11th Feb. 2020

Reliable Simulation Technology to Predict Membrane Bioreactor Performance based on the Advanced Fouling Model

Hiroshi Hamada
TORAY Industries, Inc.

Contents

1. Introduction

2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

3. Validation of simulation results

4. Automatic data analysis system

5. Conclusion

Contents

1. Introduction

2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

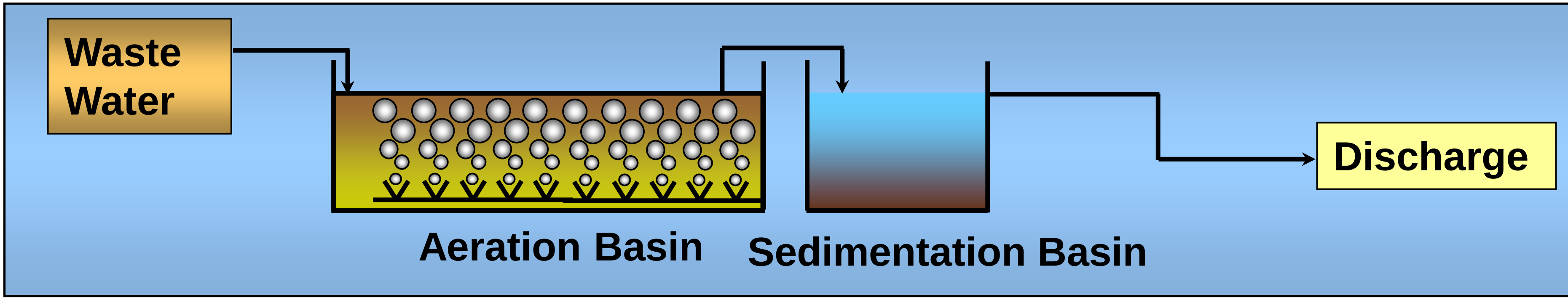
3. Validation of simulation results

4. Automatic data analysis system

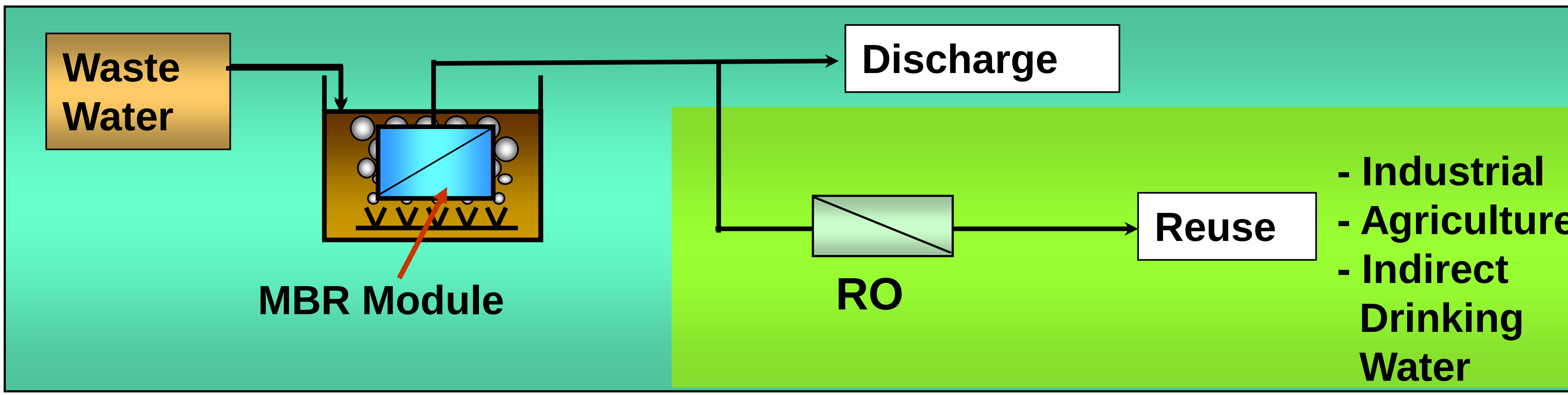
5. Conclusion

Features of Membrane Bio Reactor (MBR)

Conventional Method



MBR



Advantages of MBR

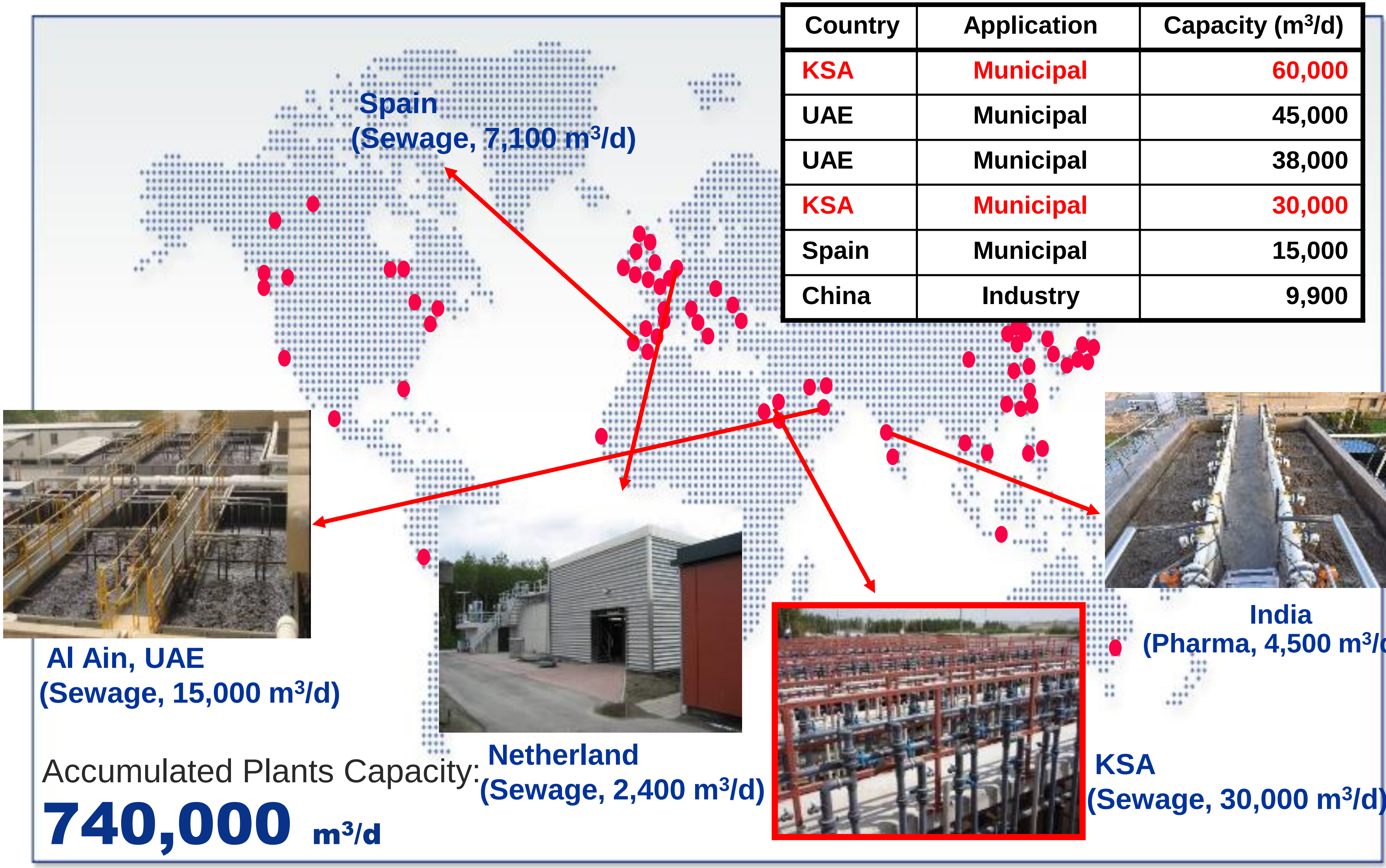
- Small footprint
- Better water quality

→Suitable for reclamation of wastewater integrated with RO membrane

Example of MBR plants

TORAY
Innovation by Chemistry

Country	Application	Capacity (m³/d)
KSA	Municipal	60,000
UAE	Municipal	45,000
UAE	Municipal	38,000
KSA	Municipal	30,000
Spain	Municipal	15,000
China	Industry	9,900



Al Ain, UAE
(Sewage, 15,000 m³/d)

