Membrane Bioreactors for Industrial Applications

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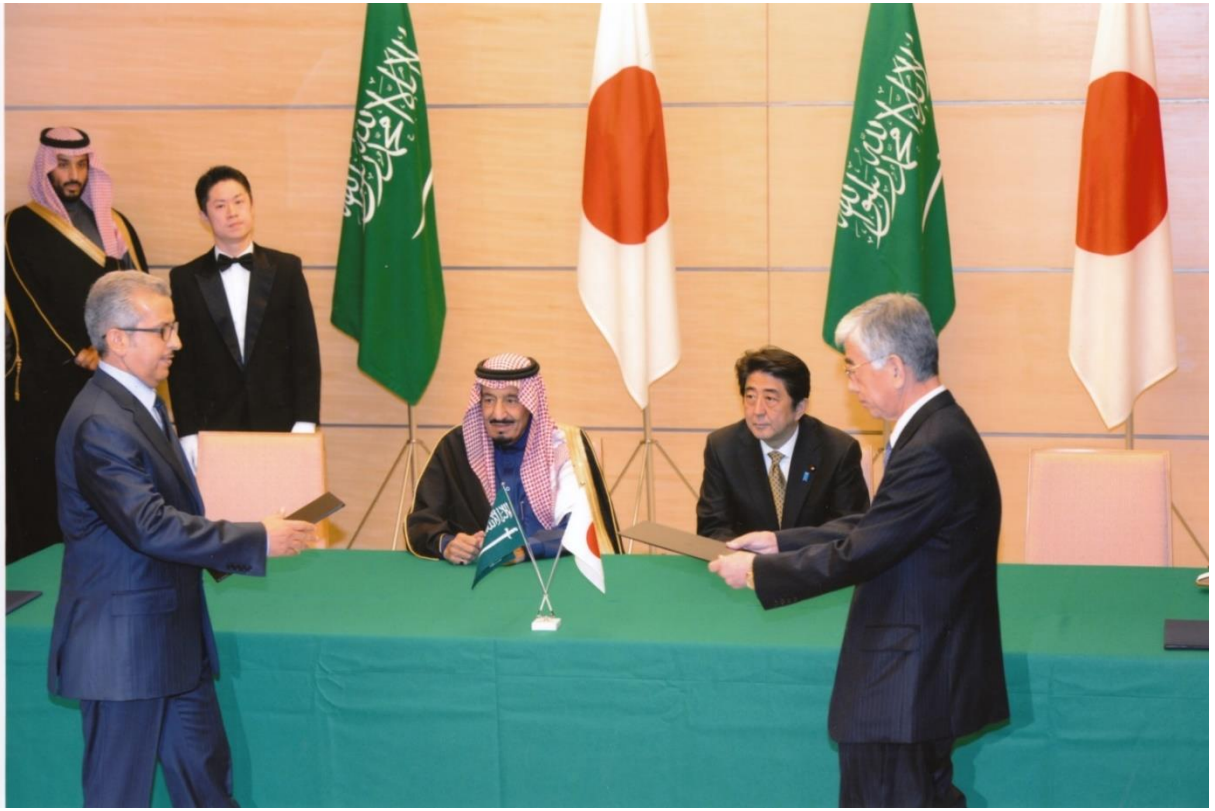
1. Introduction



Signing of Shareholders' Agreement on February 19, 2014 in Tokyo
in the presence of

Saudi Arabia's King Salman bin Abdulaziz Al Saud

and

Japanese Prime Minister Shinzo Abe

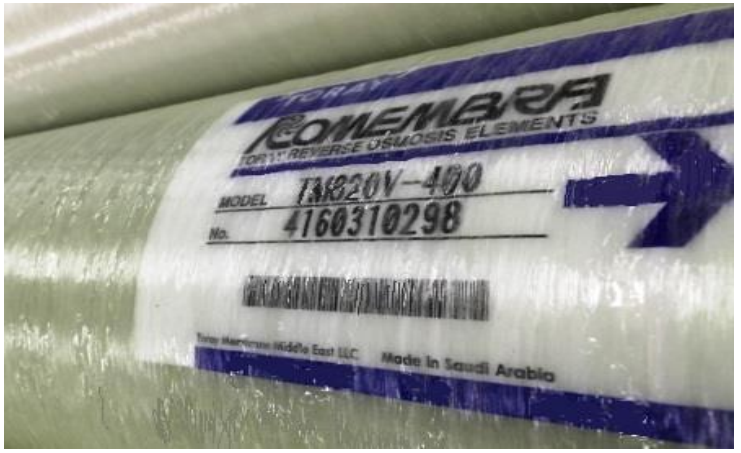
Introduction

Toray's Activities toward Saudi Vision 2030

1. Local Production

Toray Membrane Middle East LLC (TMME) in Dammam, started production of RO Membrane Elements in June 2015

2. Exporting of High Quality Products



Exporting High Quality RO Membrane Elements to MENA Region

3. Saudization

RO Membrane Elements made in Saudi Arabia, made by Saudi Arabian

4. Supplying Water in Saudi Arabia

Many of desalination plants in Saudi Arabia started water production by using TMME RO Membrane Elements.

Toray Group Business Overview

As a Japanese leading chemical company founded in 1926, Toray group has been globally expanding variety of businesses, including Environmental Engineering.

