale MBR Operation

Organic Loading Rate (OLR)

Properties of VOCs

	H (25°C, -)	Diffusivity (cm ² s ⁻¹)	K _{ow} (-)	Biodegradation (L g ⁻¹ hr ⁻¹)
Acetaldehyde	3.15 (10) ⁻³	1.4 (10) ⁻⁵	2.69	0.197
Butyraldehyde	4.26 (10) ⁻³	1.1 (10) ^{-5*}	13.36*	0.361*
Vinyl acetate	1.99 (10) ⁻²	9.2 (10) ⁻⁶	8.52	0.305

Source: Water9 (EPA)

* EPA (1994), 'Air Emissions Models for Waste and Wastewater'.
North Carolina, U. S. EPA-453/R-94-080A EPA (1994)

Overall VOC Removal

$$1 - \frac{C_e}{C_o} = \frac{R_m + R_{bio} + R_{ads}}{1 + R_m + R_{bio} + R_{ads}}$$

C_e = Effluent VOC Concentration (mg L⁻¹)

C_o = Influent VOC Concentration (mg L⁻¹)

R_m = Volatilization Fraction (Dimensionless)

R_{bio} = Biodegradation Fraction (Dimensionless)

R_{ads} = Adsorption Fraction (Dimensionless)

$$\text{Volatilization Rate} = \frac{R_m}{1 + R_m + R_{bio} + R_{ads}}$$

Equations based on Hsieh, C. (2000), Rittmann, B. E. and McCarty, P. L. (2001)
MetCalf & Eddy Inc. (2003)x

Volatilization Fraction (R_m)

$$R_m = \frac{Q_G H}{Q_L} \left[1 - \exp\left(-\frac{(K_L a)_{VOC} V}{Q_G H}\right) \right]$$

$$Q_G = \left(\frac{R_{O_2}}{E \rho_{air} 0.2318} \right) \left(\frac{C_{S20}}{\alpha F (\beta C_{SmT} - C_{LO_2})} \right) (1.024)^{20-T}$$

$$R_{O_2} = Q_L (C_o - C_e) - 1.42 \frac{X_b V}{\theta_C}$$

$$(K_L a)_{VOC} = (K_L a)_{O_2} \left(\frac{D_{L VOC}}{D_{LO_2}} \right)^n \left(\frac{R_L}{R_T} \right) = \left(\frac{R_{O_2}}{(C_{smT} - C_{LO_2}) V} \right) \left(\frac{D_{L VOC}}{D_{LO_2}} \right)^n \left(\frac{R_L}{R_T} \right)$$

Biodegradation Fraction (R_{bio})

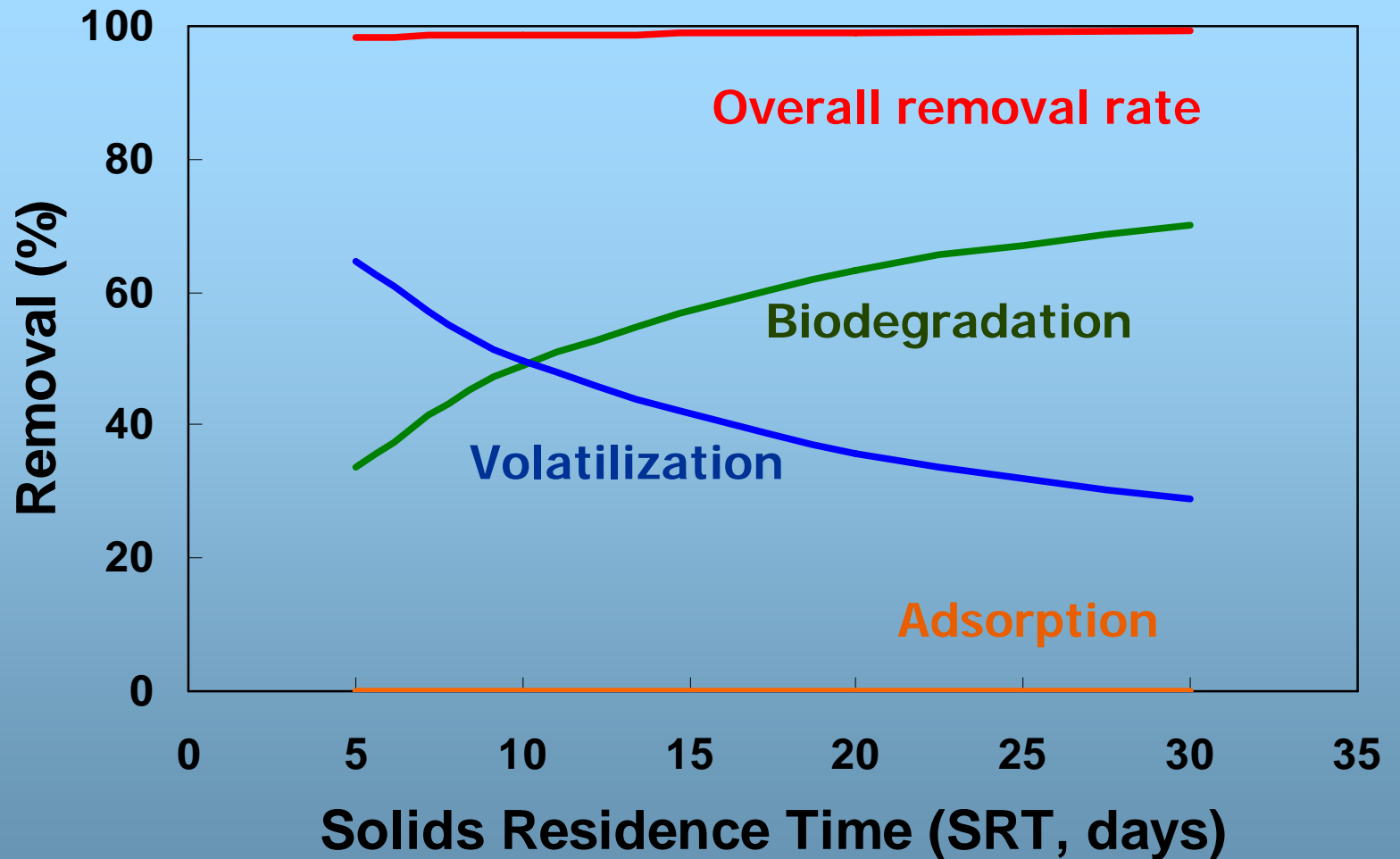
$$R_{bio} = \frac{K_b X_b V}{Q_L} = K_b X_b \theta \quad X_b = \frac{\theta_c}{\theta} \frac{Y (C_o - C_e)}{(1 + b \theta_c)}$$