Netherland
(Sewage, 2,400 m³/d)

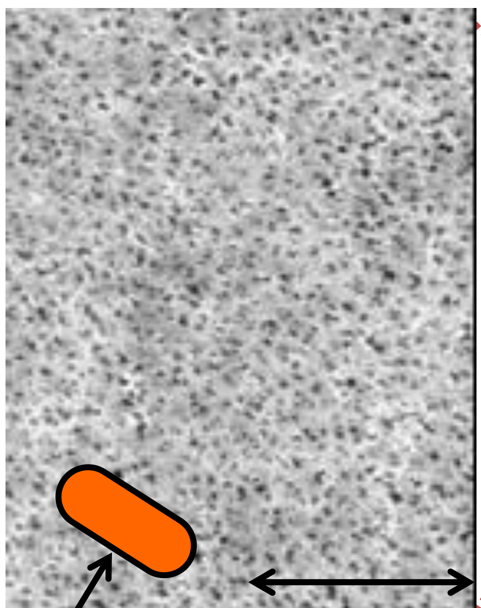
KSA
(Sewage, 30,000 m³/d)

India
(Pharma, 4,500 m³/d)

Accumulated Plants Capacity:
740,000 m³/d

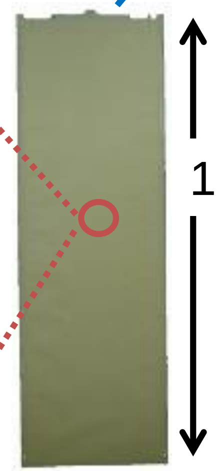
As of the end of Mar. 2019

Appearance of Toray's MBR module

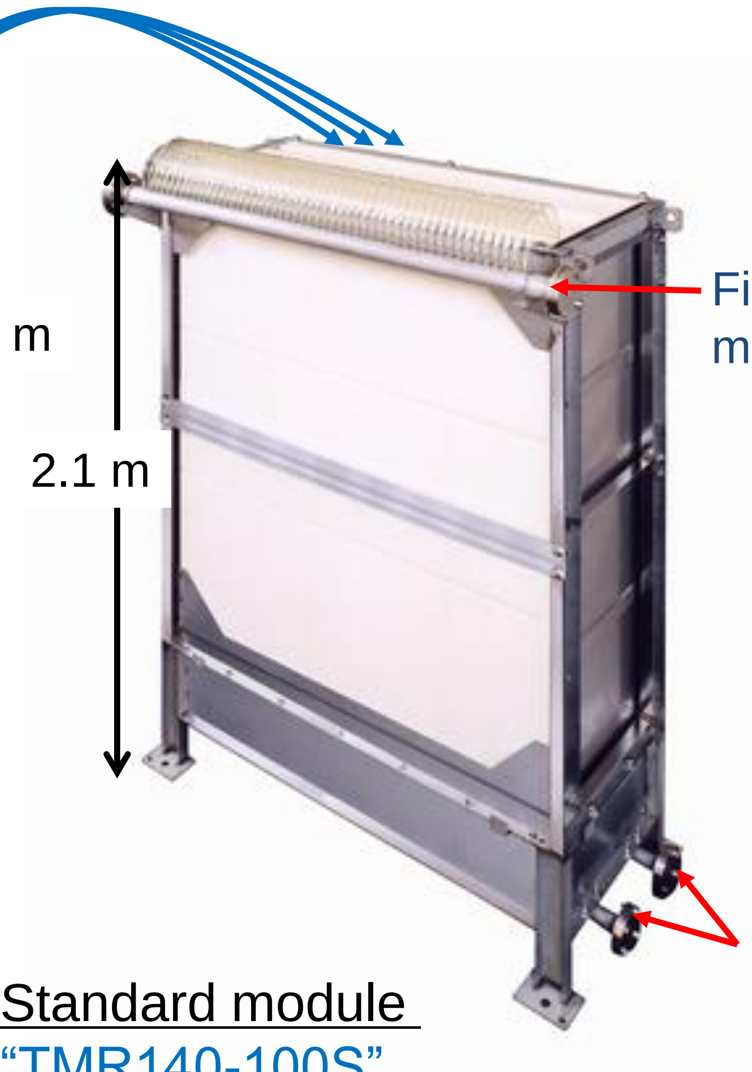


High water permeability

PVDF membrane
(pore size: 0.08μm)

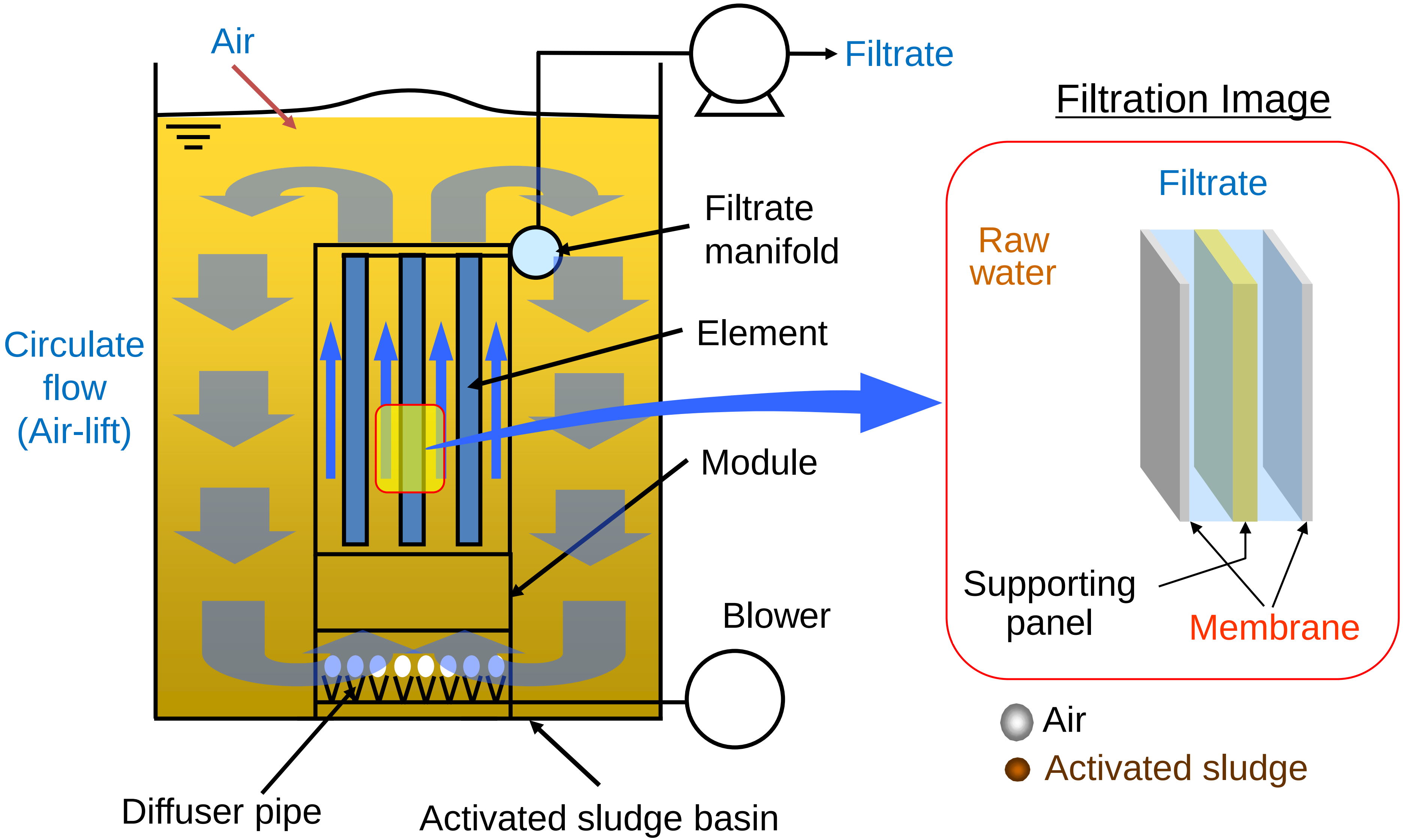


Flat sheet element
(1.4 m^2)