- Founded: **April, 1926, Shiga, Japan**
- Operation: **23 countries (sales offices & production plants)**
- Employee: **42,584 (as of March, 2013)**
- Net Sales: **1,589 billion JPY (Fiscal Year Ended Mar 31, 2013)**

Fibers, Textiles & Apparel / Plastics & Chemicals	IT-Related Products / Carbon Fibers Composite Materials	Environment Engineering < Water Treatment Division> / Life Science, Others
65%	19%	16%
Foundation Business	*Strategically Expanding Business*	*Strategically Developing Business*

Membrane Design Concepts
- Advanced PVDF Membrane for a good operation of MBR

Requirements

1. **Chemical and physical durability**
2. **High water permeability and high permeate quality**
3. **Prevention from clogging**

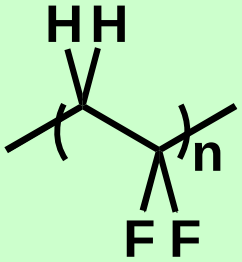
Design Concepts

1. Material

- *PVDF (poly (vinylidene fluoride))*
  > good chemical resistance and high mechanical strength

2. Pore

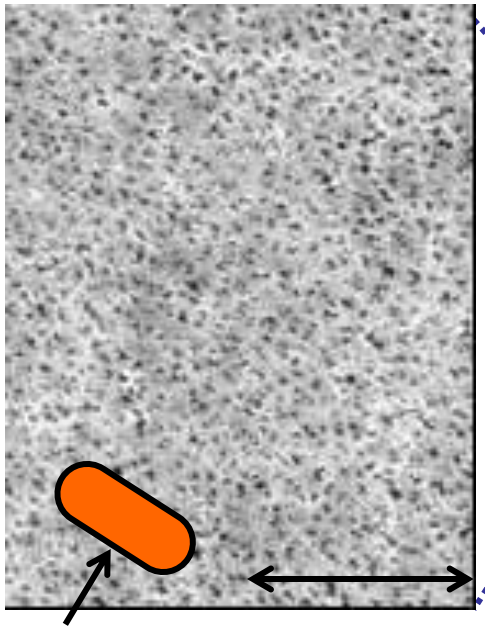
- *Numerous number*
  > high filterability
- *Small size and narrow distribution*
  > prevent from pore clogging



3. Surface morphology

- *Smooth surface*
  > prevent from the sludge accumulation onto the membrane surface

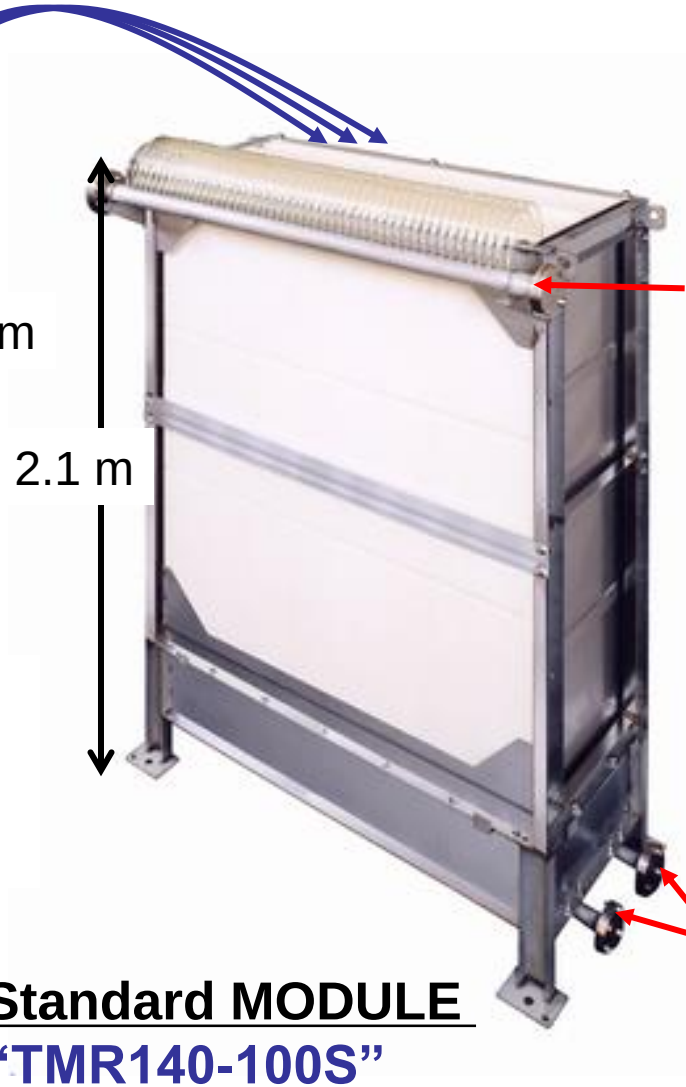
Toray's Submerged Membrane Module "MEMBRAY"



