Performance of Hybrid Submerged Membrane Bioreactor Combined with Pre-Coagulation/Sedimentation

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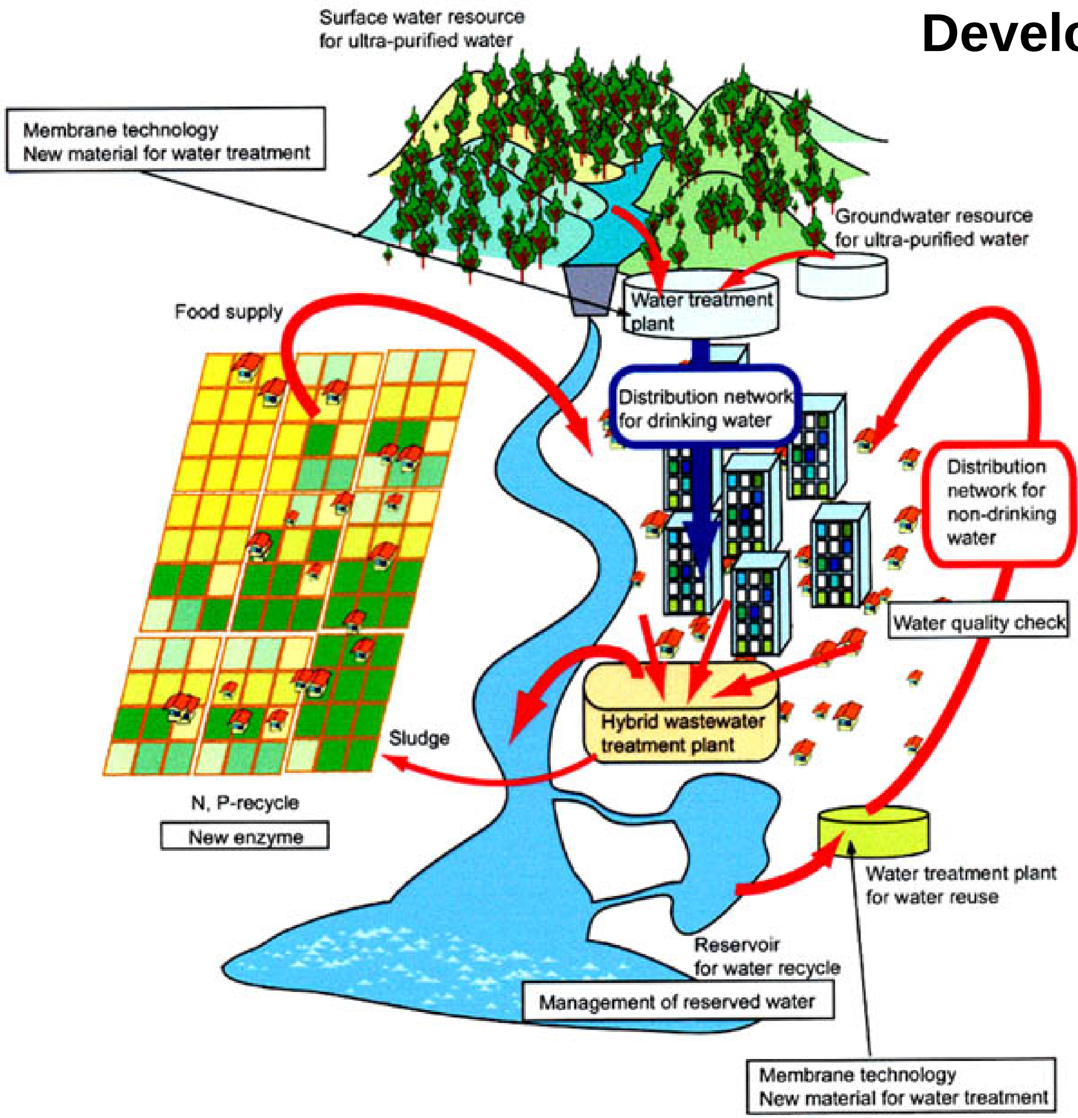
New urban water metabolic system



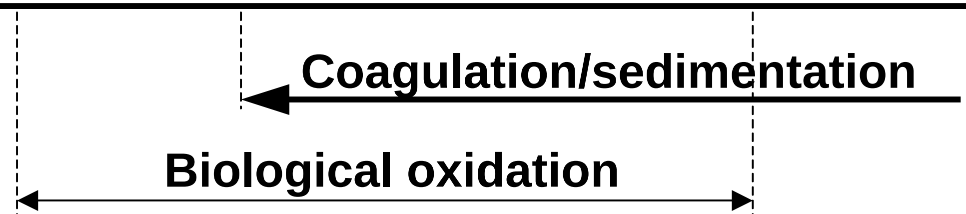
Development of elemental technology

- Advanced water purification process for membrane filtration
- Development of hybrid wastewater treatment system
- Effective utilization and recycling of wastewater treatment sludge

The major part of the contaminants in municipal wastewater is associated with particles

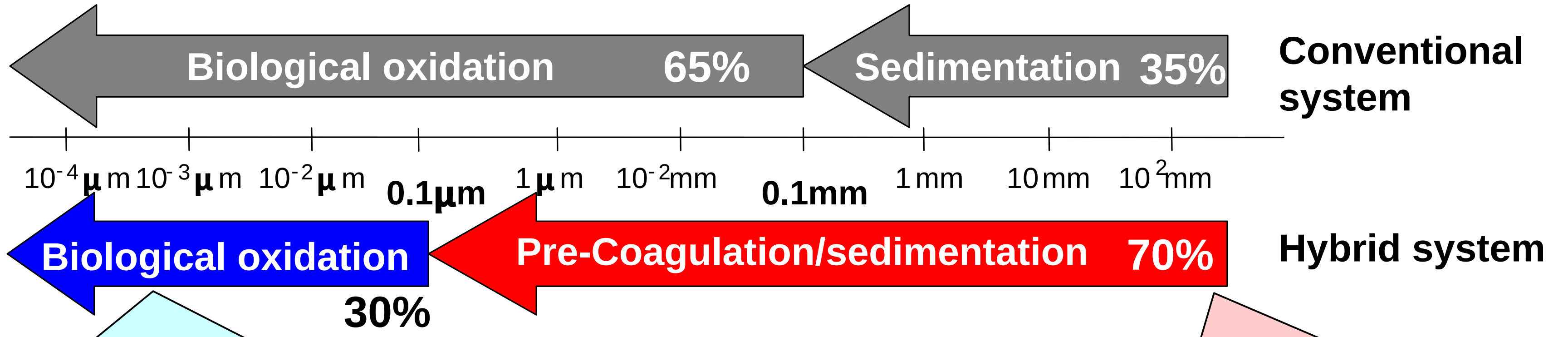
Upper; size (μm) Lower; % of total

		Classification			
		Soluble	Colloidal	Supra colloidal	Settle able
Marani et al., 2003.	COD 162 - 392 mg/L	< 0.2 13 - 28		0.2 < 72 - 87	
Levine et al., 1985.	TOC 76.5 mg/L	< 0.1 30		0.1 < 70	
Itokawa et al., 2003.	Sewage COD 480 mg/L	< 0.1 22		0.1 < 78	
	Primary clarifier effl. COD 187 mg/L	< 0.1 39		0.1 < 61	
Balmat., 1957.	BOD 315 mg/L	<0.08 40	0.08-1 16	1-100 28	100 < 15
	Biological oxidation rate 0.22 1/day	<0.08 0.39	0.08-1 0.22	1-100 0.09	100 < 0.08



Hybrid wastewater treatment system

Treatability of organic matter



- **Biological oxidation**
  - **Rotating Biological Contactor (RBC)**
  - **Submerged membrane Bioreactor (MBR)**
- **Structure and function analysis of microorganism community.**

- **New coagulant**
  - **Poly Silicato Iron (PSI)**
- **Simple and economical coagulation/sedimentation unit**
  - **Jet Mixed Separator (JMS)**

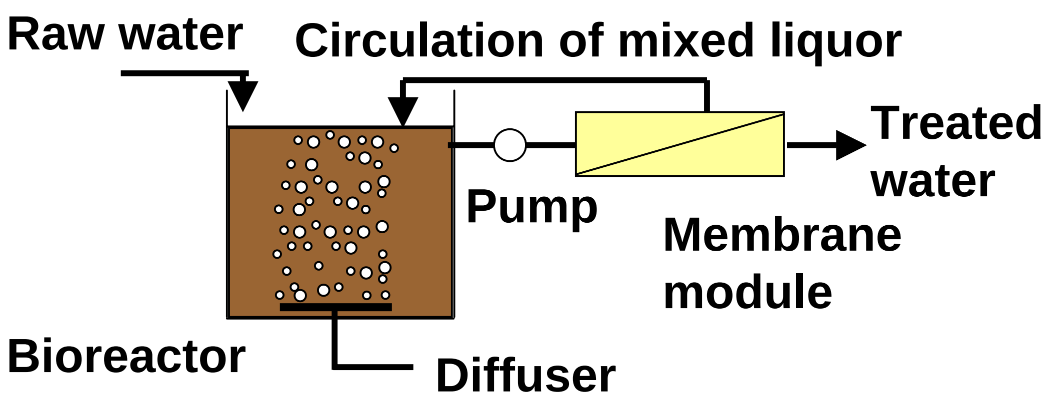
- **Water reuse**
  - **Risk analysis of treated water**
  - **Pathogens, Micro pollutants,**
  - **Growth potential of microorganisms**

Sludge treatment

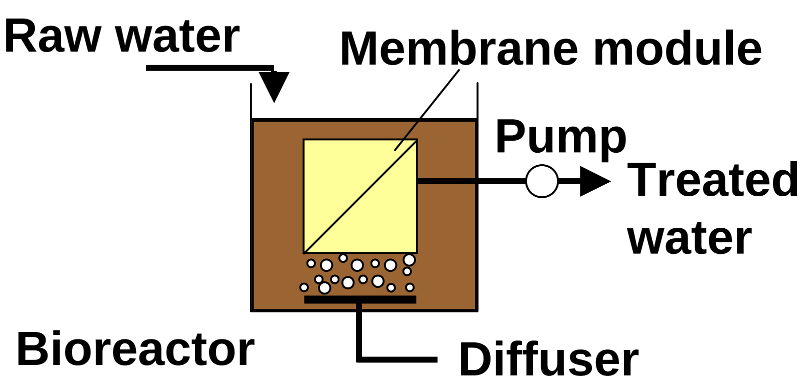
- **Energy recovery**
- **Phosphorus recovery**
- **Risk assessment (Heavy metal, Virus, Pathogens)**

Classification of MBR

Cross-flow MBR 1970〜

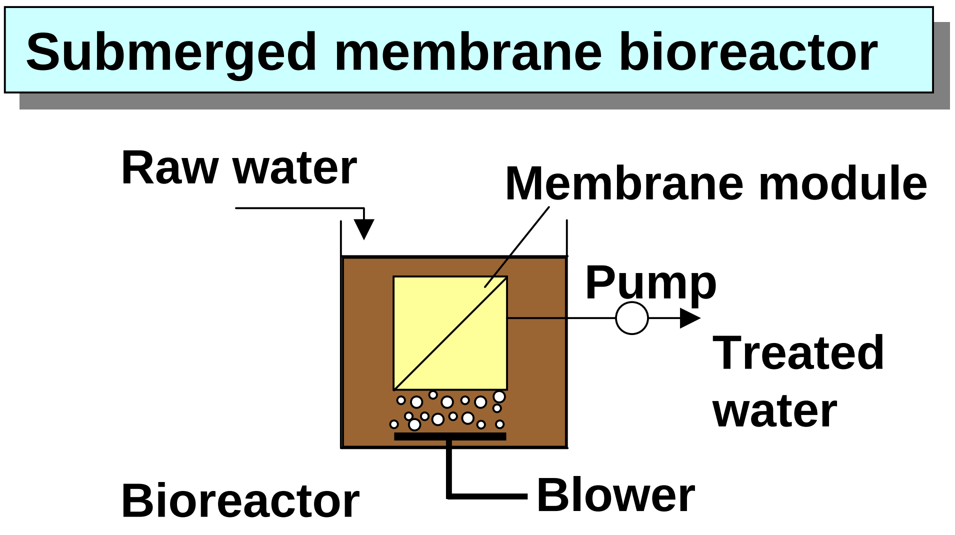


Submerged MBR 1990〜



		CF-MBR	S-MBR
Energy consumption	(kWh/m^3)	2 – 10	0.2 – 0.4
Operating pressure	(kPa)	100 – 200	< 50
Permeate flux	(m^3/m^2/day)	1 – 2	0.1 – 0.5
Membrane		UF	MF

Submerged membrane bioreactor



Advantages

- High quality of treated water
- High solid/liquid separation
- Smaller footprint

Disadvantage

- **Membrane fouling**

  caused by dissolved organic matter (DOM)

Previous studies by other researchers

- Laboratory scale experiment
- Short-tem experiment
- Synthetic wastewater

It is not clear whether experimental results obtained in the previous studies can be applied to operation of real-world MBRs.