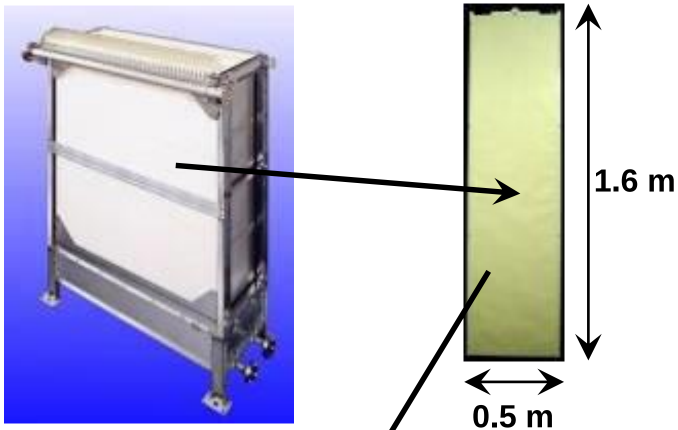
Standard module
"TMR140-100S"
(100 EL, 140m^2)

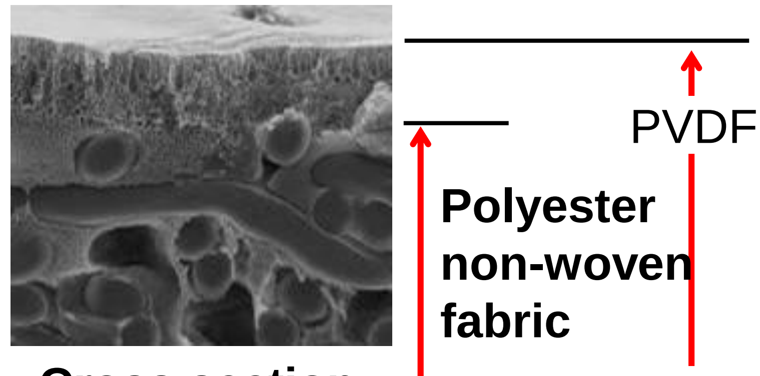
How submerged membrane module works



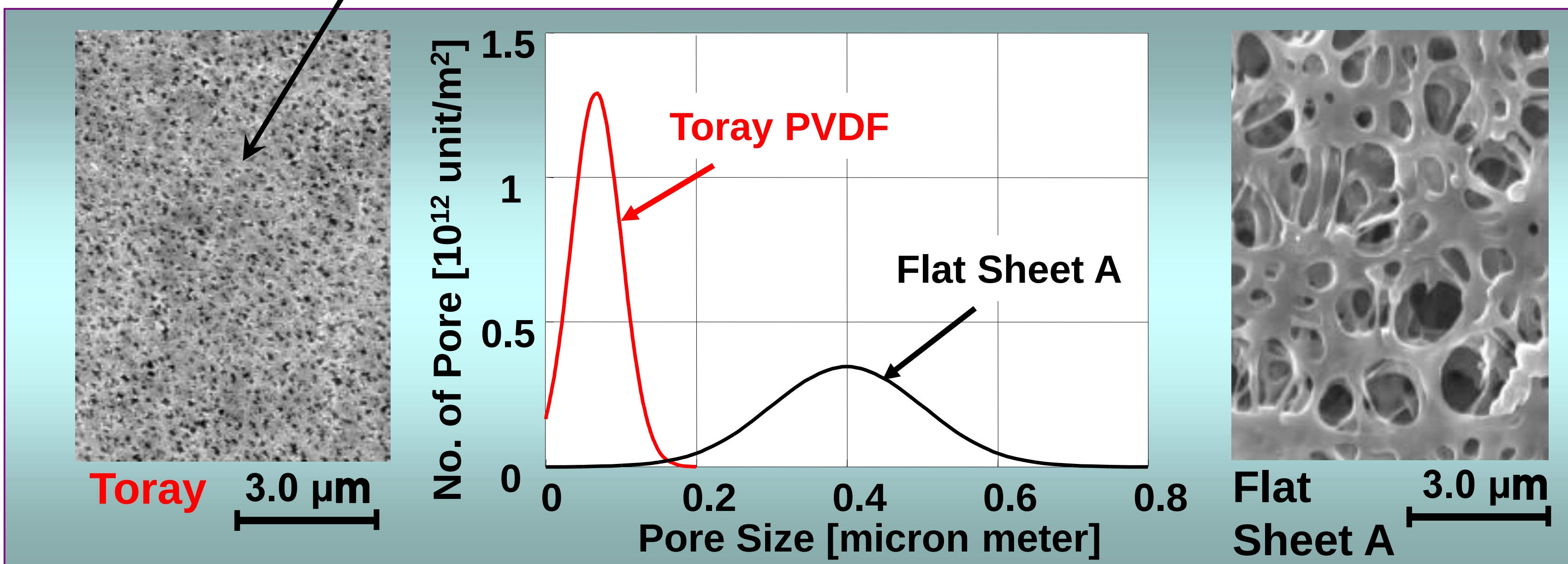
Toray PVDF flat sheet membrane for MBR

'TORAY'
Innovation by Chemistry



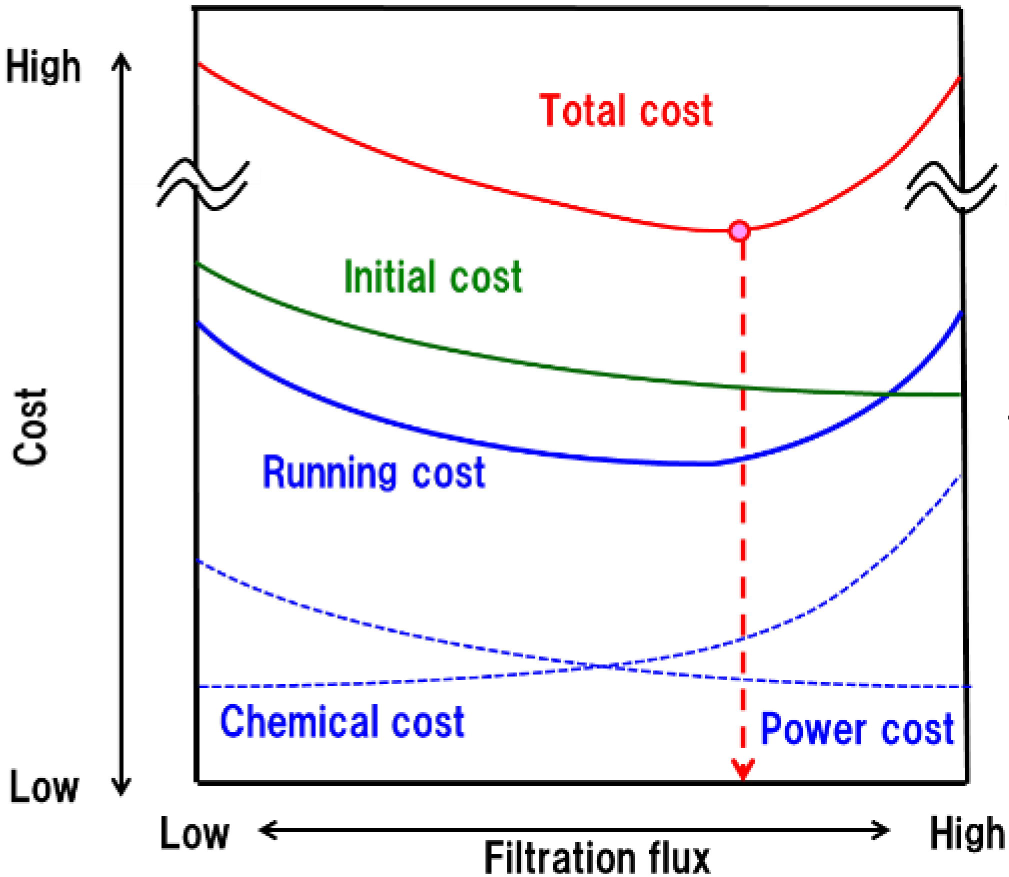


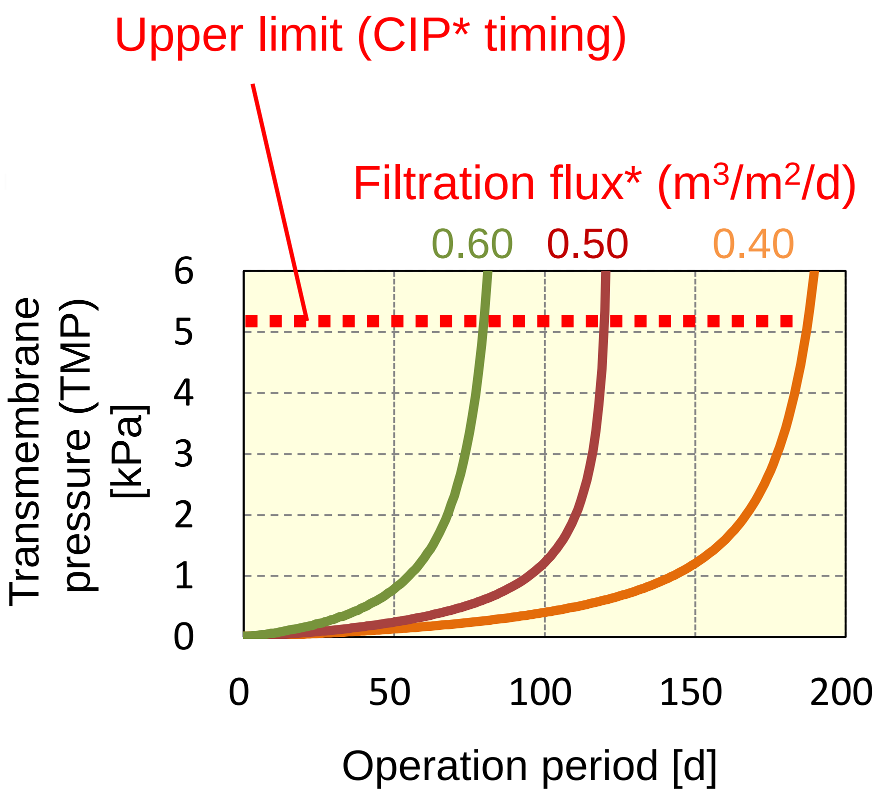
Cross section



Small pore size, narrow pore size distribution and many pores structure realizes excellent permeability and low fouling.

Importance of MBR filtration flux





***Cleaning in Place**

***Flux : flow rate per membrane area**

Determination of the filtration flux is the most important key-point for total cost.

Contents

1. Introduction

2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

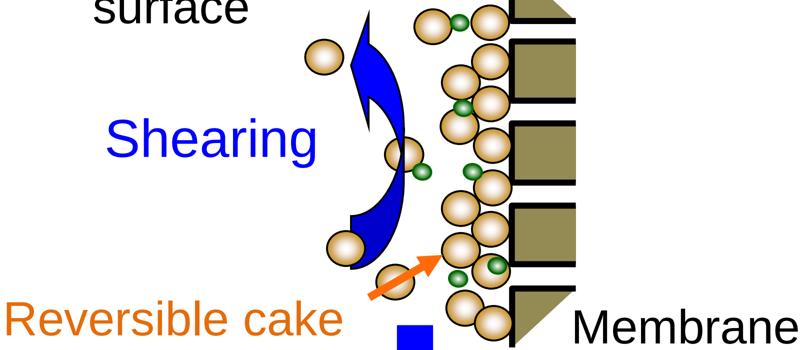
3. Validation of simulation results

4. Automatic data analysis system

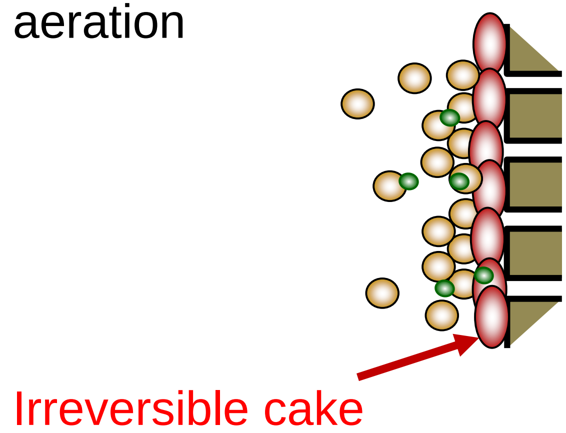
5. Conclusion

Fouling model of simulation

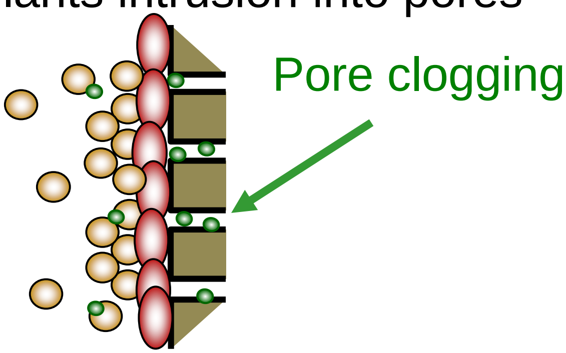
[1] “Reversible cake” formation by sludge accumulation on membrane surface

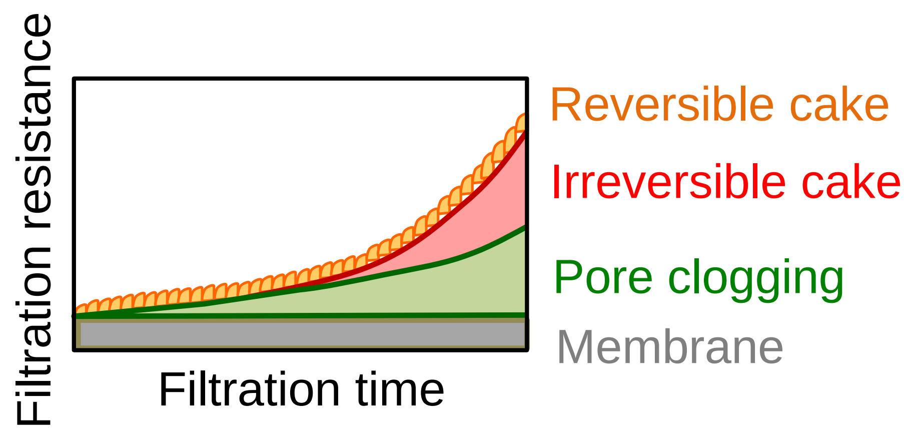


[2] “Irreversible cake ” formation impossible to be detached by aeration