Bacteria 3.0 micron

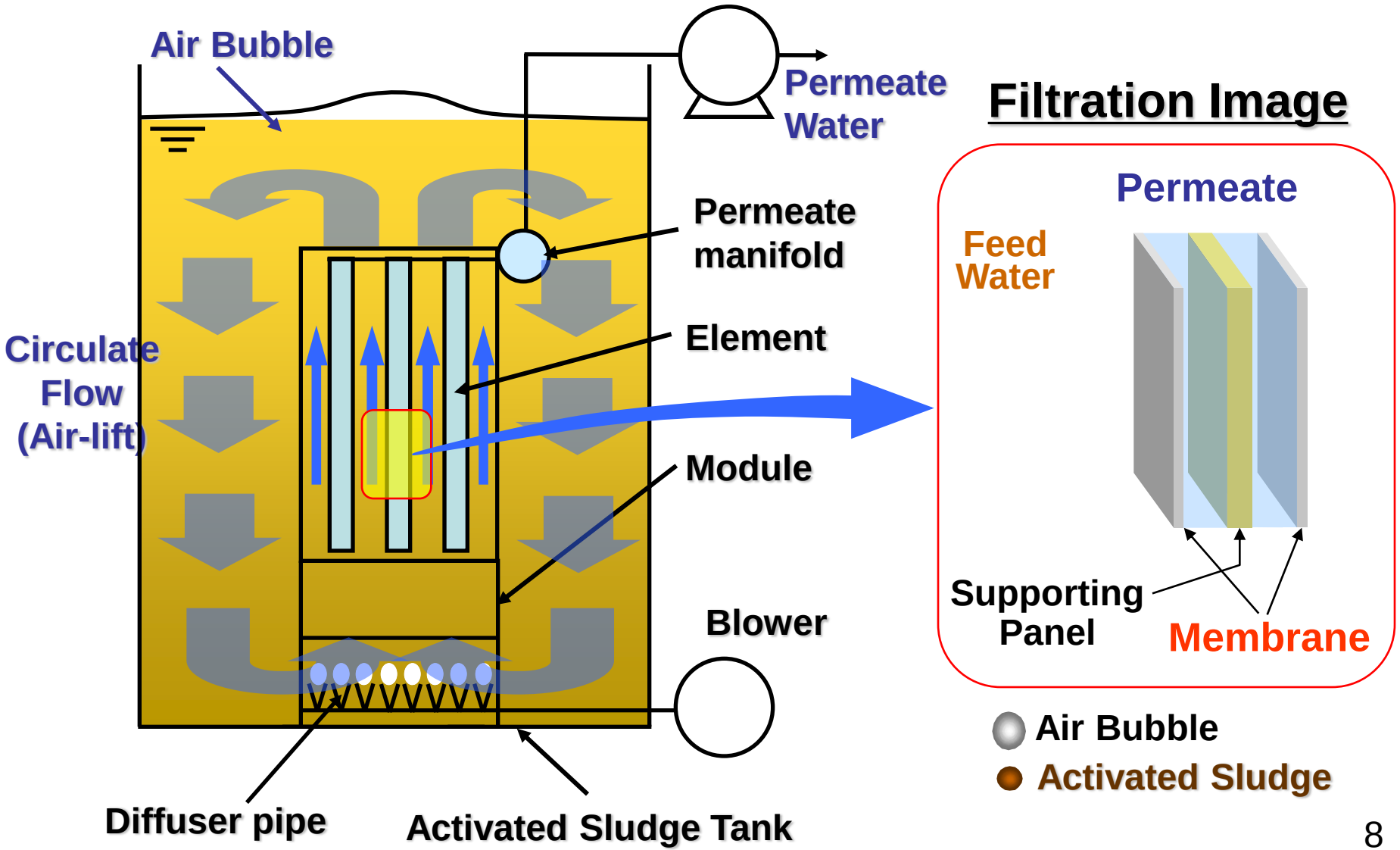
High Permeable Smooth Surface PVDF MEMBRANE (0.08 micron)

Flat Sheet ELEMENT (1.4 m^2)



Standard MODULE "TMR140-100S" (100EL, 140m^2)

How submerged membrane module works



MBR History

- AQUA RENAISSANCE ’90
  - 1986-1990, Japan
  - 20 private companies and AIST National Labs.
  - MBR, Anaerobic reactor, Membranes evaluation
- Sewage Applications
  - 1995-2000: R&D in Europe
  - 1995 First sewage application in Japan
- MBR Boom
  - 2005-2010: Europe
  - 2005-2010: Middle East
  - 2010- : China
- Lessons Learned
  - Sewage: Limited new installation (Energy consumption / Cost / Treated Water Quality)
  - Successful Industrial Applications

Recent Findings

Category	Sub-category	Elementary attribute	CAS *Sub-category or Elementary attribute score*	CAS *Category score*	MBR *Sub-category or Elementary attribute score*	MBR *Category score*
TECHNICAL ASPECTS	Reliability		1.67 (GREEN)	1.54 (GREEN)	1.67 (GREEN)	1.41 (GREEN)
	Flexibility / Modularity		1.75 (GREEN)		1.75 (GREEN)	
	Complexity		1.20 (YELLOW)		0.80 (YELLOW)	
ADMINISTRATIVE ASPECTS - NORMATIVE CONSTRAINTS		Complexity of the authorization/administrative process	2.00 (GREEN)	2.00 (GREEN)	2.00 (GREEN)	2.00 (GREEN)
SOCIAL ASPECTS		Economic Impact	2.00 (GREEN)	0.67 (YELLOW)	1.00 (YELLOW)	1.00 (YELLOW)
		Effluent quality	0.00 (RED)		1.00 (YELLOW)	
		Odour emissions	0.00 (RED)		0.00 (RED)	
		Skyline modification	0.00 (RED)		1.00 (YELLOW)	
		Soil consumption	0.00 (RED)		1.00 (YELLOW)	
		Others	2.00 (GREEN)		2.00 (GREEN)	
ECONOMIC ASPECTS		Total cost under the most favourable conditions	2.00 (GREEN)	2.00 (GREEN)	0.00 (RED)	0.50 (RED)
		Total cost under the worst conditions	2.00 (GREEN)		1.00 (YELLOW)	
ENVIRONMENTAL ASPECTS		Global warming potential	2.00 (GREEN)	1.67 (GREEN)	2.00 (GREEN)	1.67 (GREEN)
		Acidification potential	2.00 (GREEN)		2.00 (GREEN)	
		Eutrophication, fresh water	2.00 (GREEN)		0.00 (RED)	
		Eutrophication, marine	1.00 (YELLOW)		2.00 (GREEN)	
		Eutrophication, terrestrial	2.00 (GREEN)		2.00 (GREEN)	
		Photochemical oxidant formation potential	1.00 (YELLOW)		2.00 (GREEN)	
Final score			**1.58**		**1.32**	