Adsorption Fraction (R_{ad})

$$R_{ad} = 3.35 (10)^{-7} Q_w X_w K_{ow} = 3.35 (10)^{-7} \frac{X_b V}{\theta_c} K_{ow}$$

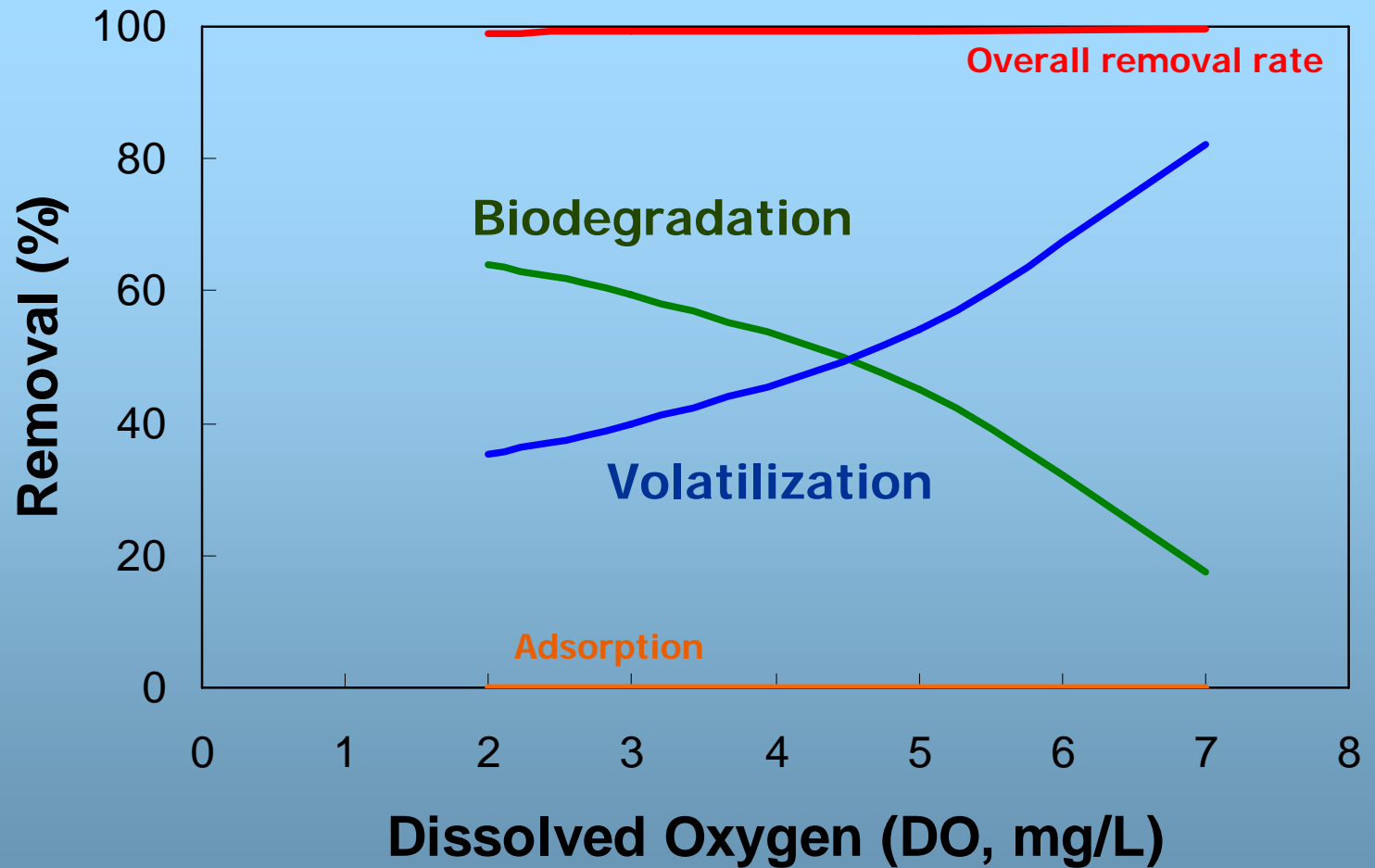
Vinyl Acetate Removal vs SRT

(OLR 4.9 kg COD m⁻³ d⁻¹, DO 2.0 mg L⁻¹)