[3] “Pore clogging” progression by foulants intrusion into pores





Fouling of the membrane is formed into the three types;
[1] Reversible cake, [2] Irreversible cake and [3] Pore clogging.

Basic equations of simulation

TORAY
Innovation by Chemistry

Fouling rate

[1] Reversible cake formation rate

$$\frac{dX_c}{dt} = X \cdot J \cdot \frac{K_{\tau 1}}{K_{\tau 1} + \tau} - \gamma \cdot \tau \cdot \frac{K_{\tau 2}}{K_{\tau 2} + P} \cdot \eta \cdot X_c^2$$

[2] Irreversible cake formation rate

$$\frac{dX_{c,ir}}{dt} = k \cdot \Delta P^n \cdot X_c$$

[3] Pore clogging rate

$$\frac{dX_b}{dt} = \lambda \cdot J^m \cdot \left(X_c + X_{c,ir}\right)$$

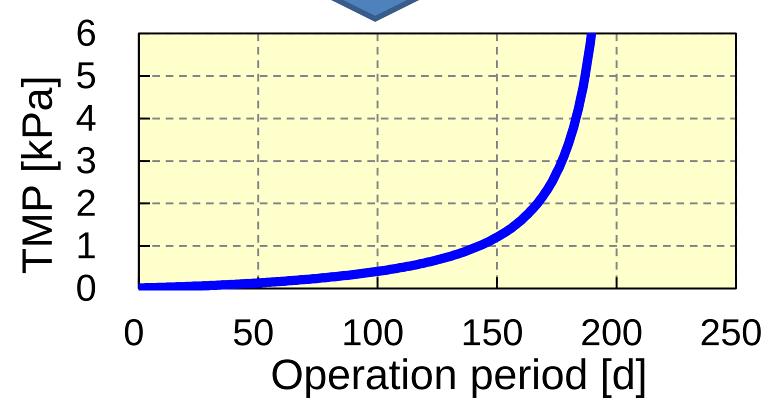
Filtration resistance

$$R_c = \alpha_2 \cdot \left(1 + \alpha_1 \cdot \Delta P\right) \cdot \left(X_c + X_{c,ir}\right)$$

$$R_b = \beta \cdot X_b^{1.5}$$

Differential pressure

$$\Delta P = \mu \cdot J \cdot (R_c + R_b + R_m)$$



Fouling parameters acquired by filtration test

- α_1 : Pressure dependency coefficient of cake
- α_2 : Resistance coefficient to the amount of cake
- $K_{\tau 1}$: Inhibition coefficient of shearing
- γ : Detachment coefficient of cake
- $K_{\tau 2}$: Friction coefficient of cake
- λ : Rate coefficient of pore clogging