Table 2. Results of the techno-economic-environmental assessment of the CAS and MBR plants: scores are obtained by attributing the same weight (1) to all categories. Scores range from 0 (worst ranking) to 2 (best ranking) (Bertanza et al, 2017)

http://www.thembrsite.com/features/a-comparative-techno-economic-environmental-assessment-of-full-scale-cas-vs-mbr-technologies/

Experiences in Industrial MBR

- **Food**
  - Cake
  - Ice Cream
  - Olive Oil
  - Milk Processing
  - Dairy
  - Protein
  - Potato
  - Vinegar
- **Meat Processing**
  - Beef
  - Chicken
  - Fish
  - Squid
- **Beverage**
  - Juice
  - Cola
- **Chemical**
  - Chemical factory (PTA, DMSO, etc)
  - Cosmetic
  - Dyeing, Textile
  - Electronics
  - Liquid Crystal
  - Paper Mill
  - Petrochemical
  - Pharmaceutical
  - Photo Film
- **Others**
  - Automotive
  - Landfill Leachate
  - Laundry
  - Marine

Applications Consideration

	SS	Oil	Inorganic Ion	Toxic Substances	Salinity	High BOD	Nutrient balance
Food	Seed, Coat	Cake, Dairy	Ca				
Meat Process-ing	Bone, Pelage, Fish scale,	Fish oil become solidified					
Beverage	Coat						
Alcohol Drinks	Chaff						
Chemical	Fiber, polymer, dispersed material, polyvinyl - alcohol	Mineral Oil	Si, Mn, Ca	Disinfecti on agent			
Marine	Toilet Paper			HCHO			

To be removed by Pretreatment

Special attention required. (Tolerance limit, separate treatment, anaerobic treatment, etc.)

To be added

Guidelines on MBR Operation

Substance		Guideline on biological treatment	Guideline on membrane module
Oil	Biodegradable		<50mg/L at MBR inlet
	Non-Biodegradable	<~10mg/L	Trace (zero)
Alkali , Acid		5<pH<9, No rapid pH change	
Salts		<1% No rapid conc. change	Cl >100mg/L: SS316L is recommended for anti-corrosion
Organic solvent, Toxic Substances	Biodegradable	Acclimated	
	Non-Biodegradable	Within the range not toxic to microorganisms.	Within the range not harmful to materials (ABS, EPDM rubber, membrane, SS)
Inorganic Ion (Ca, Si, Mn etc)			
Anti-foam	Alcohol based		
	Silicone based		Prohibited
Coagulant	Al, Fe		
	Cationic high-polymer coagulant		Inject and agitate well prior to MBR tank