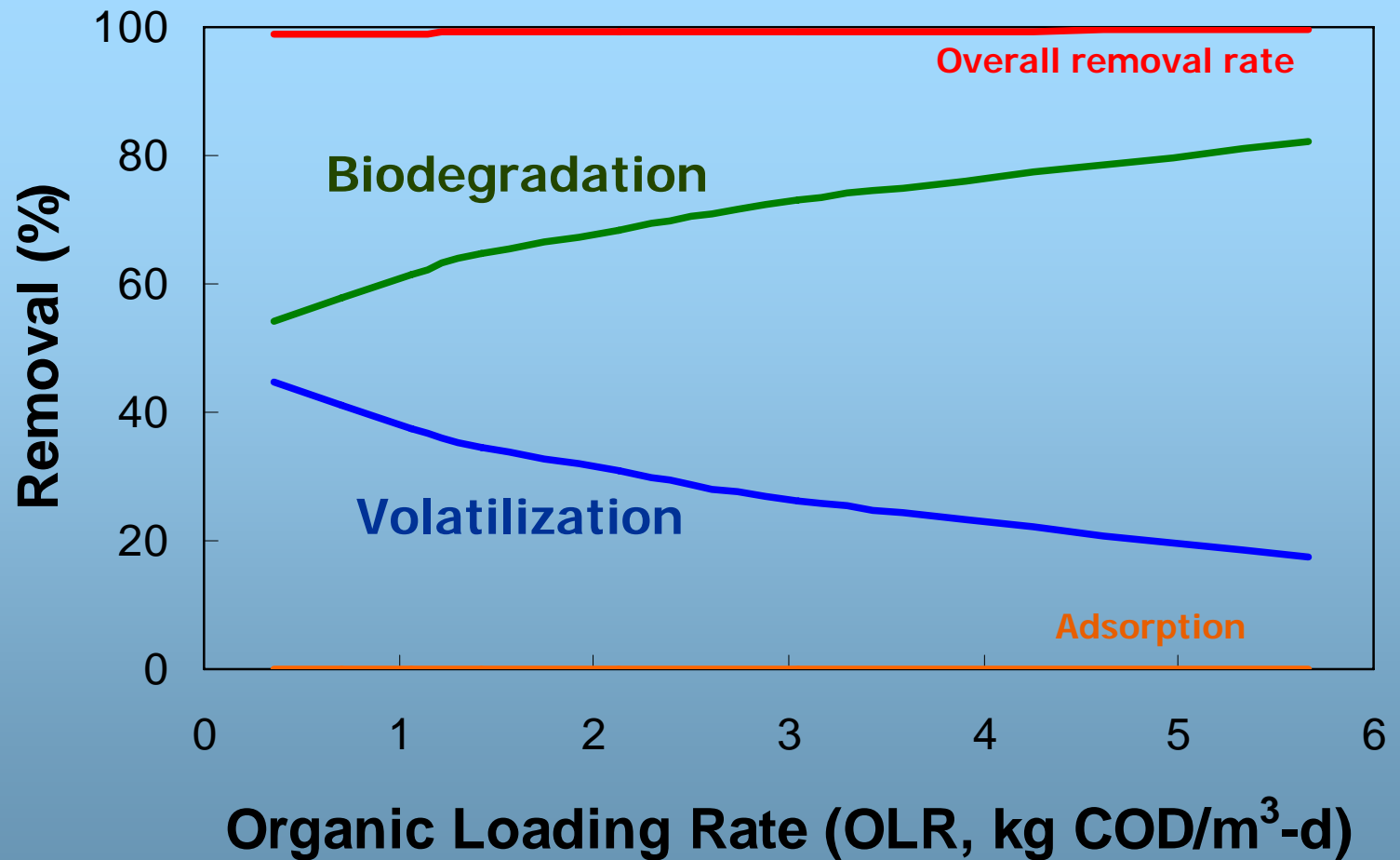
Vinyl Acetate Removal vs DO

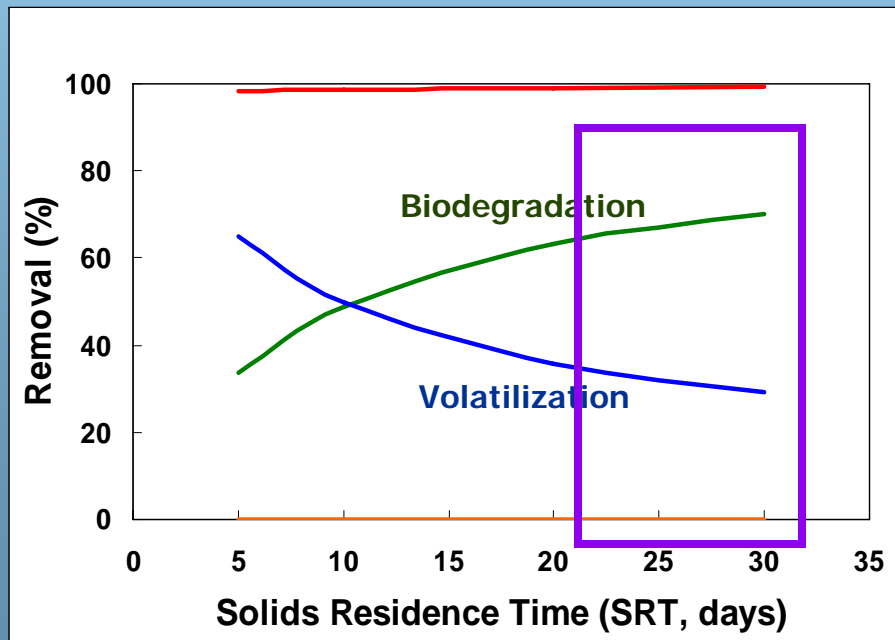
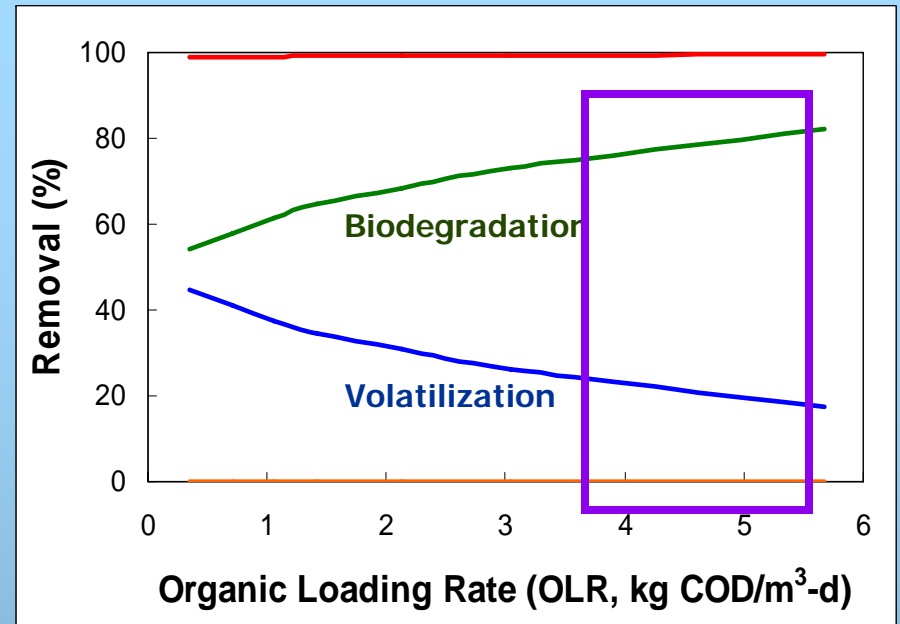
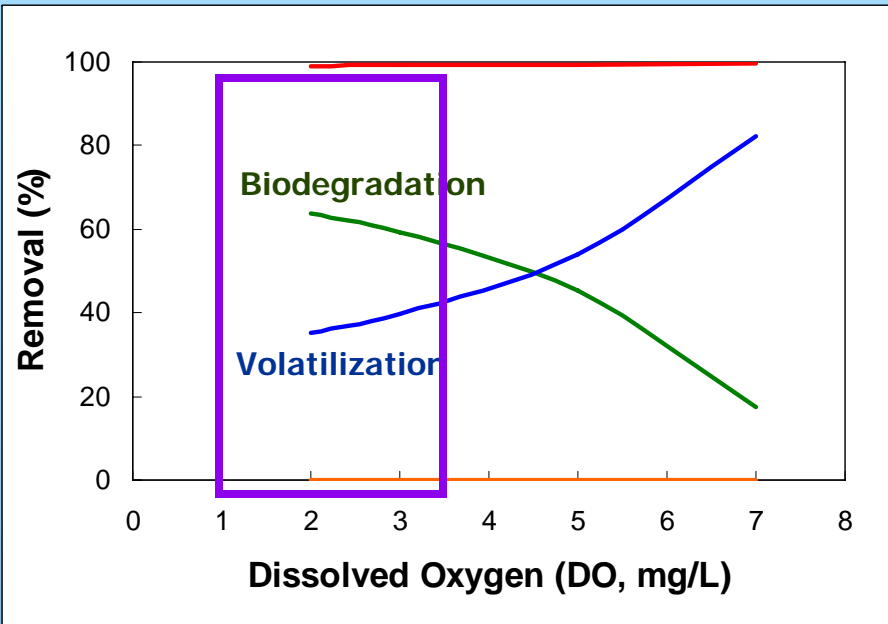
(OLR 4.9 kg COD m⁻³ d⁻¹, SRT 20 days)