Contents

1. Introduction

2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

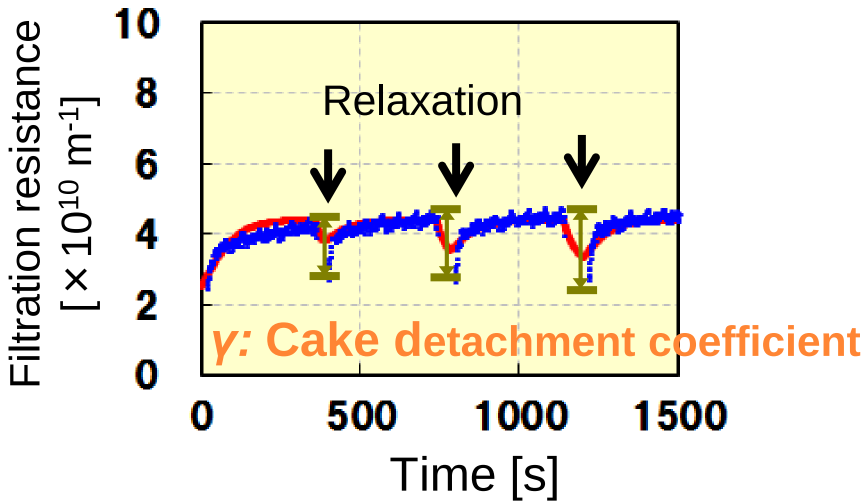
3. Validation of simulation results

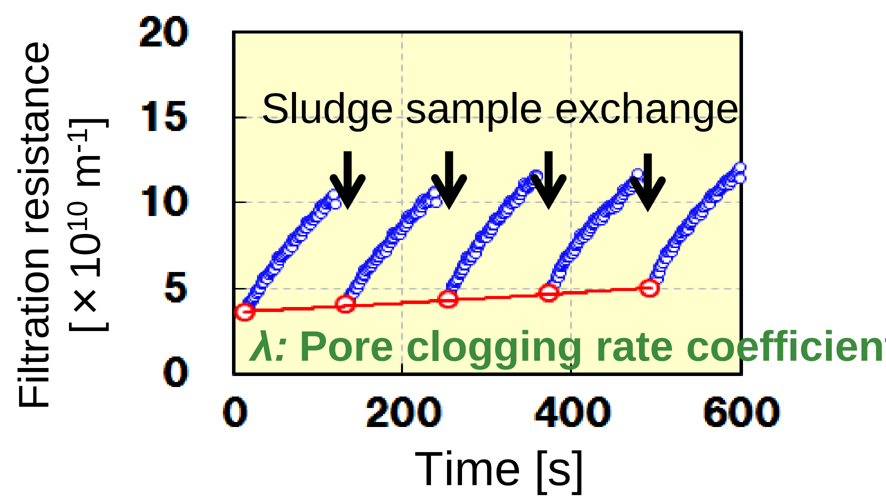
4. Automatic data analysis system

5. Conclusion

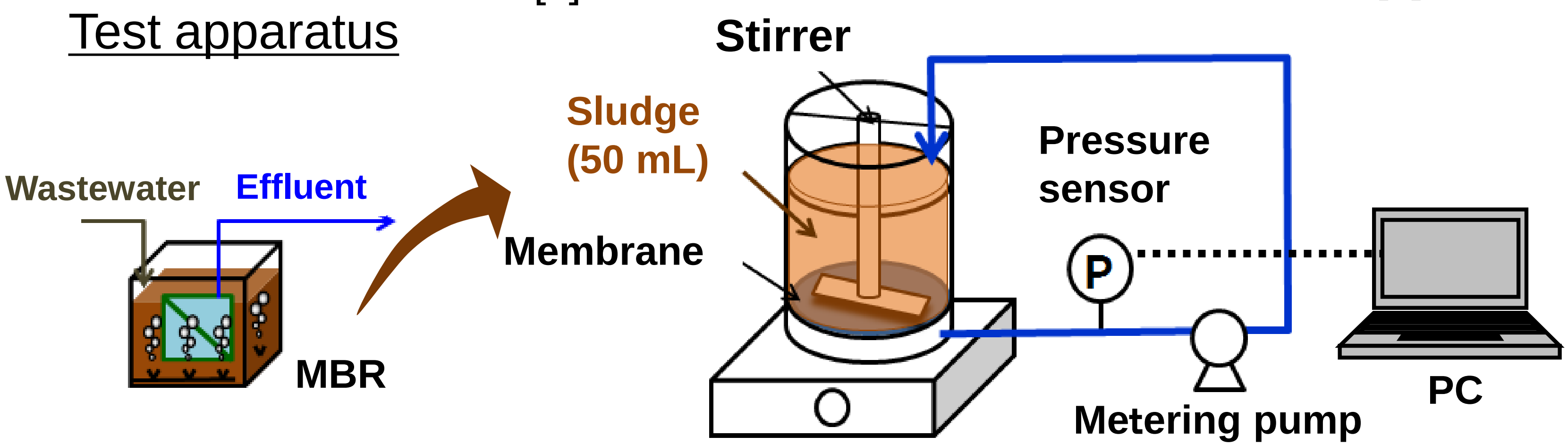
Fouling parameters acquisition method

Test example





Test apparatus



The fouling parameters are obtained through the analysis of filtration test results.