4. Industrial Applications

4-1 Chemical Factory

4-2 Liquid Crystal Factory

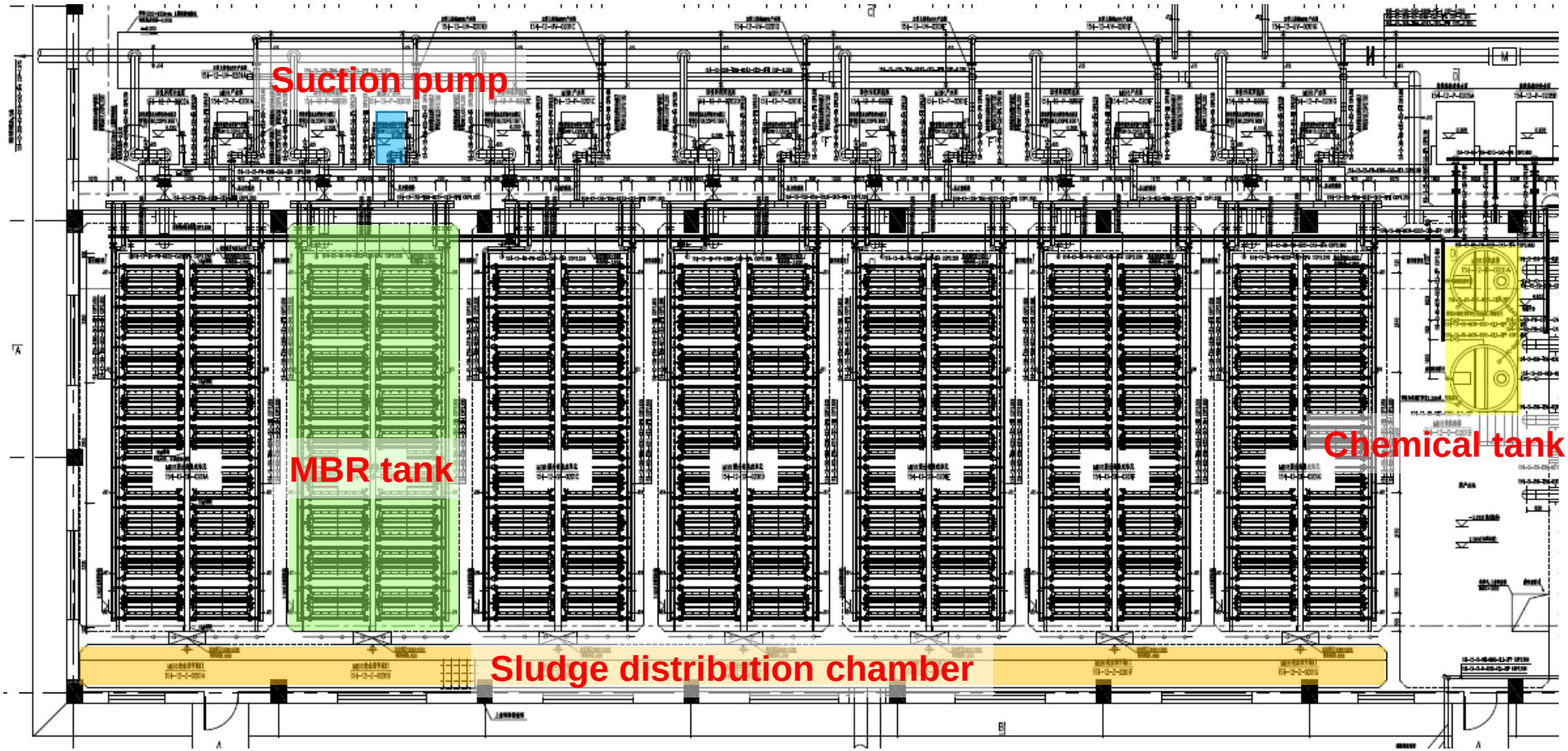
4-3 Food Processing Factory

4-4 Edible Oil Factory

4-1 Chemical Factory in China

Place of Installation:	**Northern China**
Application:	**MBR Coal Chemical Factory WW**
Design Capacity:	**9840 m^3/day (“N-1 design” adopted)**
Installed Modules:	**126 x TMR140-200D**
In operation since:	**June 2013**
Remark:	**Pilot test was conducted to assess the applicability of MBR**