Objectives

Hybrid submerged membrane bioreactor

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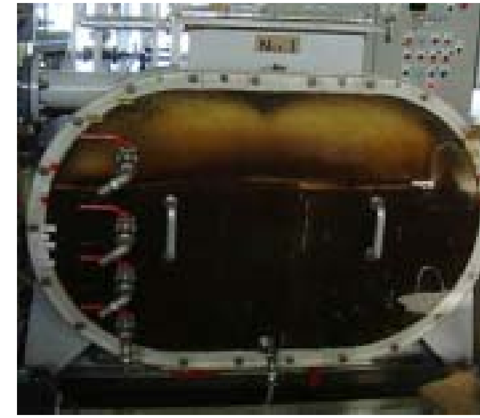
Pre-coagulation/sedimentation and membrane bioreactor

- **Pilot scale experiments were carried out to investigate;**
  - **Effect of pre-coagulation/sedimentation on MBR in terms of permeate quality and membrane fouling.**
  - **Influence of dissolved organic matter (DOM) on membrane fouling in MBR.**

Hybrid MBR system

Coagulation/sedimentation unit

Jet Mixed Separator



Rotating disc membrane (UF)

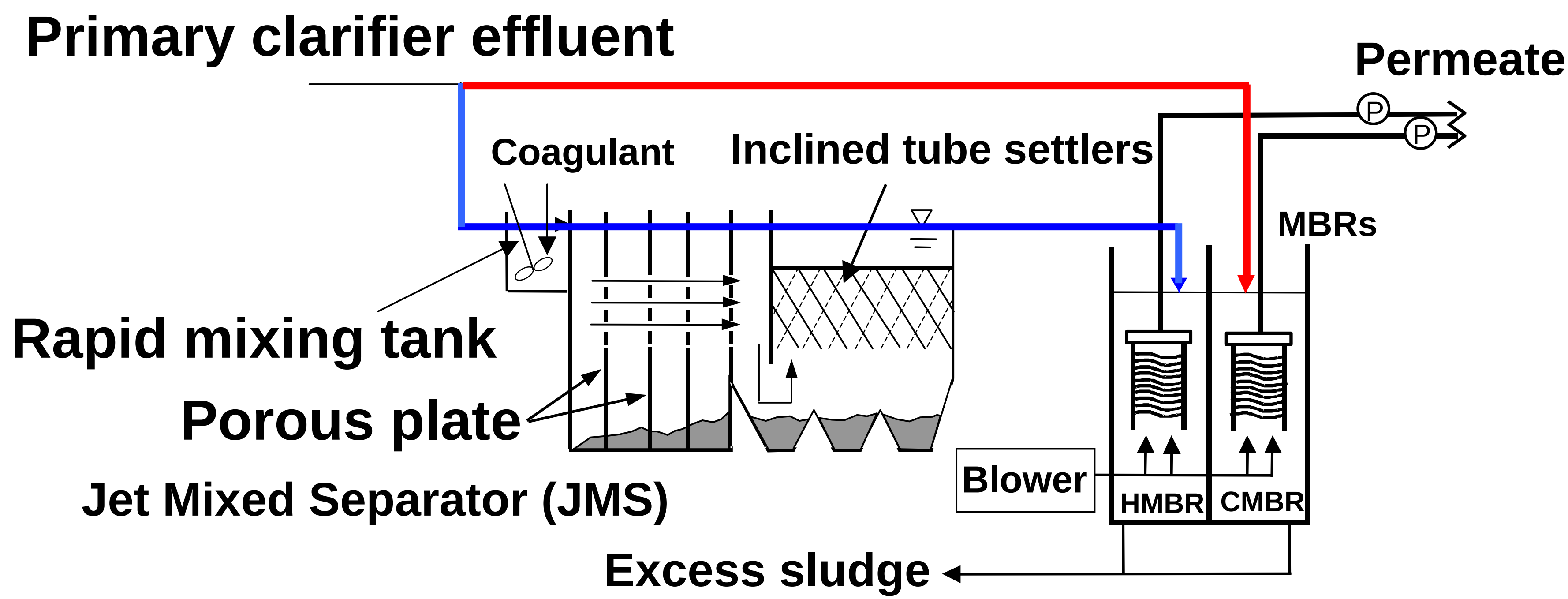
Follow fiber membrane (MF)

VSEP (NF)

Flat membrane (MF)

Submerged membrane bioreactor

Flow diagram of the pilot plant



Operating conditions of the JMS

Flow rate 50 m^3/day

HRT 1.5 hr

Coagulant

PSI : Poly Silicato Iron

10 mg-Fe/L

Conventional MBR (CMBR)
Primary clarifier effluent – MBR

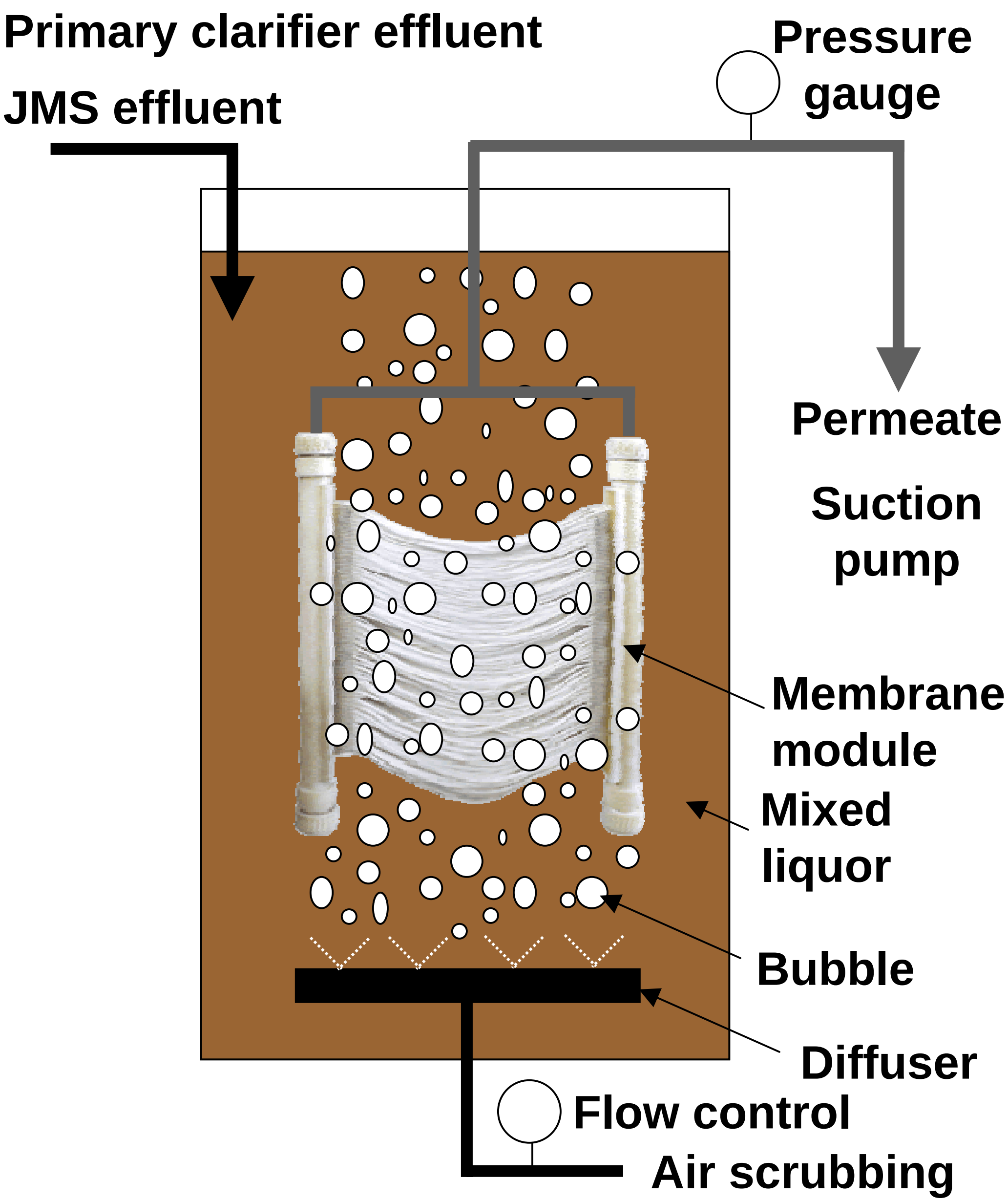
Hybrid MBR (HMBR)
Primary clarifier effluent – JMS – MBR

Characteristics of the raw water fed to MBRs

		Primary clarifier effluent	JMS effluent	Removal efficiency (%)
Turbidity	(NTU)	53.2	9.0	83
TOC	(mg/L)	35.3	16.7	53
DOC	(mg/L)	20.6	12.9	37
T-N	(mg/L)	29.7	20.7	30
NH_4^-+N	(mg/L)	13.6	12.1	11
T-P	(mg/L)	2.6	0.6	77
Alkalinity	(mg/L)	127.6	87.5	-
pH		7.1 - 8.5	6.3 - 7.2	

Removal efficiency in terms of turbidity, TOC, and T-P determined for pre-coagulation/sedimentation was attained to 83%, 53%, and 77%, respectively.

Submerged membrane bioreactor



•MBR

Effective volume 180 L×4

•Characteristic of membrane

Module Hollow fiber membrane

Pore size 0.2 0.4 μm

Area 3 m^2

Material Polyethylene

•Suction mode

Suction for 12 min., stop for 3 min.