Contents

'TORAY'
Innovation by Chemistry

1. Introduction

2. **Simulation method**
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

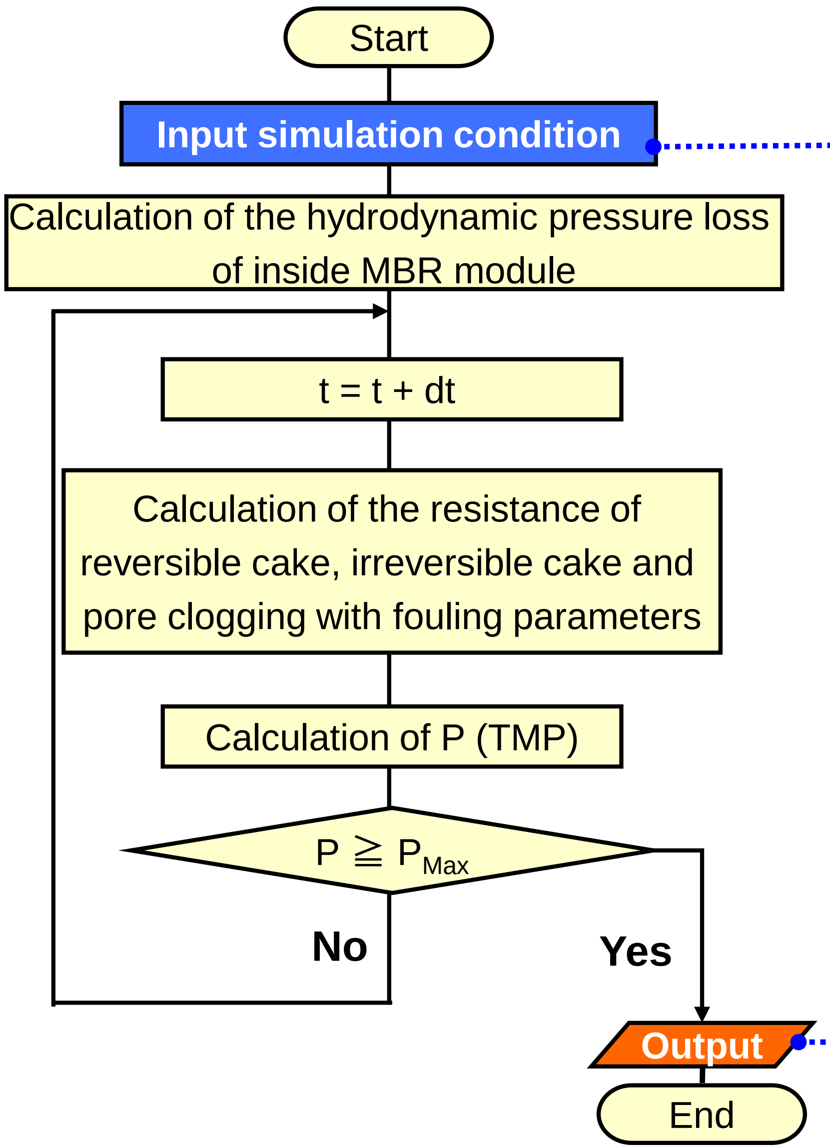
3. Validation of simulation results

4. Automatic data analysis system

5. Conclusion

Simulation program

TORAY
Innovation by Chemistry



Input contents

●Sludge characteristics

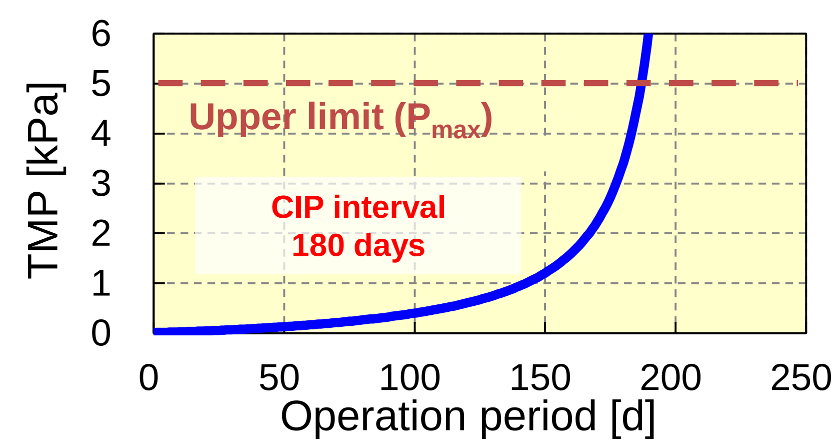
- **Fouling parameters**
  - ex. γ : Detachment coefficient of cake
  - λ : Rate coefficient of pore clogging
- **Sludge temp. MLSS**

●Operation conditions

- **Flux** ・**Aeration rate** ・**Relaxation time**
- **Maximum pressure P_{max}**

●Module specifications

Example of simulation results



Contents

1. Introduction

2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

3. **Validation of simulation results**

4. Automatic data analysis system

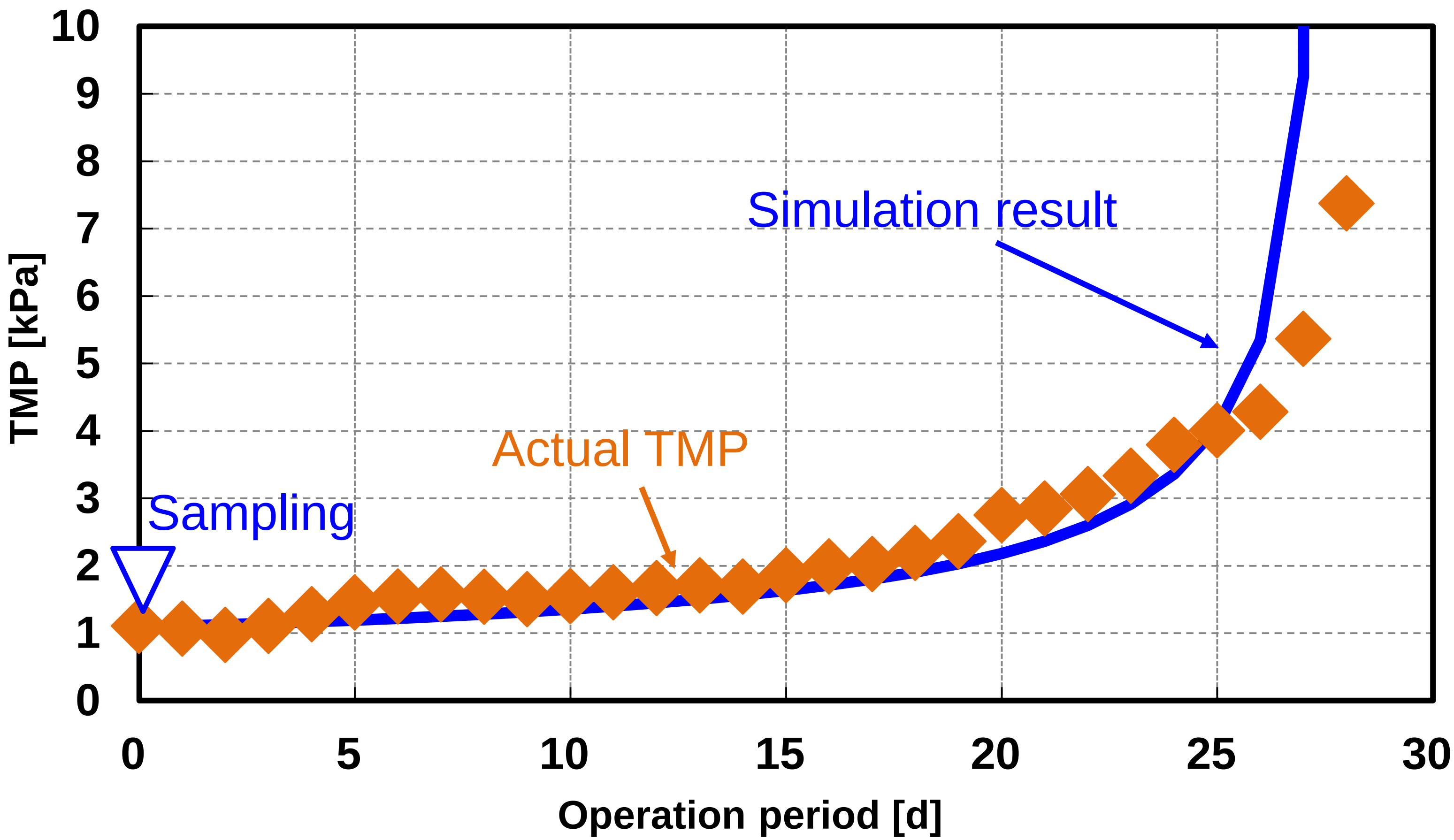
5. Conclusion

Comparison of simulation result and actual TMP

TORAY
Innovation by Chemistry

Case 1

Raw water type : Sewage (25 - 30° C)   Flux : 0.60 $m^3/m^2/d$



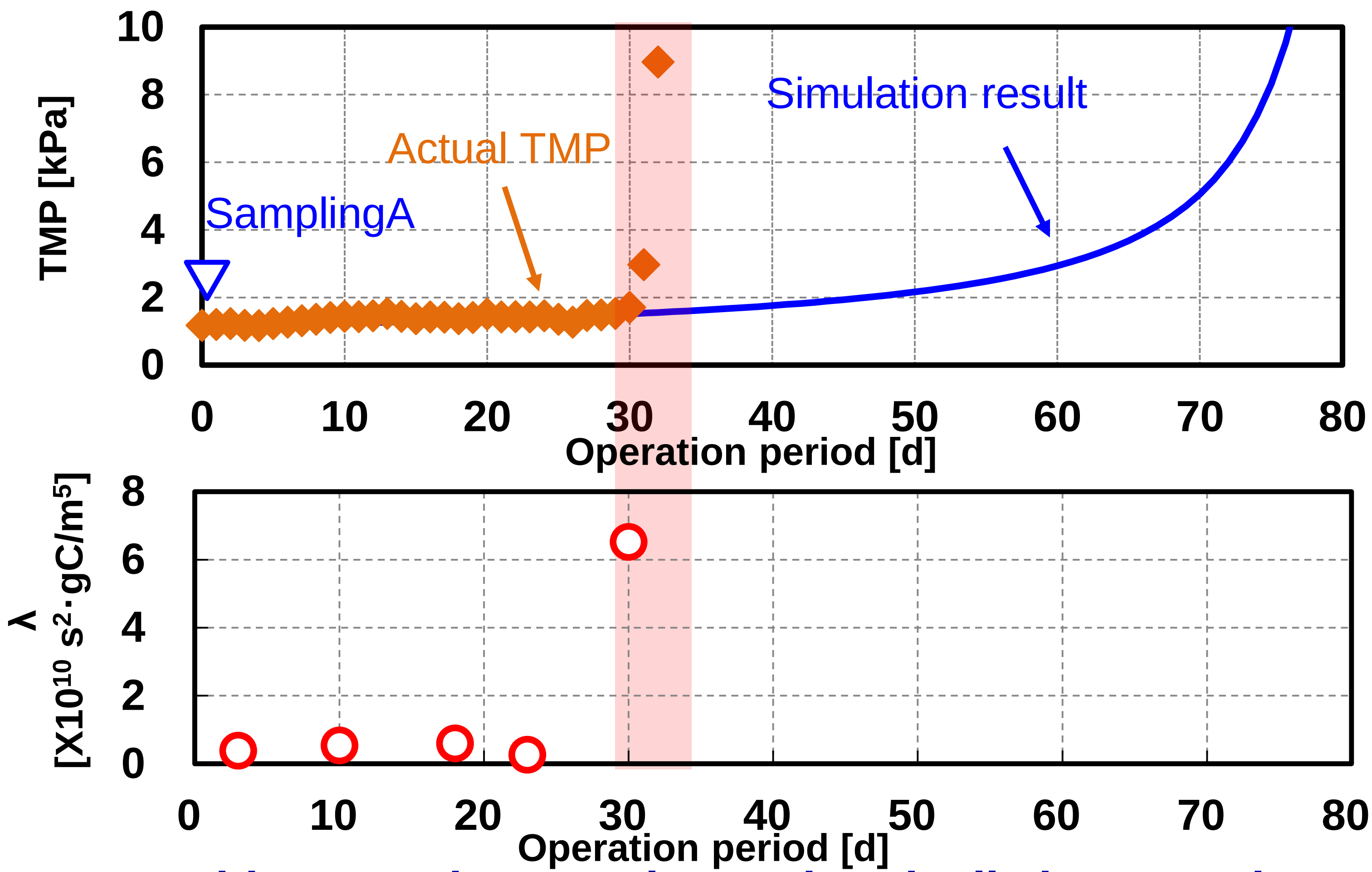
The simulation results were very close to the actual results of MBR plants.