4-1 Chemical Factory in China - Layout



4-1 Chemical Factory in China - MBR Tank

• MBR tanks (7 tanks) in a building: protection from cold weather

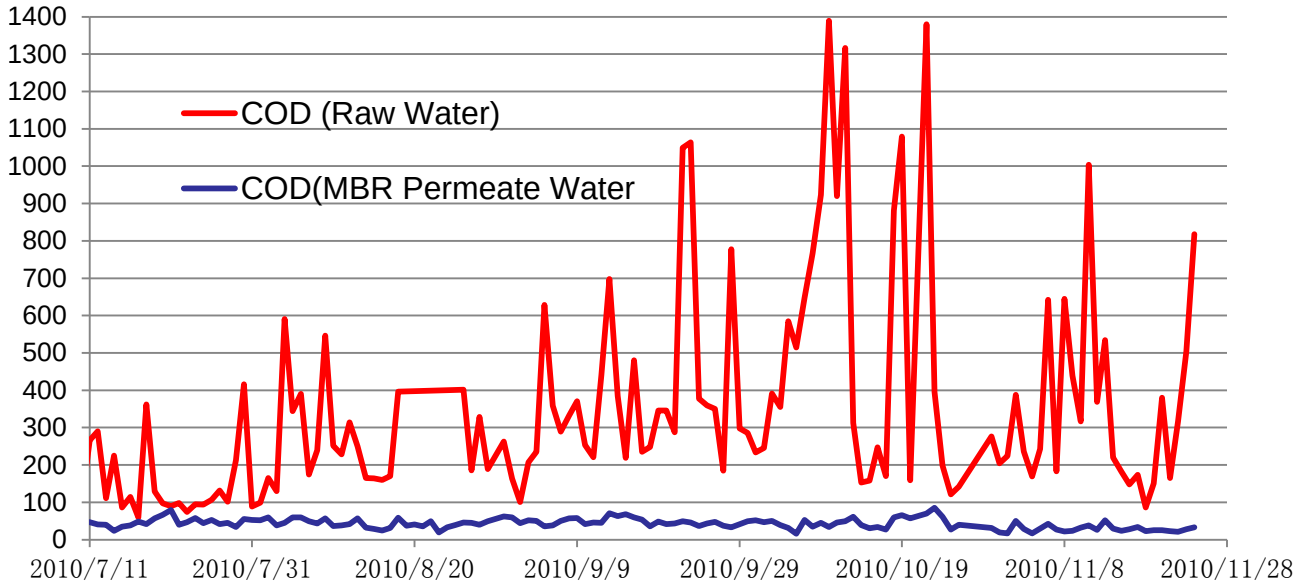
• Pump room

4-1 Chemical Factory in China - MBR Tank

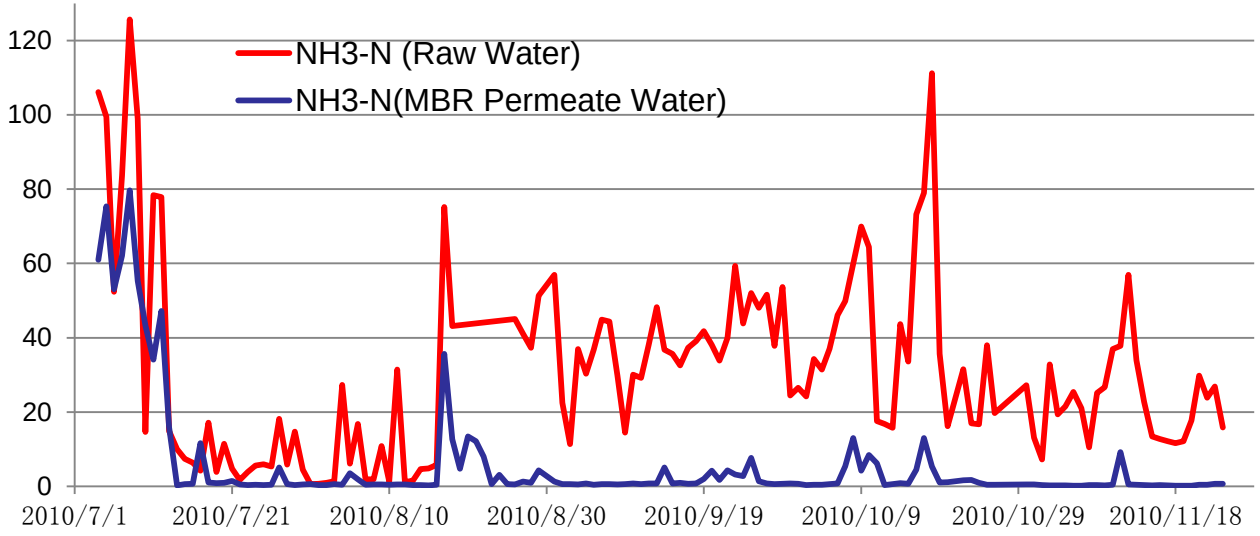
- **Combined permeate header (upper & lower)**
- **Auto diffuser cleaning & guide rail system installed**

4-1 Chemical Factory in China - COD and NH3-N

COD(mg/L)



NH3-N(mg/L)



4-1 Chemical Factory in China - COD and NH3-N

5 months pilot study

	1st month (July)	5th month (November)
Treated Water COD	46 mg/L	29 mg/L
Treated Water NH_4^+-N	20 mg/L	< 1 mg/L

Activated Sludge was well acclimatized in 5 months.

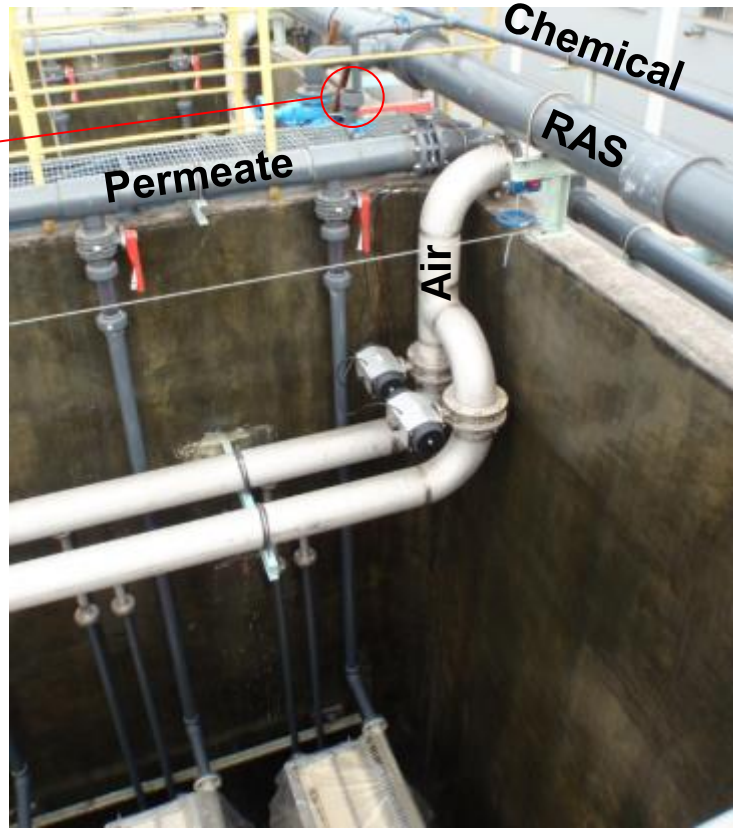
4-2 Liquid Crystal Factory

Place of Installation:	**China**
Application:	**MBR Liquid Crystal Factory WW**
Design Capacity:	**11000 m^3/day**
	(Phase I 6500 / II 4500)
Installed Modules:	**100 x TMR140-200W**
	(Phase I 60 / II 40)
In operation since:	**November 2008 (I)**
	March 2012 (II)

4-2 Liquid Crystal Factory

- **Chemical pre-treatment (coagulation/precipitation/neutralization)**
- **High salinity WW – SS316L membrane module equipped with plastic manifold & diffuser**

4-2 Liquid Crystal Factory – MBR Tank



End of air header

- COD in Raw Water: 1,750 to 2,296 mg/L
- COD in MBR Treated Water: < 90 mg/L

- 10 trains of 10 x TMR140-200W
- Common air diffuser cleaning
- Separated chemical piping for injection height control