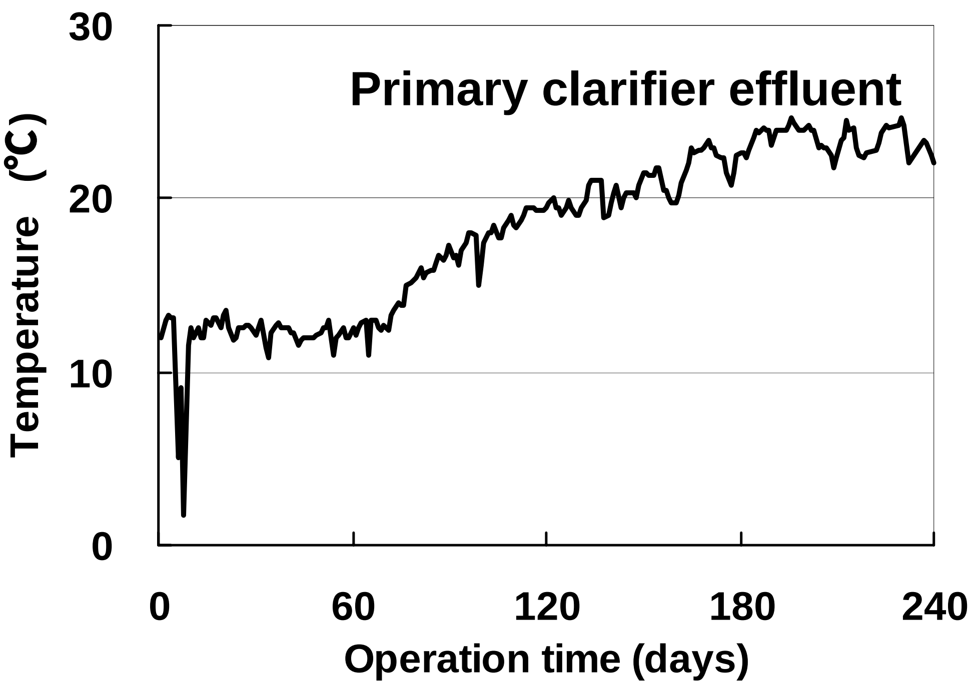
•Air scrubbing condition

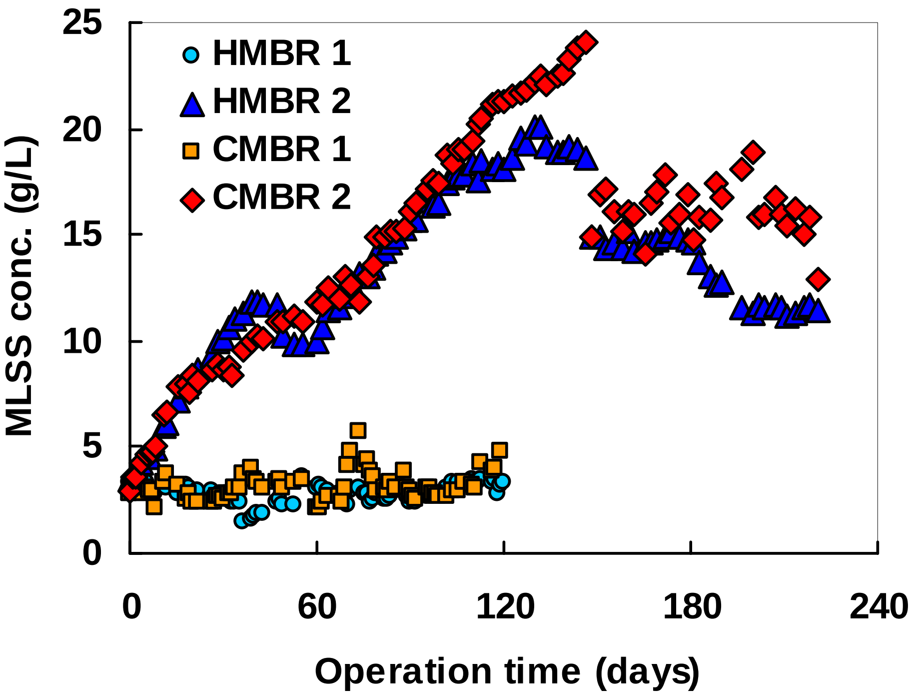
Continuous or Intermittent mode

Operating conditions of the MBRs

		HMBR 1	HMBR 2	CMBR 1	CMBR 2
HRT	(hour)	4.5-6.0	3.6-4.5	4.5-6.0	3.6-6.0
MLSS conc.	(g/L)	2 - 4	10 <	2 - 4	10 <
MLVSS/MLSS		0.6	0.6	0.7	0.7
Flux	(m/day)	0.3-0.4	0.4-0.5	0.3-0.4	0.3-0.5
Pore size	(μm)	0.4			

Changes in water temperature and MLSS concentrations.



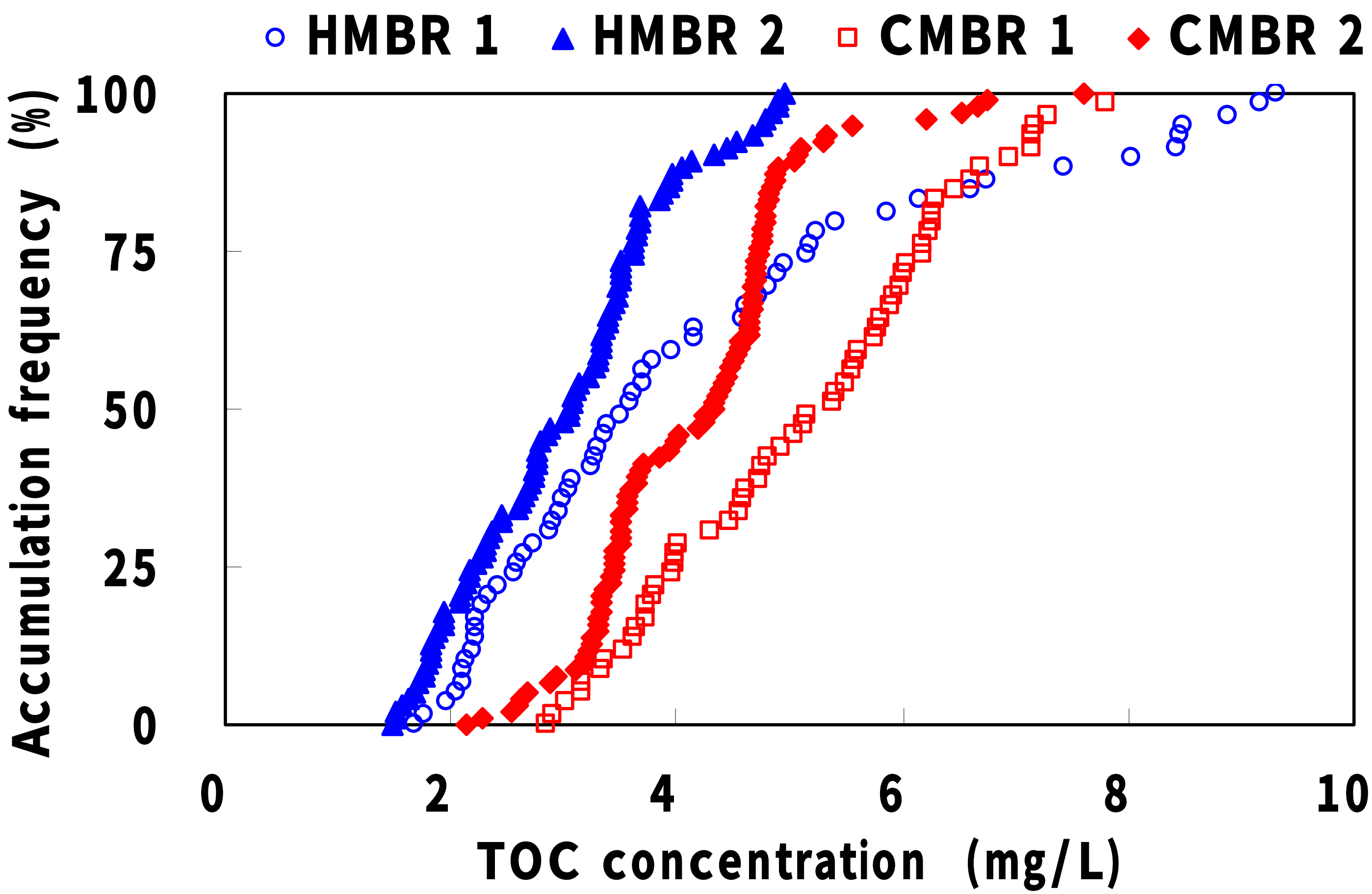


- MLSS concentration in HMBR1 and CMBR1 was attempted to be kept around 2 – 4 g/L.

- Until 148 days of the operation, MLSS concentration in HMBR 2 and CMBR 2 was not controlled and consequently increased with operation time.

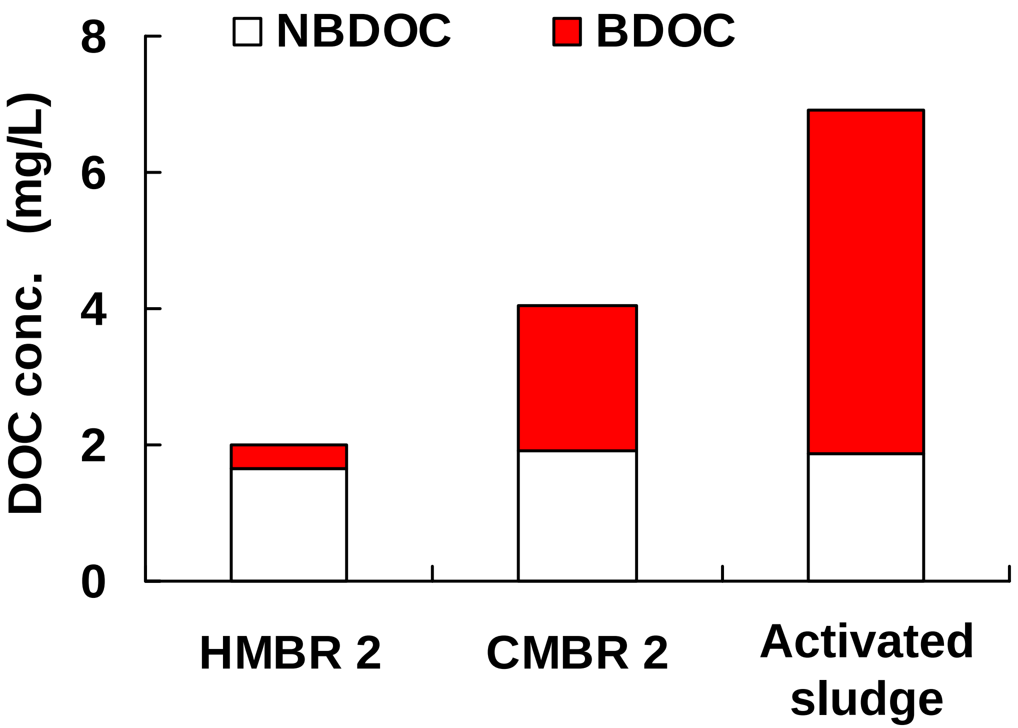
- After day 148, MLSS concentration in HMBR2 and CMBR2 was attempted to be kept around 15 g/L

Accumulation frequency of TOC concentration in the permeate



Average TOC concentration in the permeate obtained from HMBR2 was 3.0 mg/L.

Biodegradability of DOC in the treated water



Temperature 13.7 ℃

MLSS concentration

HMBR 2 10.9 g/L

CMBR 2 12.4 g/L

Activated sludge 2.0 g/L

HRT of MBR 4.5 hr.