Vinyl Acetate Removal vs OLR

(DO 2.0 mg L⁻¹, SRT 20 days)





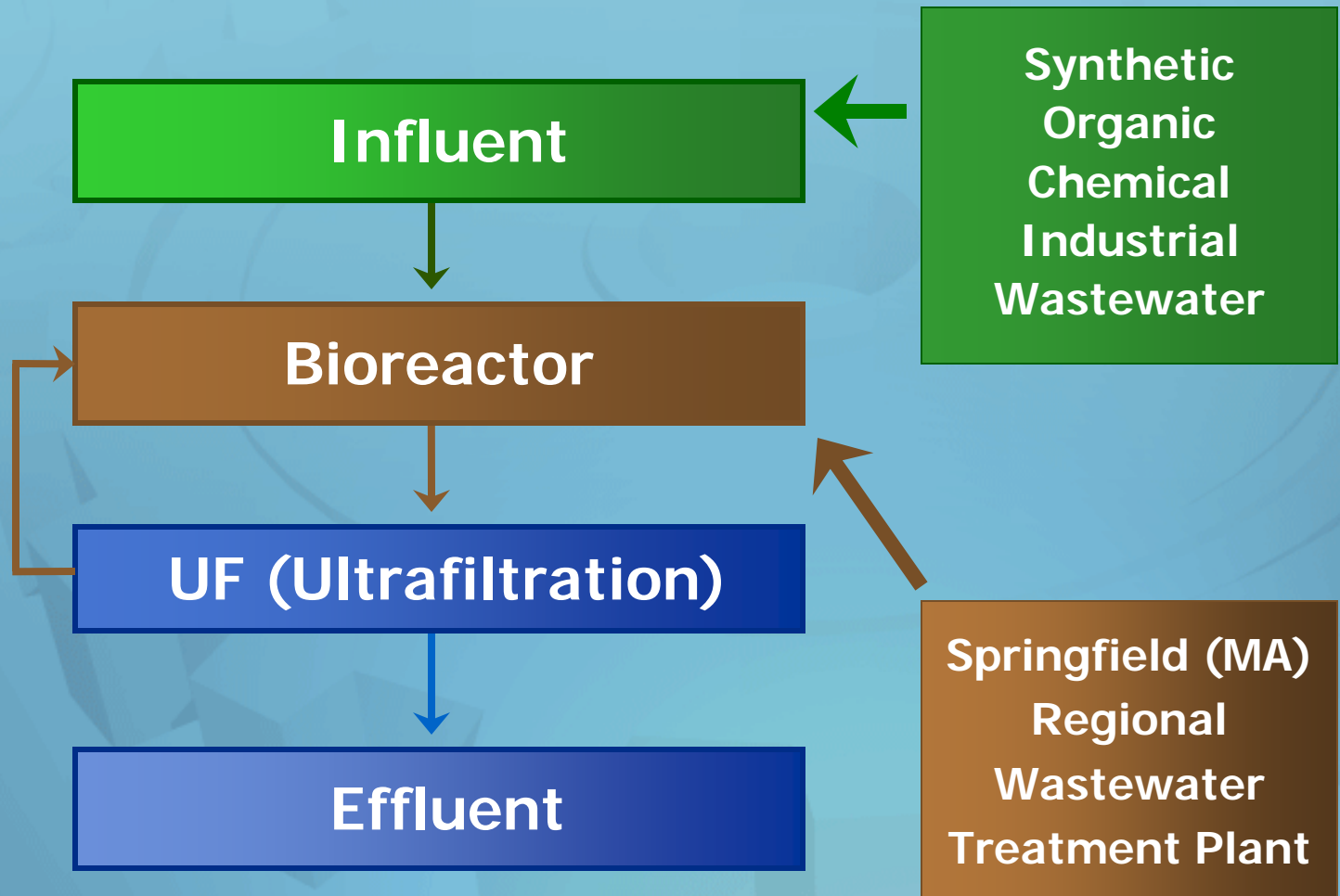
Lower DO

**Longer SRT
Higher OLR**

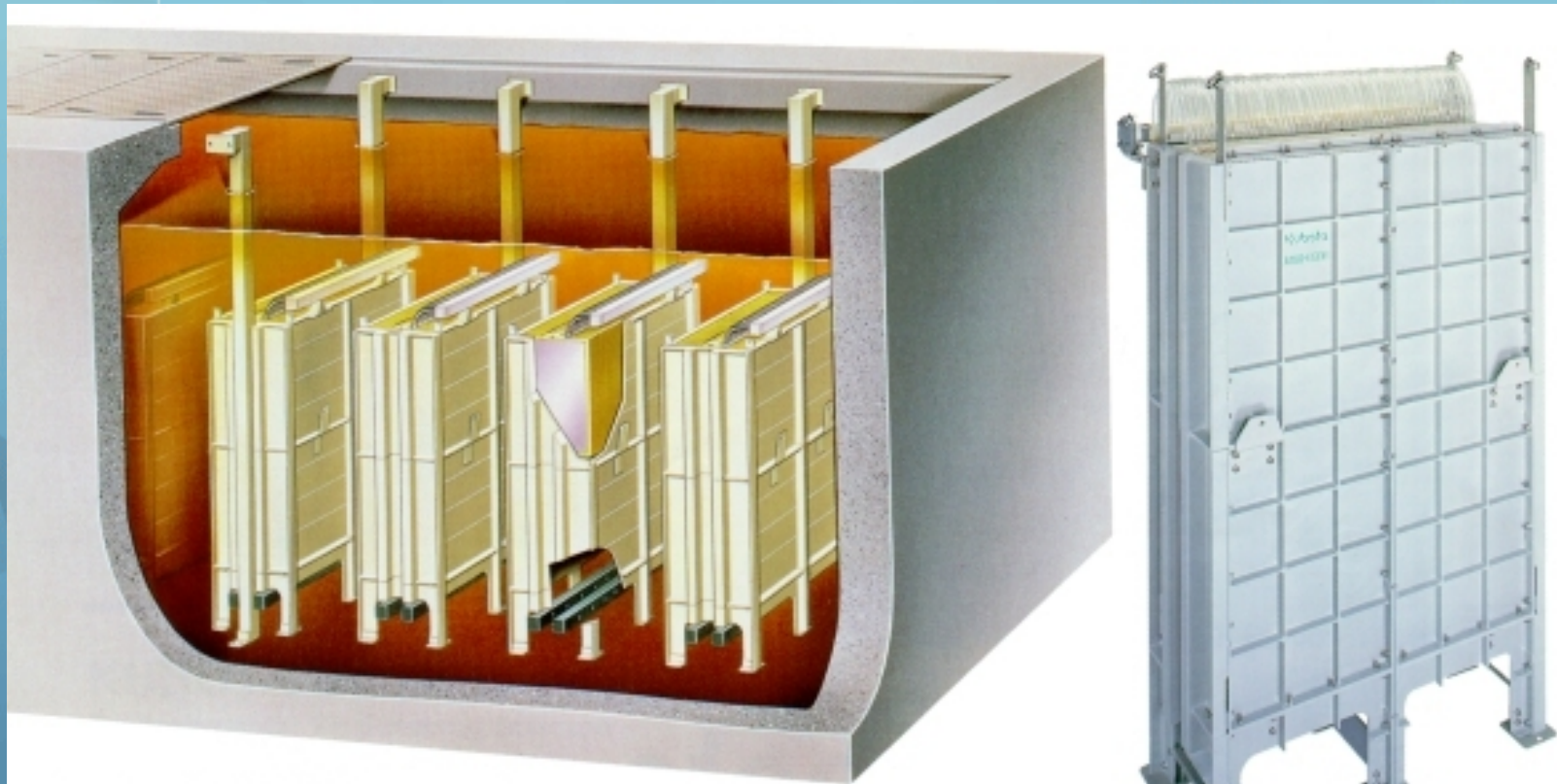


MBR

Overview of MBR Process



Submerged MBR Schematic

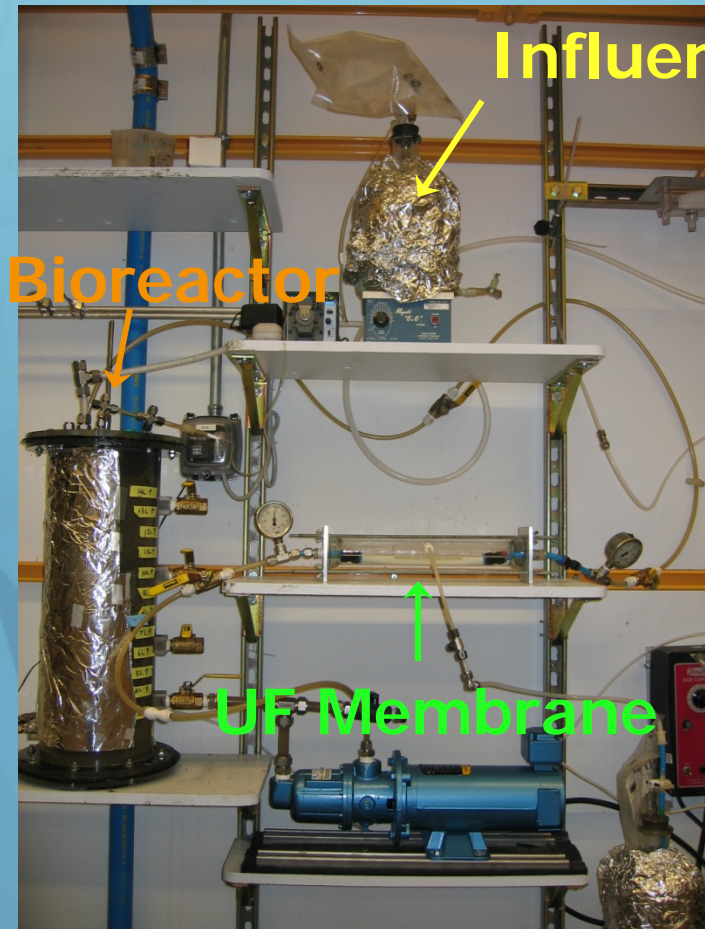


Typical MBR Layout

A MBR basin can be constructed of concrete or steel. To facilitate installation and maintenance, optional guide rails are available. MBR basins should be covered to avoid the introduction of fouling debris and mitigate the effects of ambient temperature on plant operation.