4-3 Food Processing Factory

Place of Installation:	**Peru**
Application:	**MBR Food Processing WW**
Design Capacity:	**850 m^3/day**
Installed Modules:	**18 x TMR140-100S**
In operation since:	**October 2011**
Remark:	**Wastewater from livestock and seafood processing factory and restaurant**

4-3 Food Processing Factory

4-3 Food Processing Factory – Process Flow Scheme

Raw Water

Sedimentation

DAF

Aeration tank

MBR

Irrigation

RO

Reuse

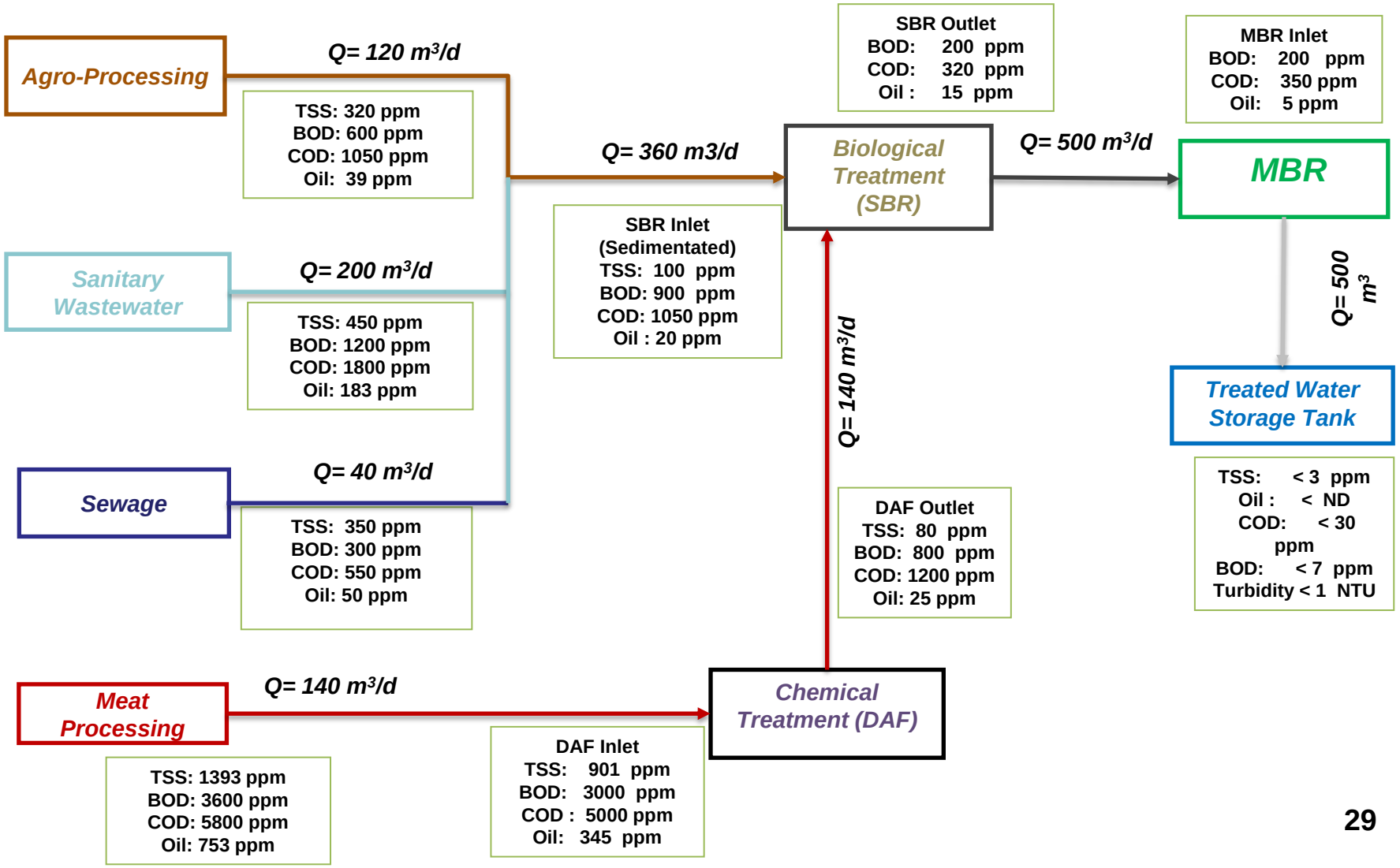
4-3 Food Processing Factory – MBR Tank

- 3 MBR tanks
- Gravity filtration
- Common air diffuser cleaning

4-3 Food Processing Factory – MBR Treated water for Irrigation

- **MBR permeate: Irrigation of neighboring wildlife refuge**

4-3 Food Processing Factory – Overall Flow Scheme



4-4 Edible Oil Factory

Place of Installation:	**Singapore**
Application:	**Edible Oil Production Wastewater**
Design Capacity:	**170 m^3/day**
Installed Module:	**8 x TMR090-100S**
In operation since:	**July, 2014**
Remarks:	**Treated water for Cooling Water (Mixed with NEWater)**

4-4 Edible Oil Factory Plant Overview

- Process Flow: DAF → MBR → UV
- Mix with NEWater, and use for cooling tower

4-4 Edible Oil Factory
- Pretreatment (DAF) and Post treatment (UV)

DAF

UV

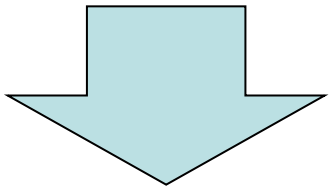
4-4 Edible Oil Factory – MBR Tank

4-4 Edible Oil Factory - Flux Enhancer

MPE50: Nalco's Flux Enhancer

5. MBR's Key Advantage

- Good Water Quality
- Applicable to hard degradable substrate by retention of microorganisms and diversified microbial ecosystem in MBR



- NO downstream coagulation / sedimentation?
- NO Activated Carbon?