Biodegradable organic carbon (BDOC)

HMBR 2 < CMBR 2 < Activated sludge

Non-biodegradable organic carbon

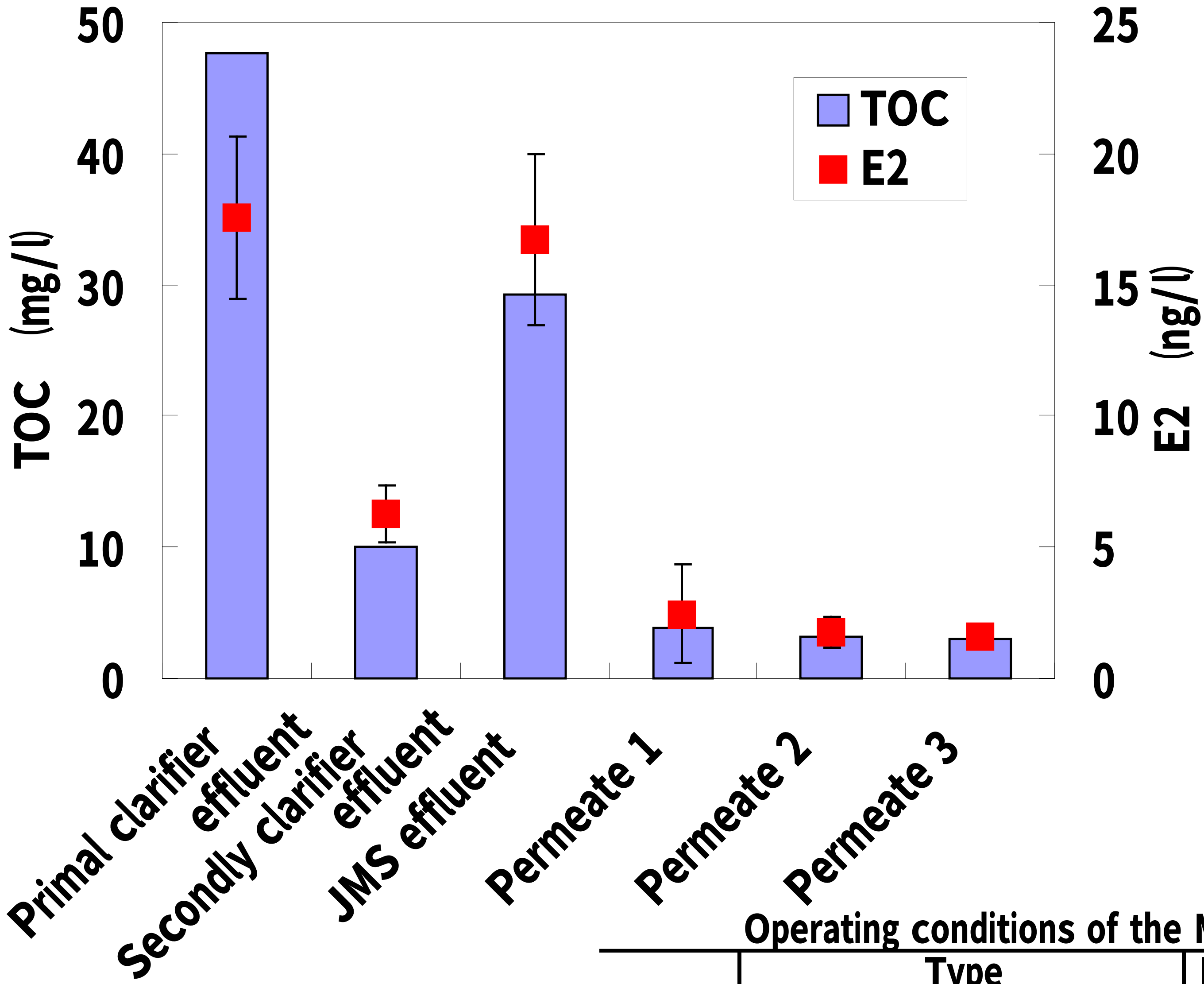
HMBR 2 = CMBR 2 = Activated sludge

BDOC concentration in the treated water obtained from HMBR2 was almost zero.

Water quality in various processes

		Primary clarifier effluent	JMS Effluent	Permeate			
				HMBR 1	HMBR 2	CMBR 1	CMBR 2
Turbidity	(NTU)	53.2	9.0	0.0	0.0	0.0	0.0
TOC	(mg/L)	35.3	16.7	4.6	3.0	5.0	4.2
T-N	(mg/L)	25.4	17.9	16.9	16.5	18.8	18.4
NH_4^+ - N	(mg/L)	13.6	12.1	3.1	1.8	0.7	0.6
T-P	(mg/L)	2.6	0.6	0.03	0.03	0.39	0.58
Alkalinity	(mg/L)	127.6	87.5	8.8	4.0	20.7	27.0
pH		7.1-8.5	6.3-7.2	4.3-7.4	4.0-7.0	6.3-7.4	6.0-7.6

Concentration of 17β-estradiol (E2) in various processes



Operating conditions of the MBRs

	Type	MLSS	HRT
MBR 1	Hollow fiber (MF : HMBR)	5 g/l	4.5 h
MBR 2	Flat type (UF : HMBR)	8 g/l	2 h
MBR 3	Flat type (MF : HMBR)	15 g/l	4.8 h

ELISA was used to determine 17β-estradiol concentration.

Effect of microbial activity on E2 concentration

Sample		E2 (ng/l)	DOC (mg/l)
No.1	Dissolved E2 of mixed Liquor	0.95	4.05
	Extracted from activated sludge	12.10	—
	Permeate	1.06	2.78
No.2	Dissolved E2 of mixed Liquor	7.07	16.24
	Extracted from activated sludge	20.84	—
	Permeate	3.49	4.27
A.S	Dissolved E2 of mixed Liquor	9.90	16.63
	Extracted from activated sludge	8.36	—

Operating conditions of the hollow fiber MBRs			
No.1	HMBR	: MLSS 8g/l	: HRT 5.2h
No.2	CMBR	: MLSS 8g/l	: HRT 6h

Evaluation of membrane fouling

Definition of membrane fouling

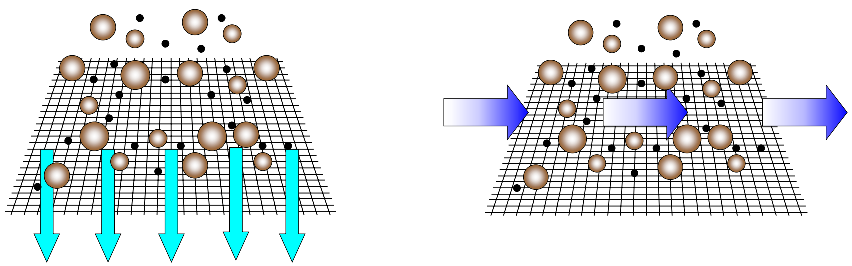
•Reversible fouling can be canceled by physical membrane cleaning.

Membrane module was taken out from the membrane chamber and washed by spraying pressurized water.

•Irreversible fouling can be canceled by chemical membrane cleaning.

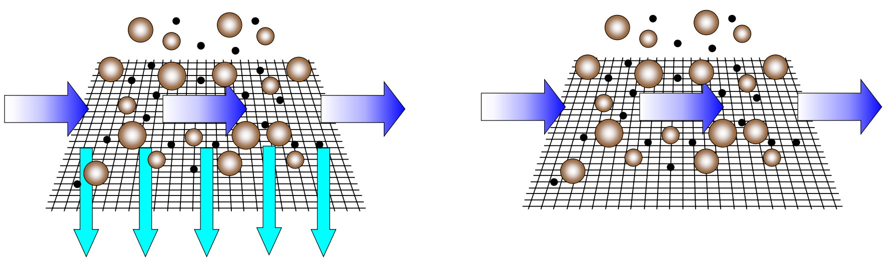
Membrane module was soaked in hydrochloric acid (pH2) and subsequently in solution of sodium hypochlorite for 24 hours.

Intermittent air scrubbing



Suction for 12 min. Stop for 3 min.

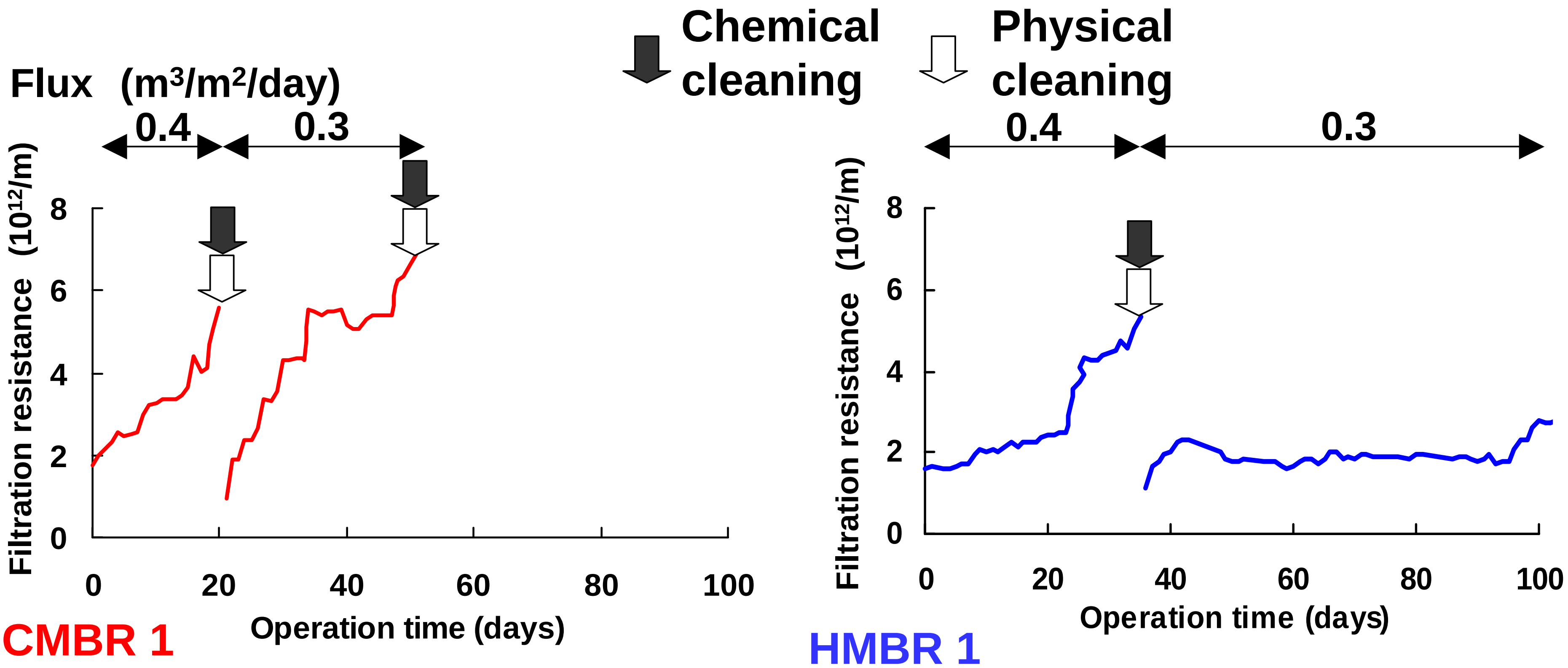
Continuous air scrubbing



Suction for 12 min. Stop for 3 min.