Comparison of simulation result and actual TMP

'TORAY'
Innovation by Chemistry

Case 2

Raw water type : Sewage (22 - 28° C)   Flux : 0.60 $m^3/m^2/d$



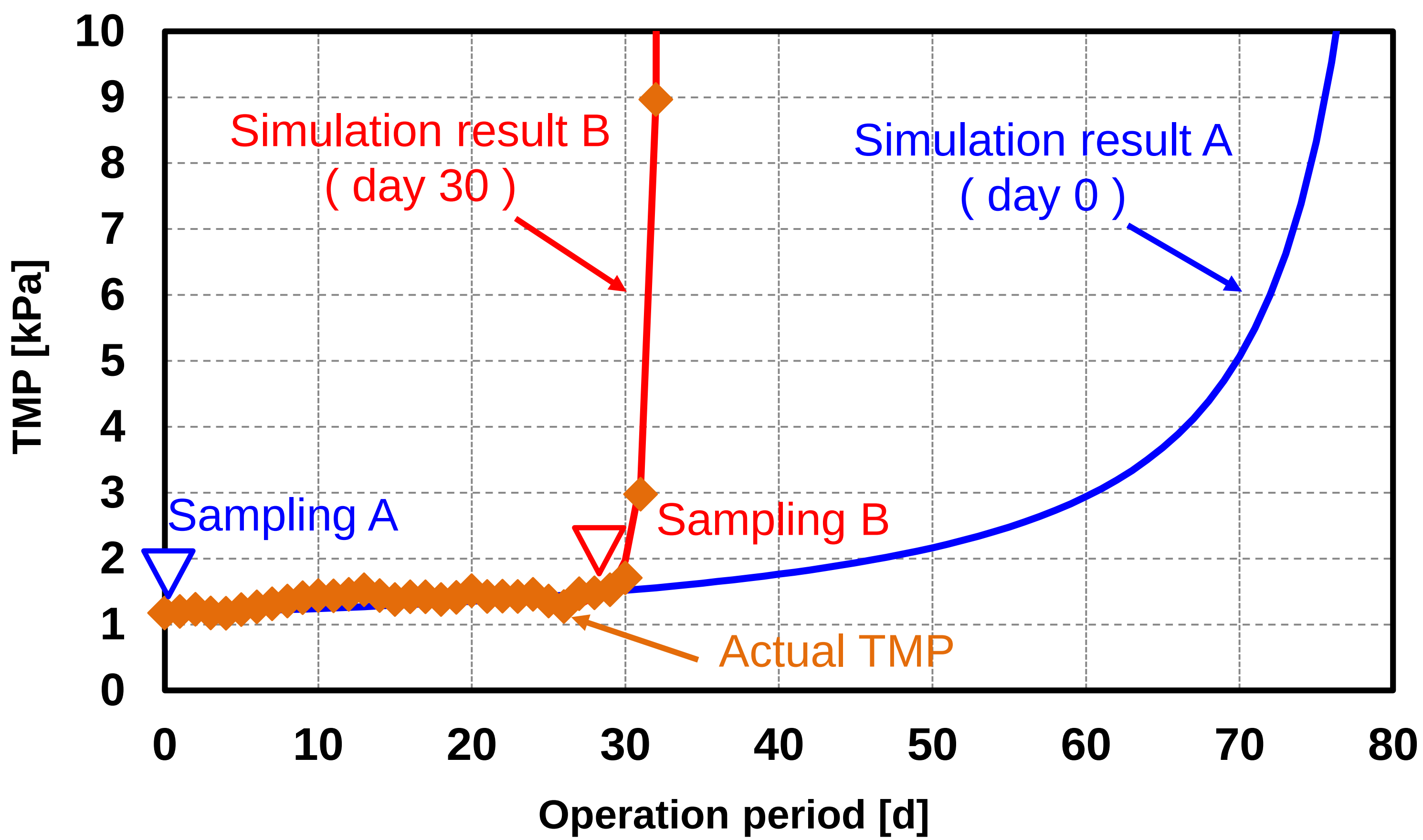
In this case, the actual TMP drastically increased because of sludge characteristics change.

Comparison of simulation result and actual TMP

'TORAY'
Innovation by Chemistry

Case 2

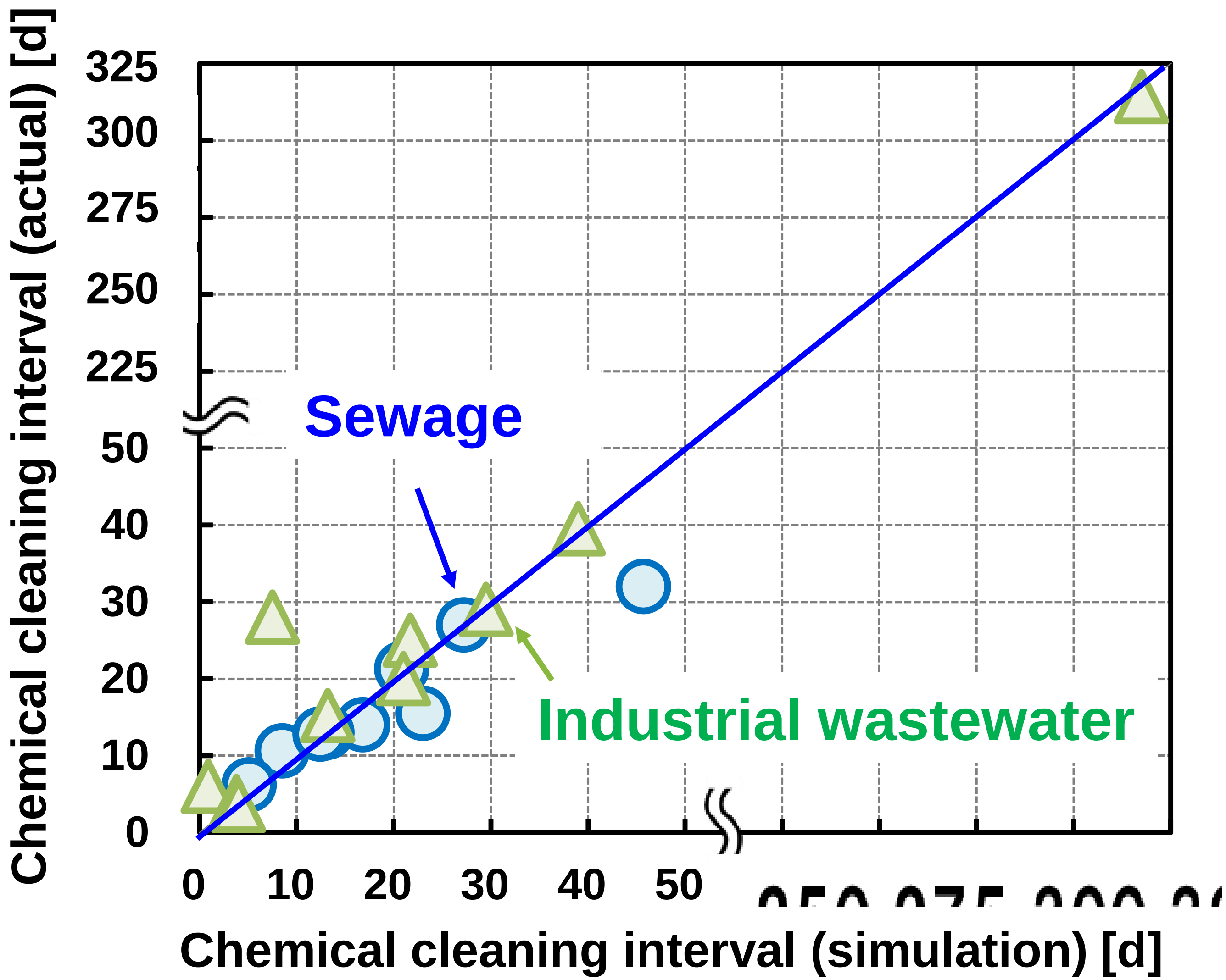
Raw water type : Sewage (22 - 28° C)   Flux : 0.60 $m^3/m^2/d$



The performance of the actual MBR plants could be estimated with simulation even when sludge characteristic change occurred.