5. MBR Key Advantages

- **Very good treated water quality by a long SRT and existence of highly acclimatized microorganisms to treat hard-degradable components in the wastewater.**

Only MBR can do this.

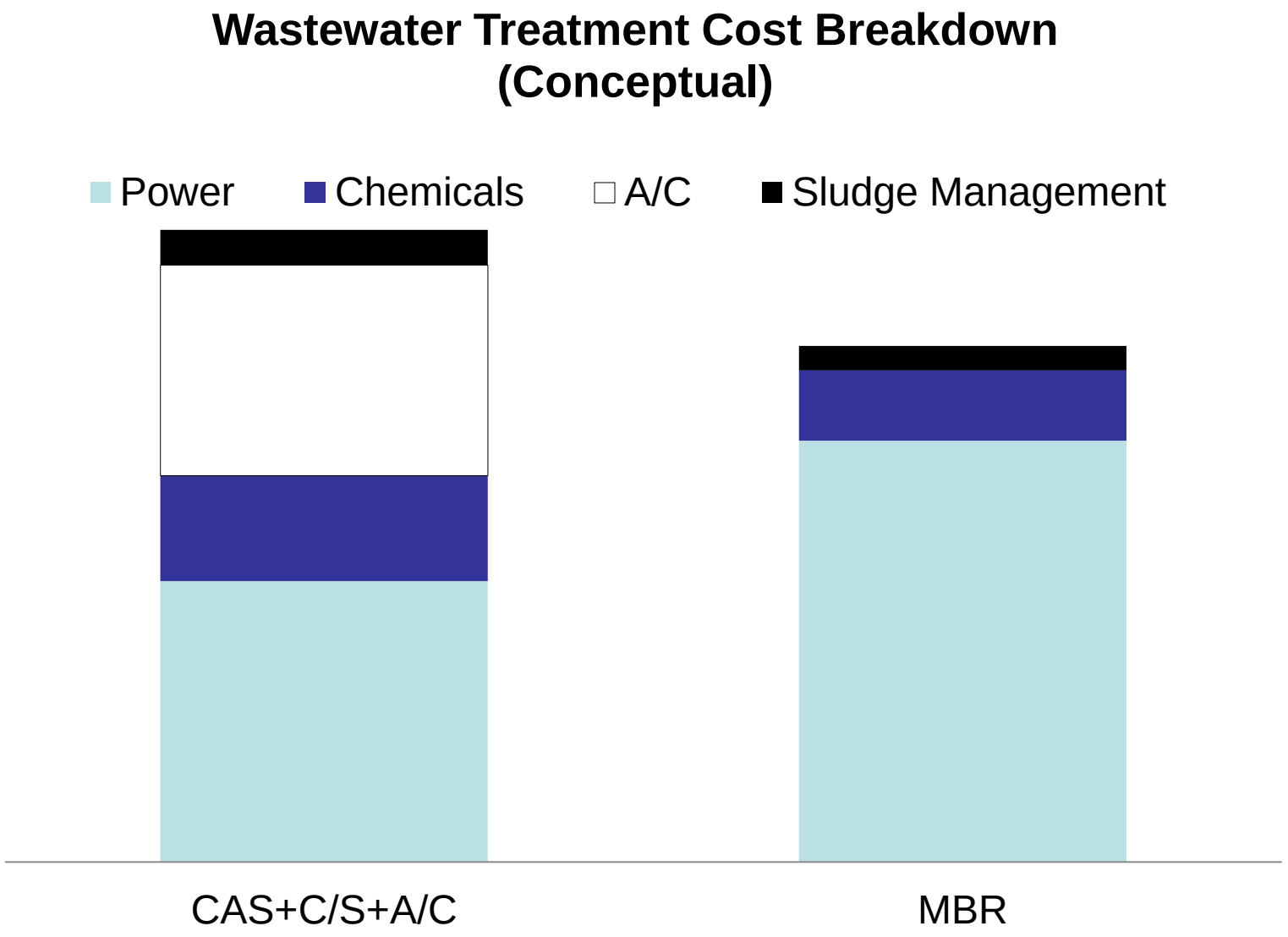
$$D > \mu$$

D: Dilution Rate ($m^3/m^3/Day$)

μ: Specific Growth Rate (g/g/Day)

- **Less excess sludge production due to a long SRT.**

MBR Key Advantages



Good collection system

- Microorganisms which treat hard degradable substrate have very low specific growth rate and yield.
- Substrate inhibition
- Treatability study of each stream and determination of buffer tank size.

Conclusion

Great Potential of MBR for Industrial Application

- Cost Saving
- Less Water Consumption by Reuse: MBR+RO

Sharing MBR Experience with You

- Good Engineering for Collection System
- Consideration on Turn Down / Shut Down
- Pilot Study

Thank you very much.

www.toraywater.com