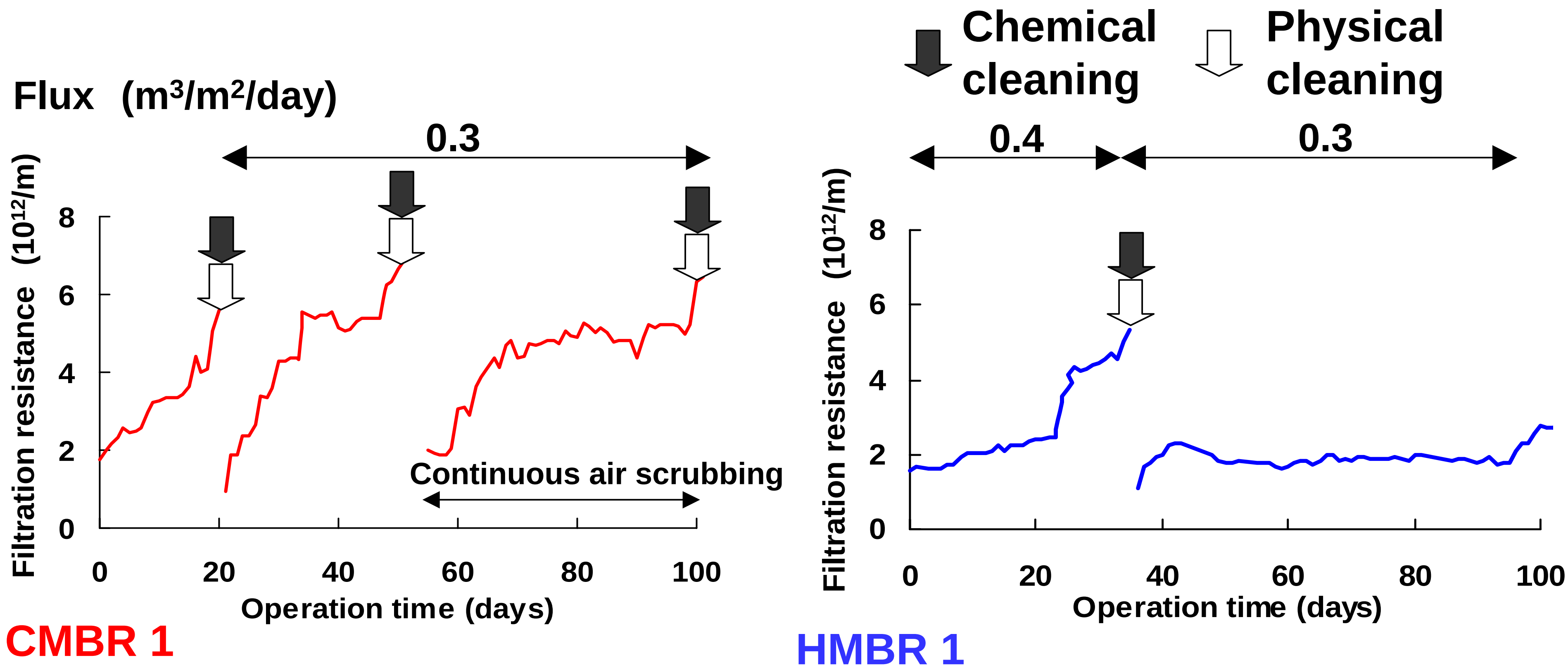
Air scrubbing   Permeate

Membrane permeability (MLSS conc. 2 - 4 g/L)



By reducing permeate flux, rapid increase of filtration resistance in CMBR1 was observed while increase rate of filtration resistance in HMBR1 was retarded.

Membrane permeability (MLSS conc. 2 - 4 g/L)

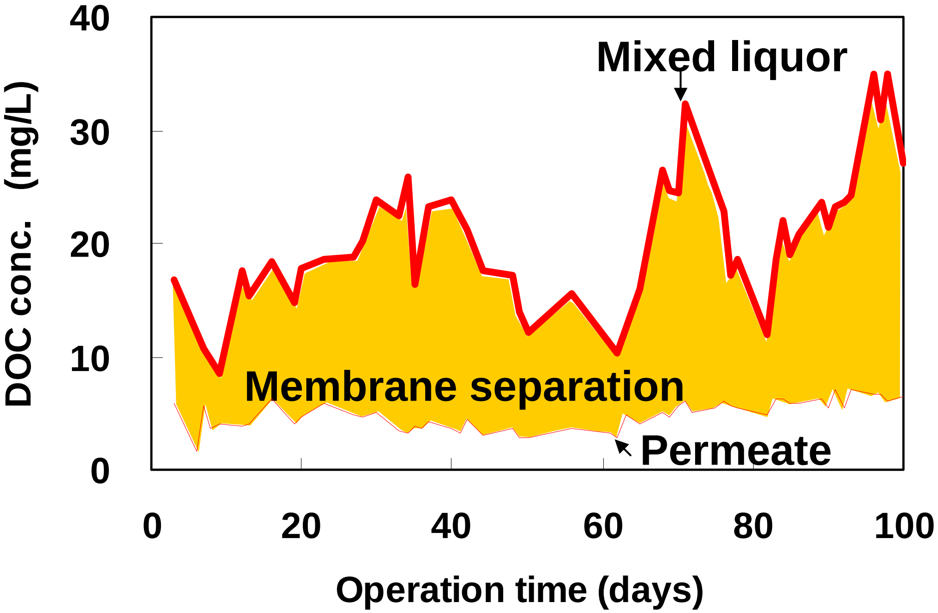


- By changing air scrubbing condition, rapid increase of filtration resistance in CMBR1 was observed.
- In contrast with the results with CMBR1, relatively high membrane permeability was maintained with HMBR1.

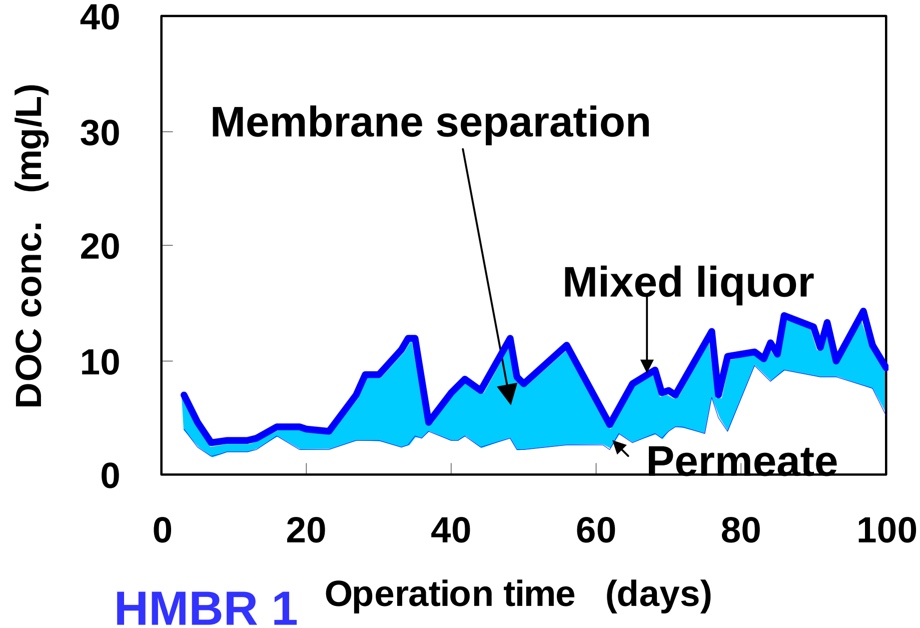
DOC concentration of mixed liquor

F/M ratio (mg-TOC/mg-VSS/day)

CMBR 1 0.055 HMBR 1 0.040



CMBR 1

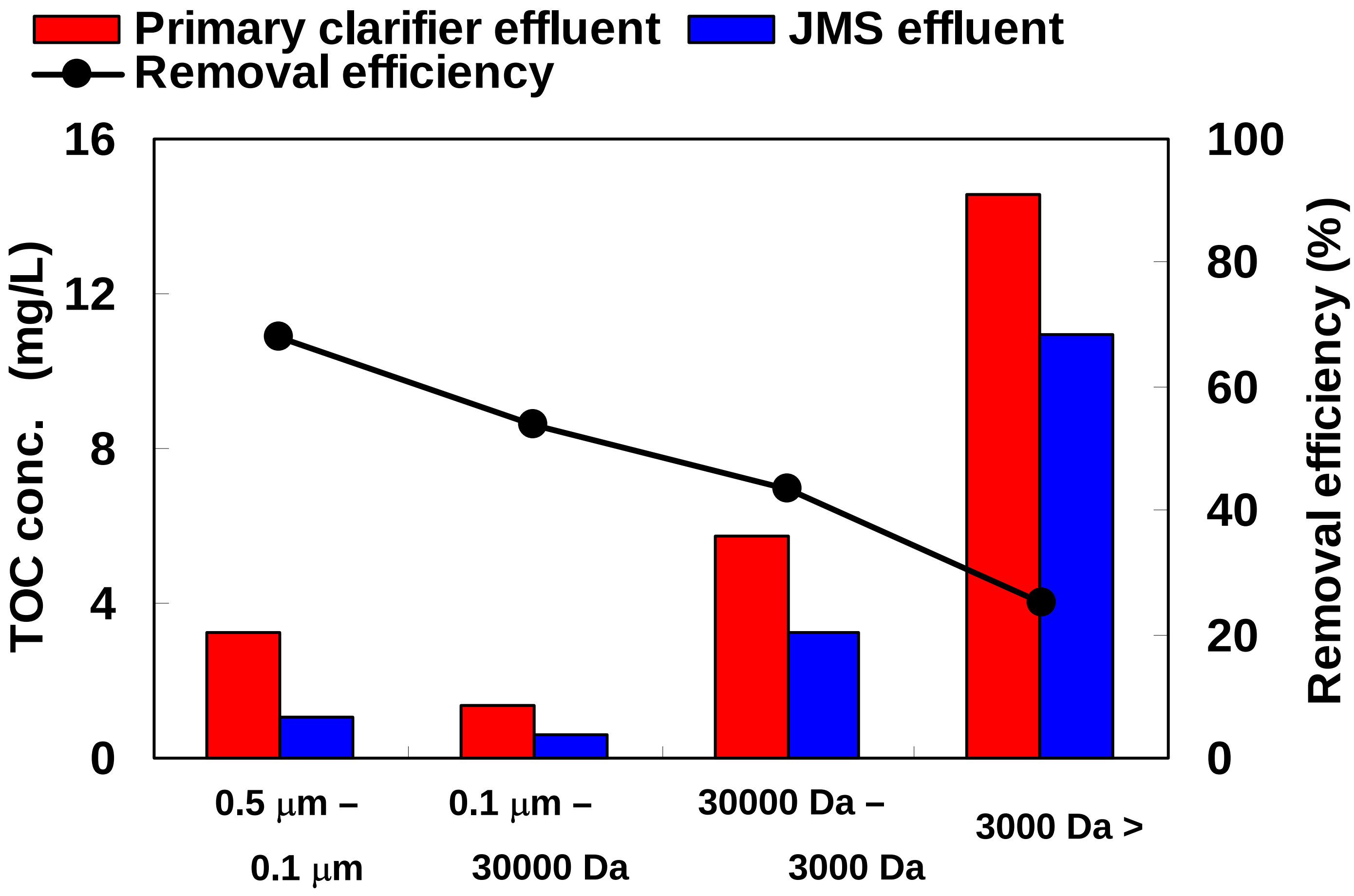


HMBR 1

Higher DOC concentration in CMBR probably corresponded to more rapid increase of filtration resistance in CMBR.