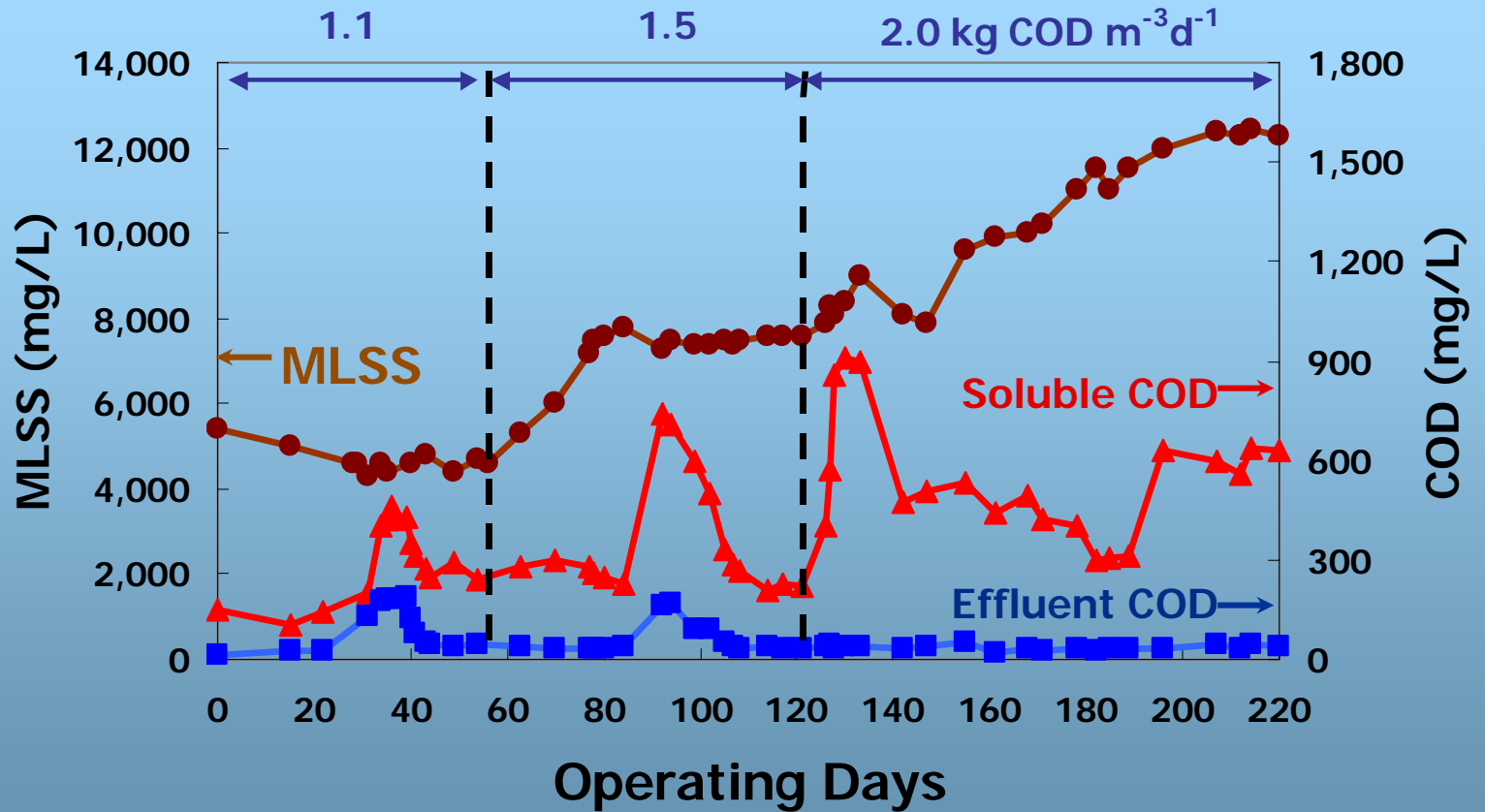
Source: Enviroquip

Bench-scale MBR System



- Tubular (AquaTech)
- Polyethersulphone
- 40,000 MWCO
- CFV: 1.8 m/s
- TMP: 4 bars

MBR Operation at varying OLR



Organic Removal Characteristics

Organic Loading Rate (kg COD m ⁻³ d ⁻¹)		1.1	1.5	2.0
Influent	pH	7.4 – 7.7		
	BOD ₅ (mg L ⁻¹)	4,500		
	COD (mg L ⁻¹)	6,900 – 7,300		
Effluent	pH	7.4 – 7.8	7.4 – 7.6	6.9 – 7.4
	BOD ₅ (mg L ⁻¹)	1.0	3.3	7.0
	COD (mg L ⁻¹)	40 – 48	35 - 40	30 – 46

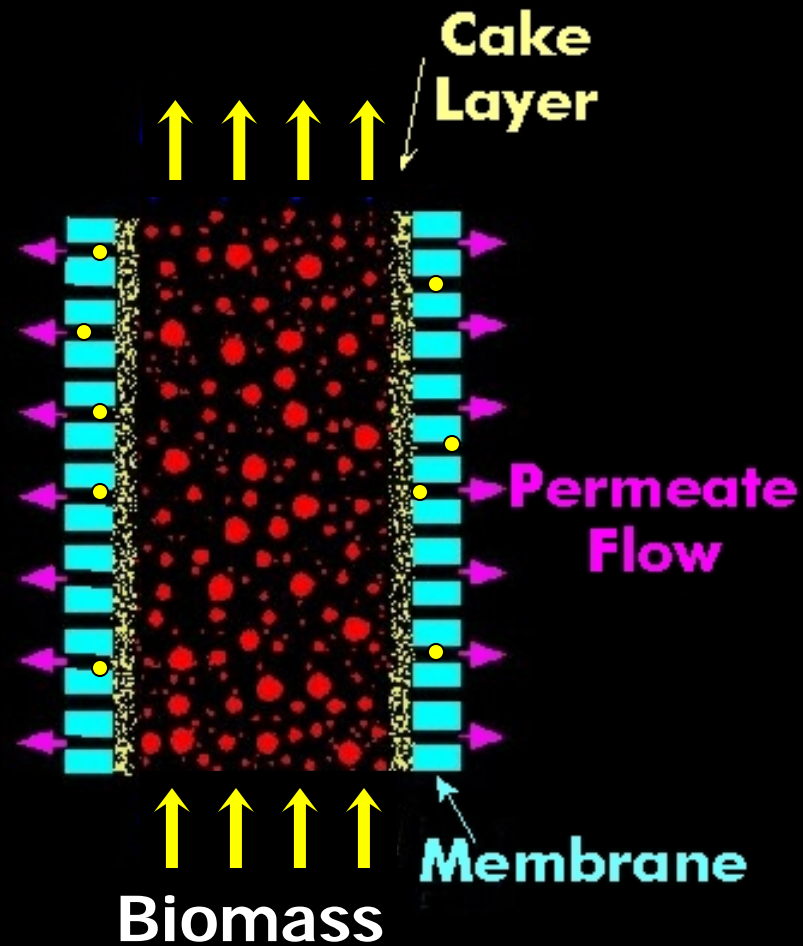
VOC Removal at Varying Organic Loading Rate

Removal (%)		Biodegradation		Volatilization	
VOC	OLR	1.1	2.0	1.1	2.0
	Vinyl acetate		93.9	99.4	6.1
		85.2	88.8	14.4	10.8
Acetaldehyde		99.1	99.0	0.8	0.9
		95.3	96.5	3.9	2.9
Butyraldehyde		97.7	97.6	2.1	2.2
		96.6	97.5	2.9	2.2