Verification of MBR simulation results

TORAY
Innovation by Chemistry



The optimal flux can be calculated by the simulation technology.

Contents

1. Introduction

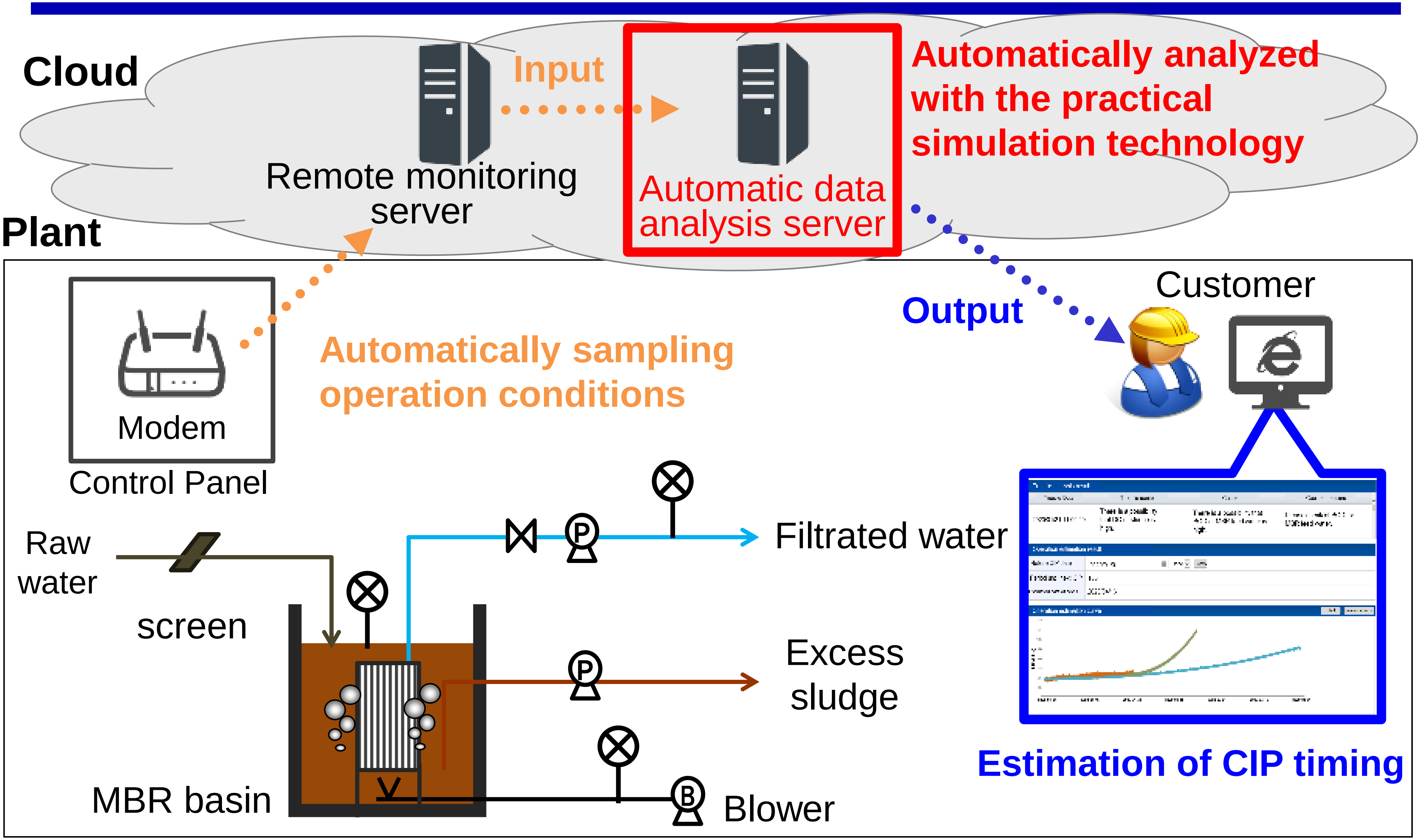
2. Simulation method
   2.1 Fouling model
   2.2 Fouling parameters acquisition method
   2.3 Simulation program

3. Validation of simulation results

4. Automatic data analysis system

5. Conclusion

Automatic data analysis system (ICT)



Operation of MBR plant can be supported by estimation of CIP timing with simulation.

Estimation of CIP timing

'TORAY'
Innovation by Chemistry

Trouble analysis result

Trouble Date	Trouble con...
2020/01/31 11:00:00	There is a possibility that DO of sludge is high.

Trouble Analysis:
Indication of trouble occurrence, cause and countermeasure

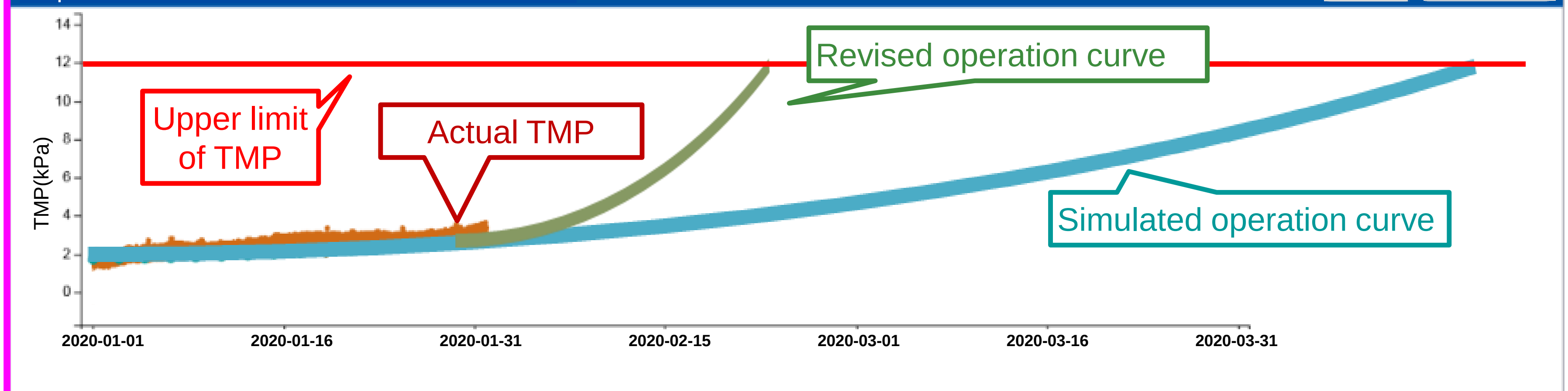
Operation estimation result

Before CIP date	2020/01/01
Period until next CIP	106
Estimated date of next CIP	2020/04/16

Operation estimation:
Indication of differential pressure increase curve and CIP timing.

Operation estimation curve

Shift | Reference curve



This system enables estimation of CIP timing and trouble analysis.

Conclusion

- The practical quantitative simulation technology to predict MBR TMP behavior was developed utilizing the original fouling models with fouling parameters.

- The simulation results were very close to the actual results of MBR plants.

- This simulation technology would be very useful for the optimal design and operation conditions of MBR process to minimize the total cost.

- The combination of the simulation technology and ICT greatly supports MBR operation by estimation of CIP timing.

Thank you for your attention.

TORAY

Innovation by Chemistry