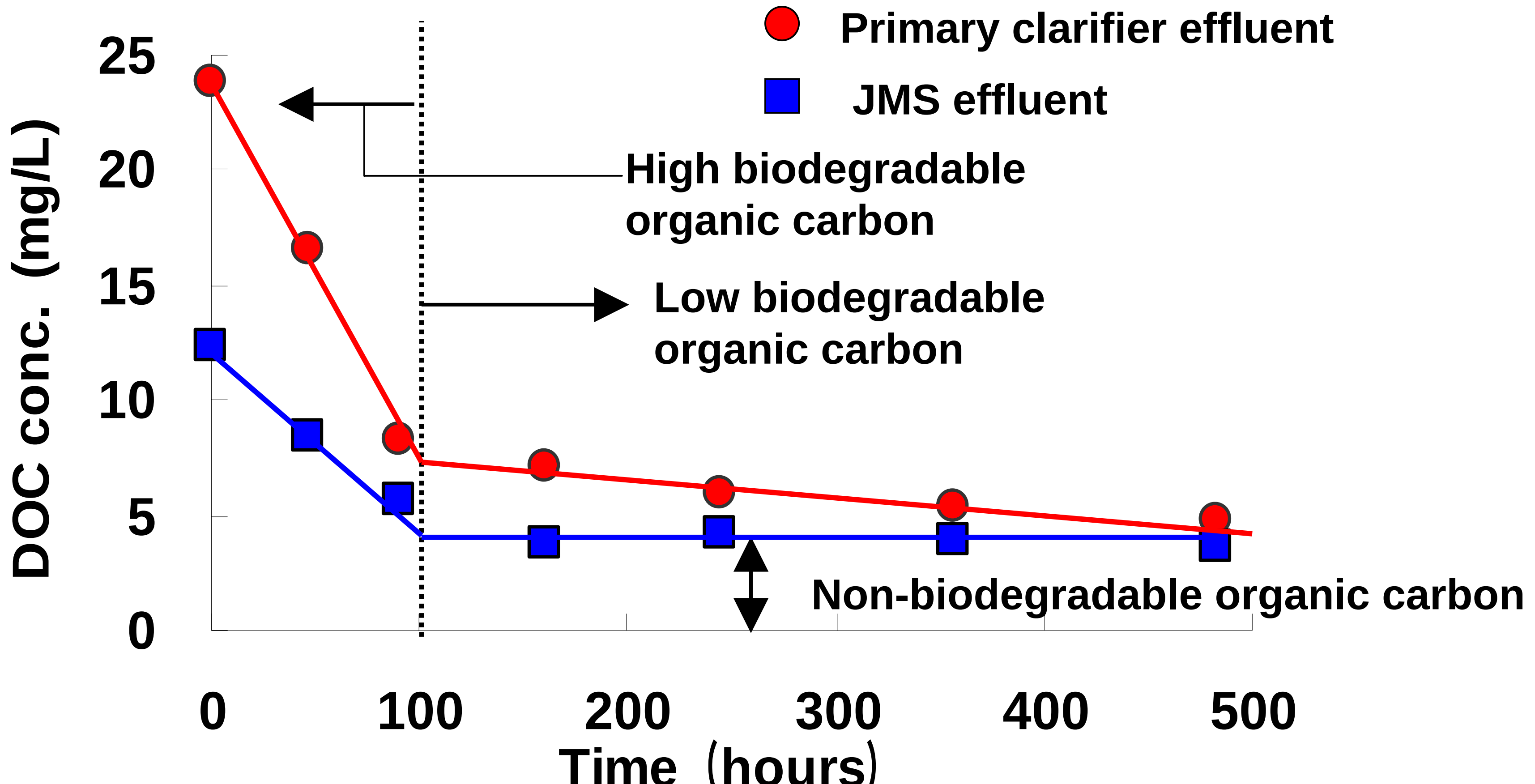
Treatability of organic carbon ⇔ Membrane fouling

Fraction of DOC in the feed water



Removal efficiency of high molecular organic matter was higher than that low molecular organic matter.

Biodegradability of DOC in the feed water



Low biodegradable organic carbon

= High molecular weight organic compound

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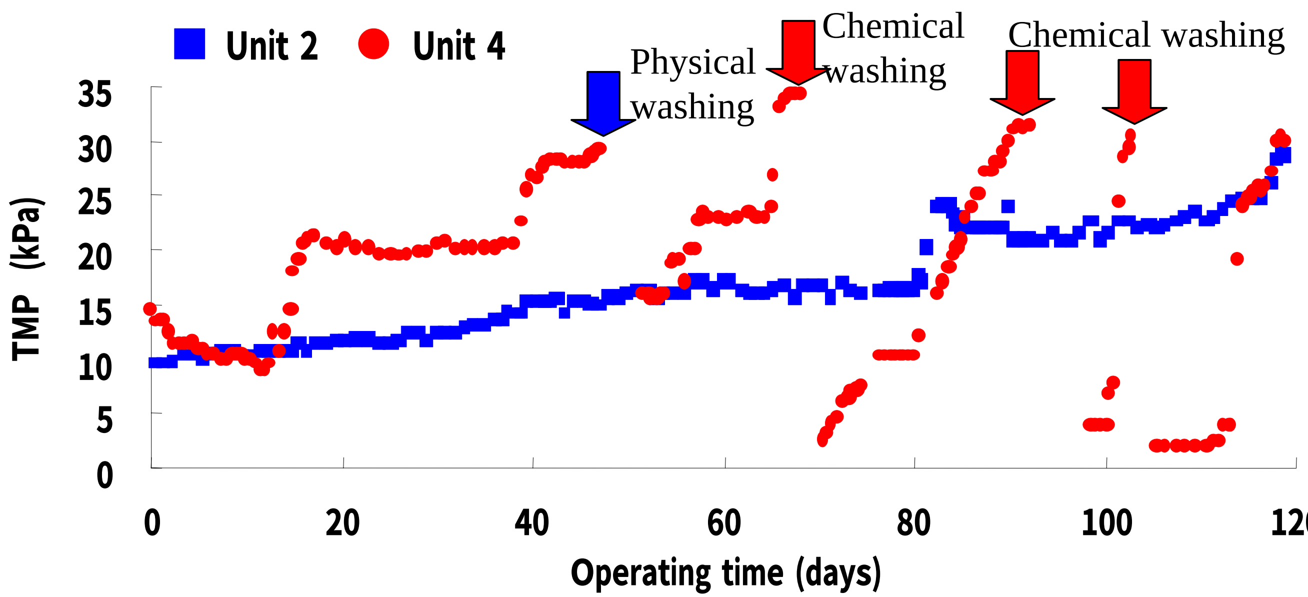
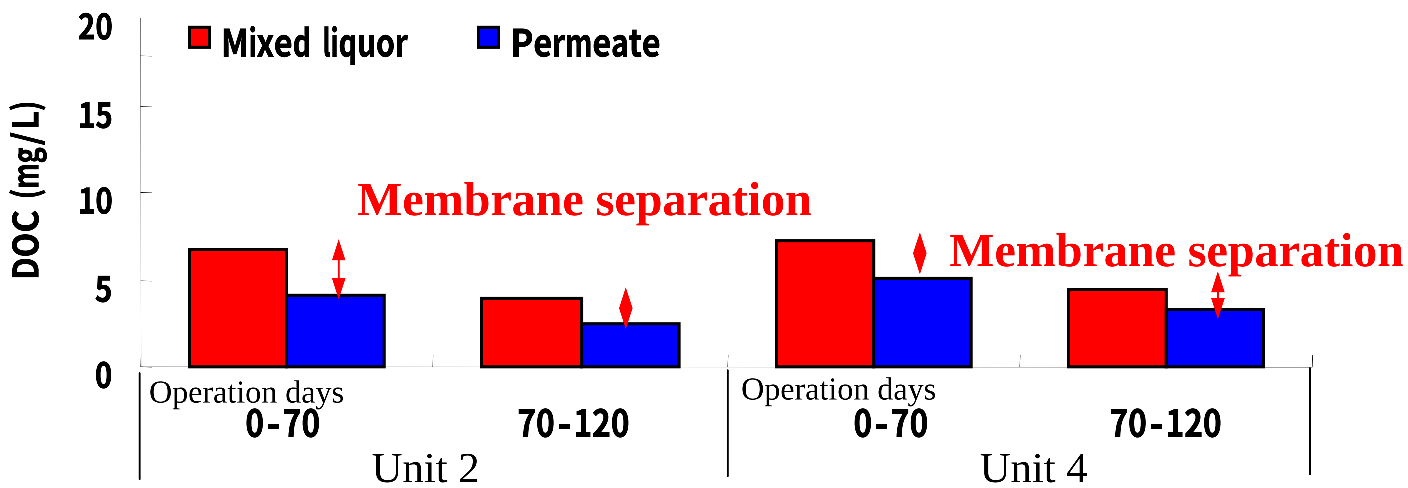
Irreversible membrane fouling

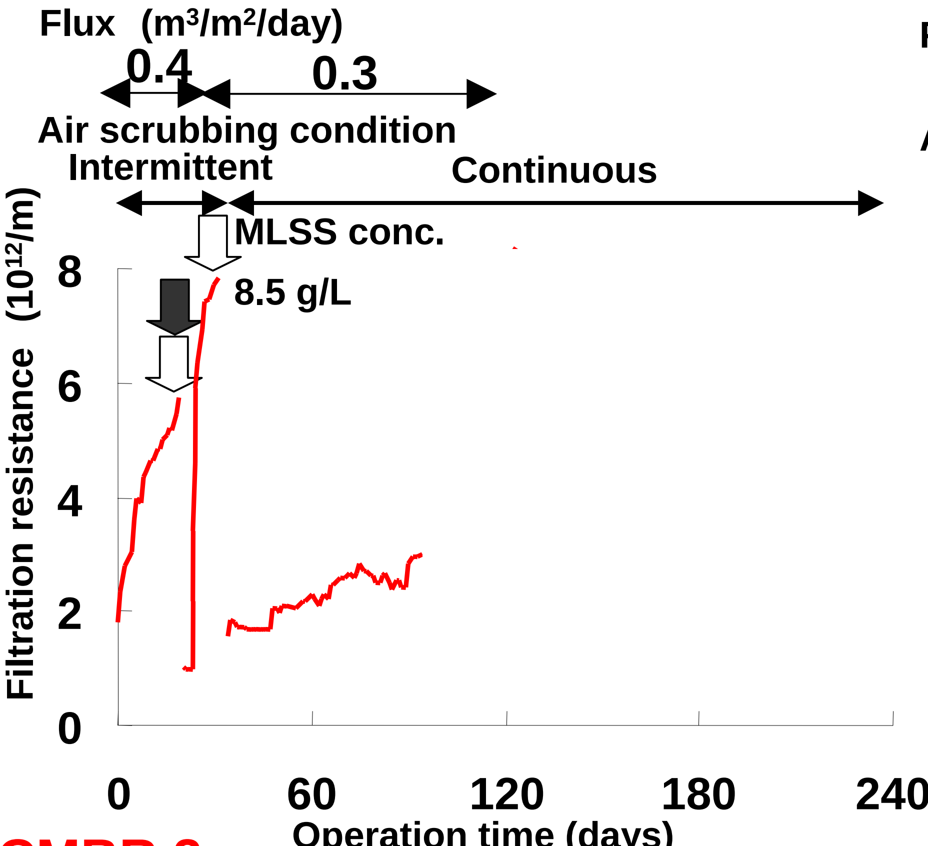
Variation of transmembrane pressure(TMP) : MLSS > 8000 mg/L