Membrane Fouling

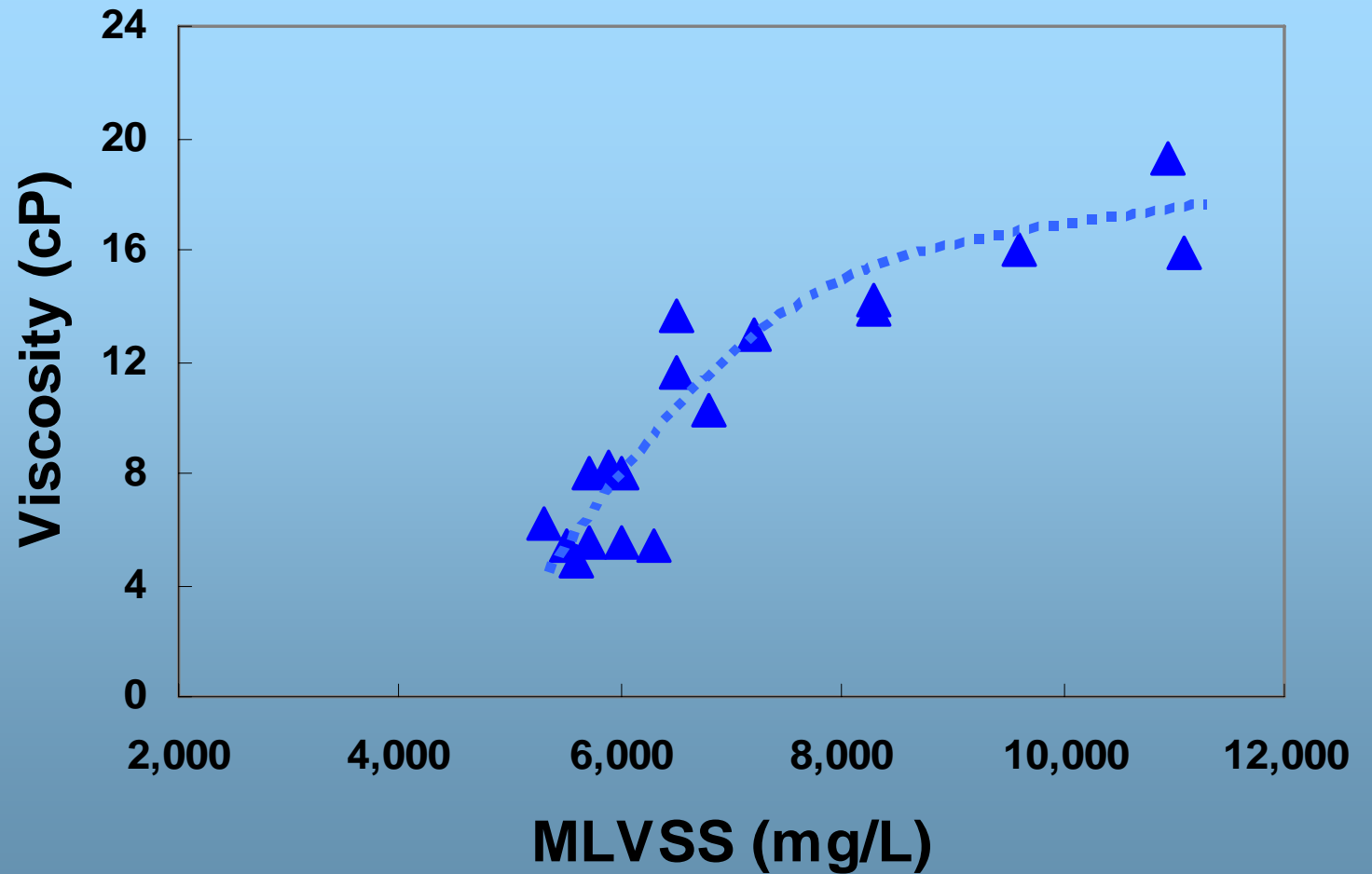
Crossflow Filtration

Membrane Resistances
Intrinsic Membrane
Resistance
Cake Resistance
Fouling Resistance