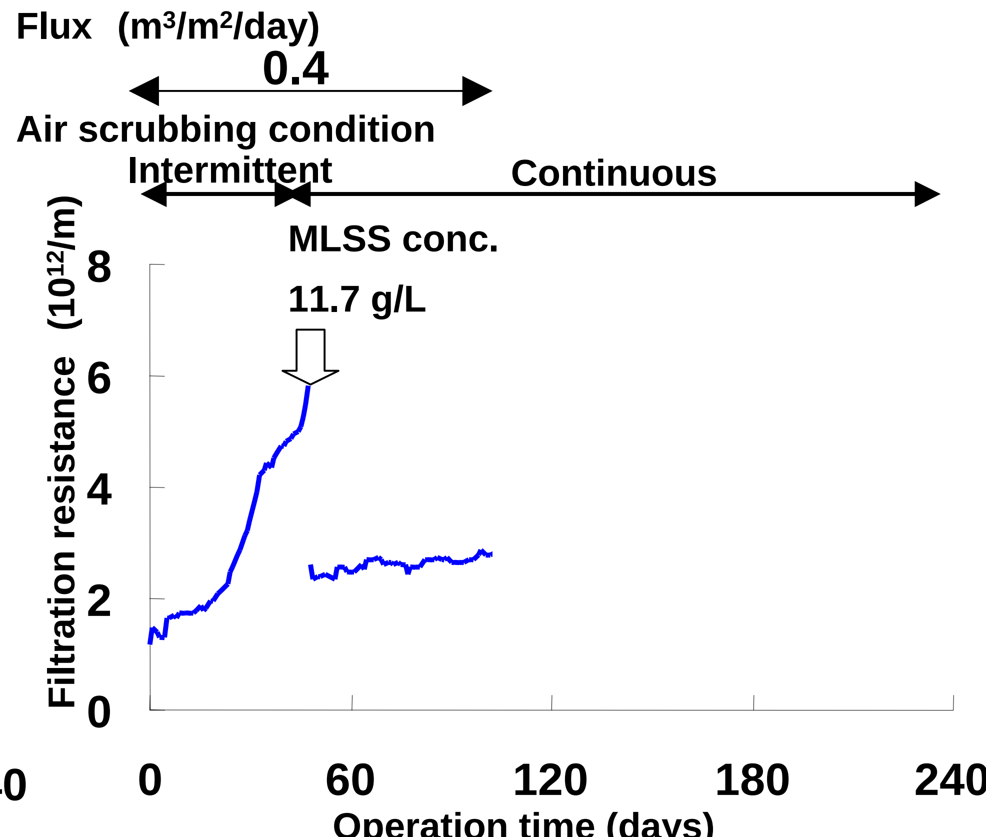


Membrane permeability (MLSS conc. > 10 g/L)

⇩ Physical membrane cleaning ⬇ Chemical membrane cleaning



CMBR 2



HMBR 2

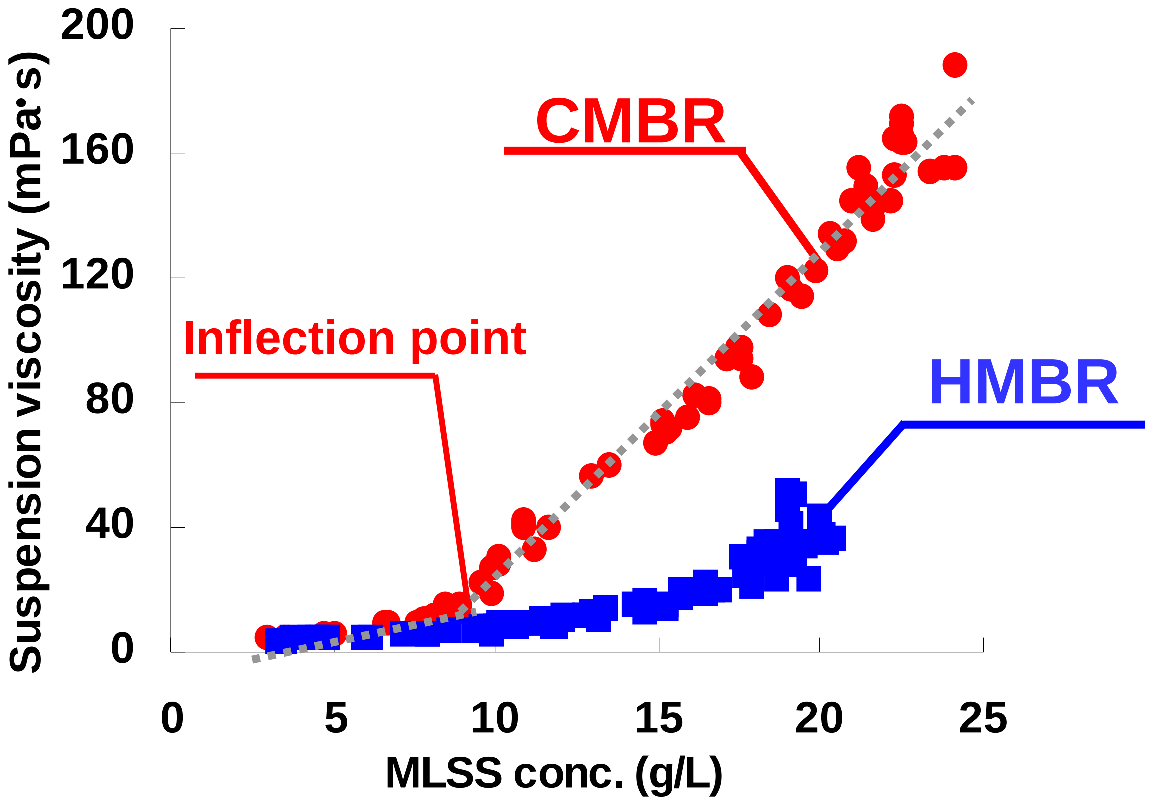
Before physical membrane cleaning

After physical membrane cleaning

Continuous air scrubbing was effectively for cake removal.

Upper limit of MLSS concentration in CMBR

What control is suspension viscosity ?

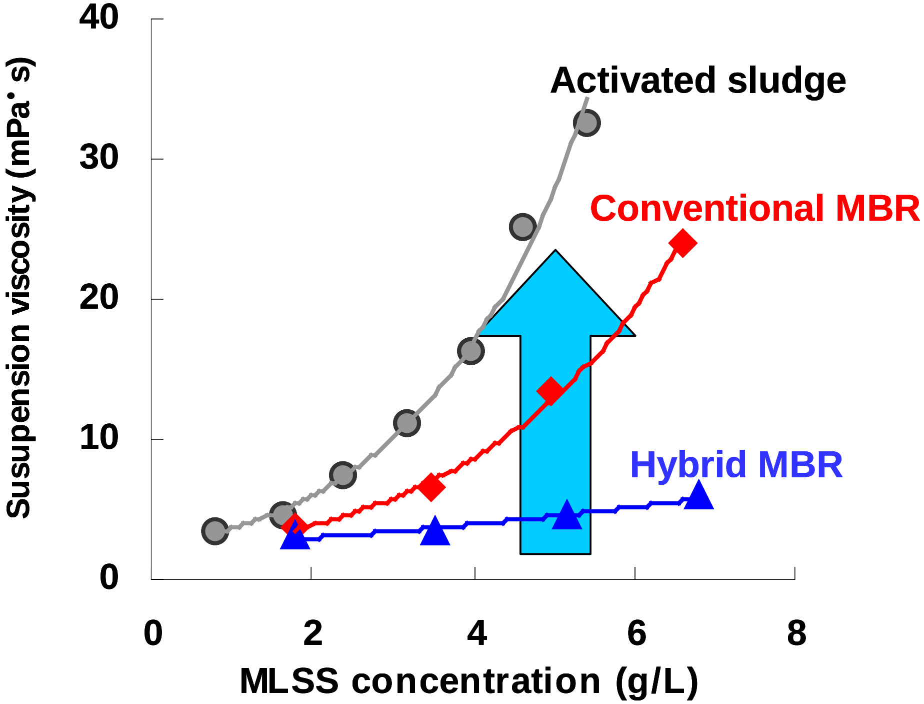


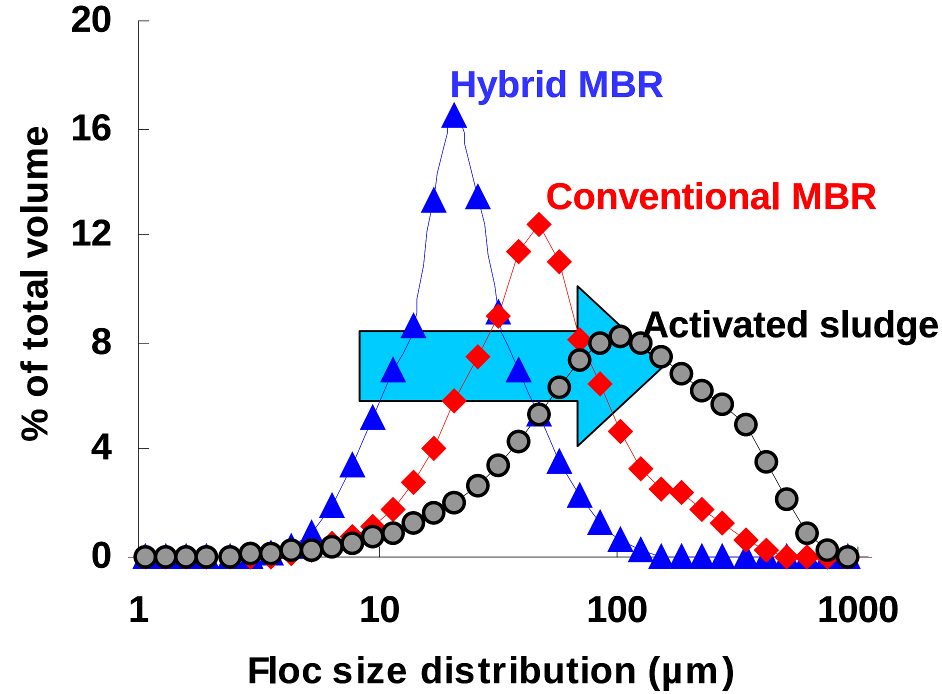
- **Upper limit of MLSS concentration for an efficient operation in CMBR was suggested to be around 10 g/L.**
- **When a MBR is used as the HMBR, higher MLSS concentration would be applicable.**