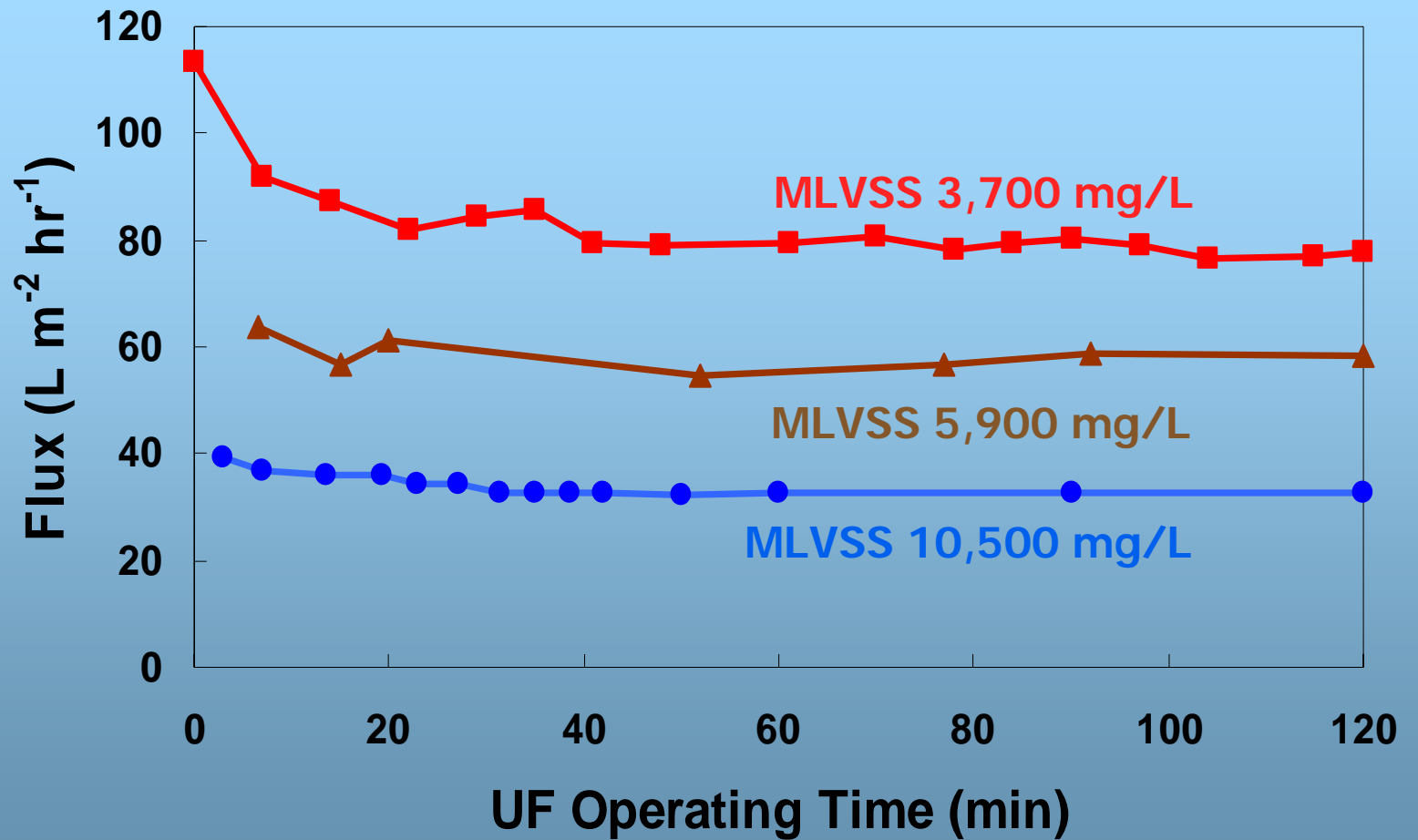


Source: Kubota

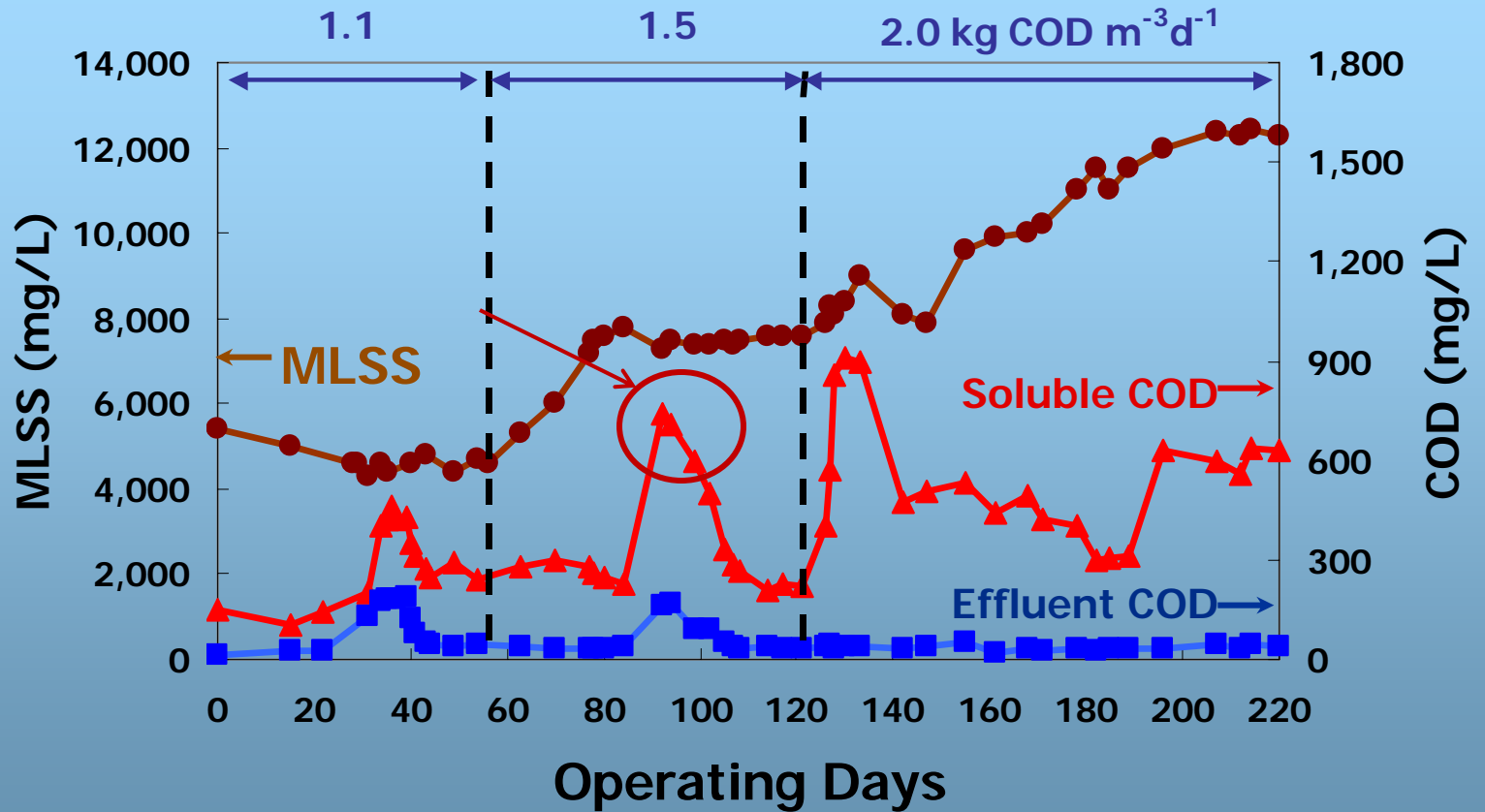
MLVSS vs. Viscosity at 36.7 s^{-1} , 30 sec



Initial UF Flux Decline at Various MLVSS



MBR Operation at varying OLR



Floc Structure at MLVSS 6,000 mg/L

Unstable: rods, small weak floc, little EPS, high SCOD

Viscosity

SCOD

B-EPS Protein

B-EPS TOC

5.5 cP

700 mg/L

13 mg/g VSS

28 mg/g VSS

Stable: cocci, larger floc, similar flux despite higher μ

Viscosity

SCOD

B-EPS Protein

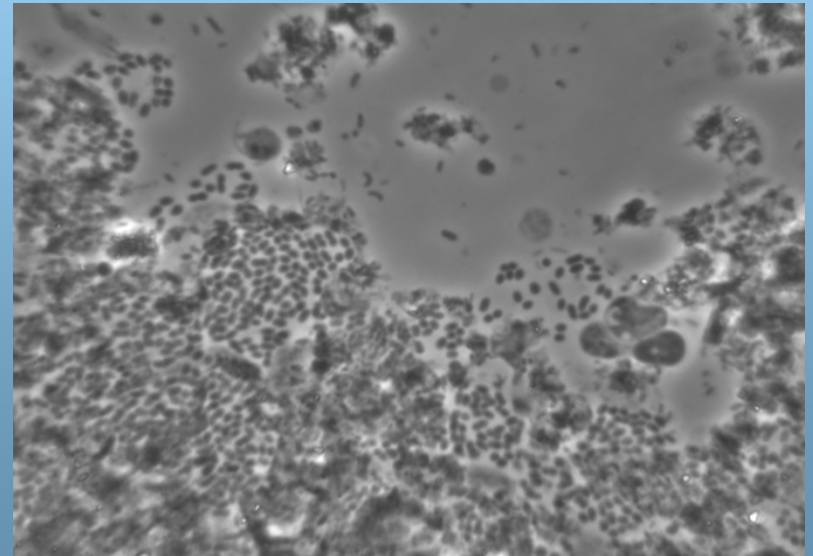
B-EPS TOC

8.2 cP

230 mg/L

65 mg/g VSS

42 mg/g VSS



Conclusions

Maximize Biodegradation, Minimize Volatilization

→ Lower DO, Higher OLR, Longer SRT

Vinyl acetate, with increasing OLR from 1.1 to 2.0 kg m⁻³ d⁻¹

→ Biodegradation increased from 93.9 to 99.4 %

→ Volatilization decreased from 6.1 to 0.6%

At All OLR, > 99.8% of BOD₅ and 99.3% of COD Removal

> 99.7% of VOC Removal

Modeling Underestimated the MBR Performance

→ Site-specific Biodegradation Rate

→ Low VOC Concentration in Effluent & Headspace Detected

Higher MLVSS Concentration → Increase Viscosity

→ Decrease Mass Transfer → Decrease Flux

Acknowledgements

National Environment Technology Institute (MA)

AquaTech Co. Ltd.

Solutia Inc. (MA): Lisa A Caraway, Dr. Gautham Parthasarathy

Dr. John E. Tobiason and Dr. James F. Holden

Anna Mermelstein, Dan Buttrick, Annalisa Onnis