Relationship between MLSS conc., viscosity and floc size distribution

Sample

Activated sludge, Conventional MBR sludge, Hybrid MBR sludge





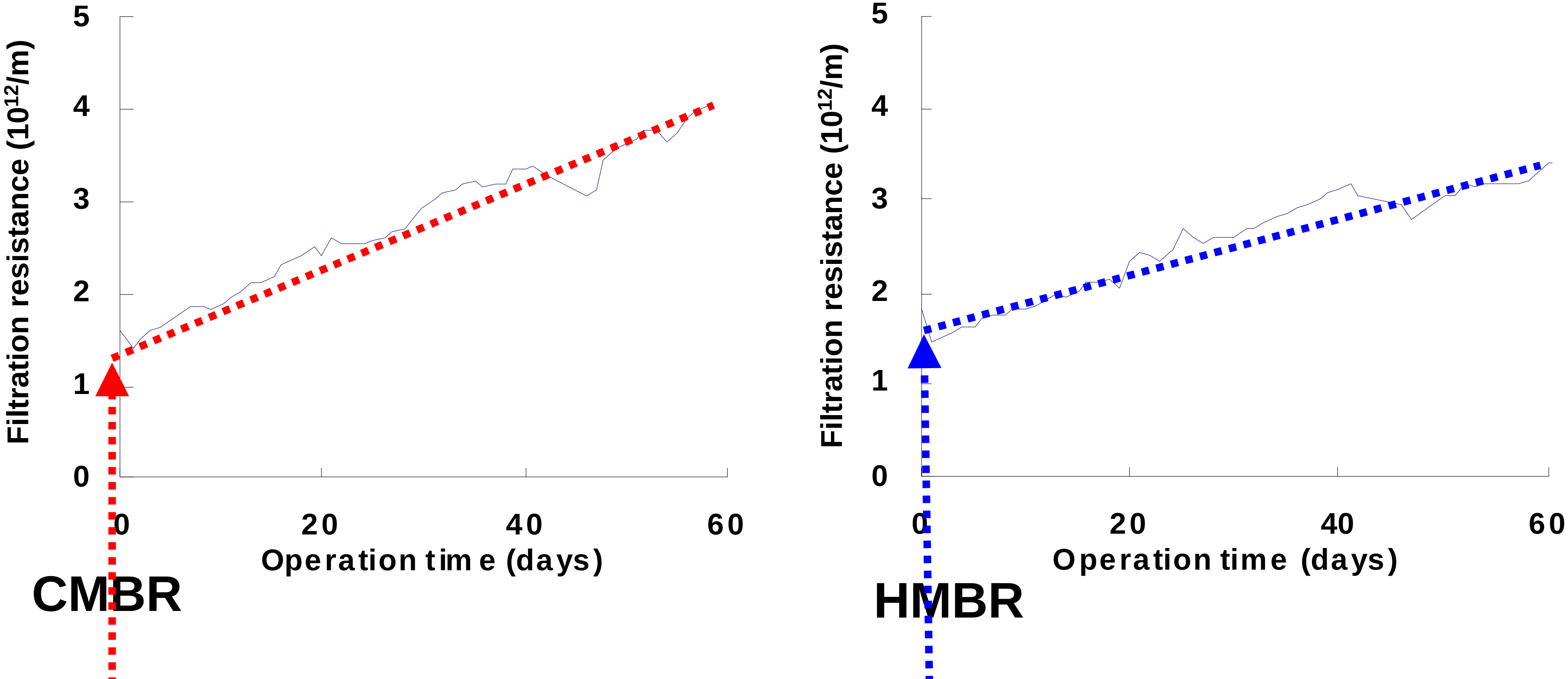
Suspension viscosity is controlled by MLSS conc. and floc size.

Operating conditions of the MBRs

		HMBR	CMBR
HRT	(hour)	4.5	
MLSS conc.	(g/L)	10	
Flux	(m/day)	0.4	
Pore size	(μm)	0.2	
Suction mode		Suction for 12 min., Stop for 3 min. Continuous air scrubbing	

Influence of DOM (dissolved organic matter) on membrane fouling was investigated.

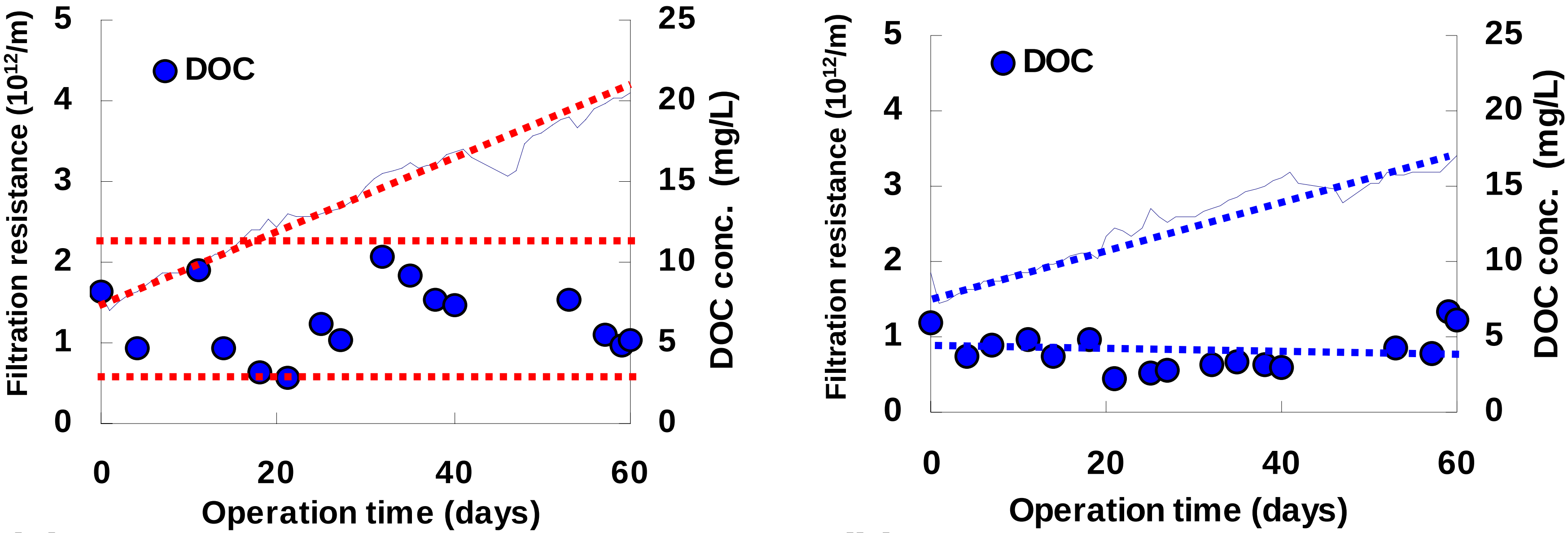
Changes in the total membrane filtration resistance



Increase rate of filtration resistance observed in HMBR was 30 % less rapid than that in CMBR.

The effect of pre-treatment for HMBR was confirmed.

Influence of DOC on membrane fouling



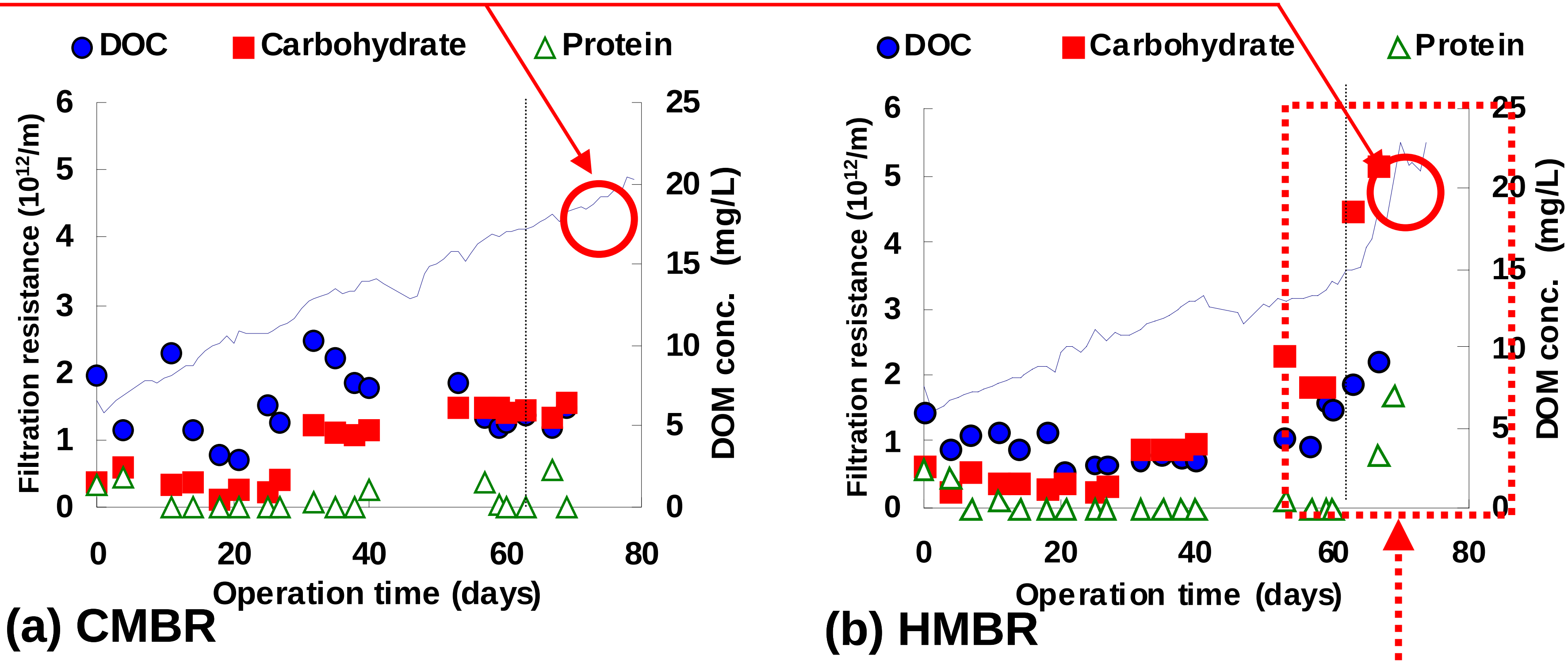
(a) CMBR

(b) HMBR

Higher DOC concentration corresponded to more rapid increase of filtration resistance.

Influence of DOM on membrane fouling

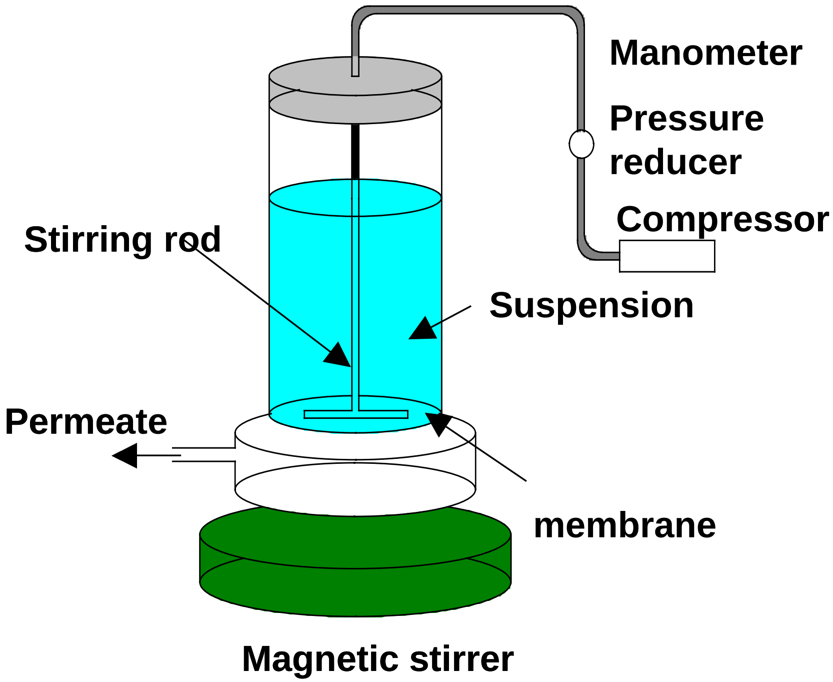
To get the information of mechanisms in membrane fouling , dead-end test was carried out.



Rapid increase in filtration resistance was observed in HMBR

Rapid increase of DOM in the membrane chamber of HMBR was observed

Laboratory scale dead-end filtration experiment



Filtration membrane characteristics	
Pore size	0.1 μm
Diameter	58.5 cm
Filtration area	26.9 cm^2
Operating conditions	
Operating pressure	40 kPa
Rotation of stirring rod	300 rpm

Samples

- **Biomass suspension**

  Resistance = SS+colloid+soluble

- **After centrifugation**

  Resistance = colloid+soluble

  Biomass suspension was centrifuged at 3,000 rpm for 5min.

- **After filtration**

  Resistance = soluble

  Biomass suspension was filtered with a membrane with nominal pore size of 0.5 μm.

Characteristics of the suspensions tested in dead-end tests.

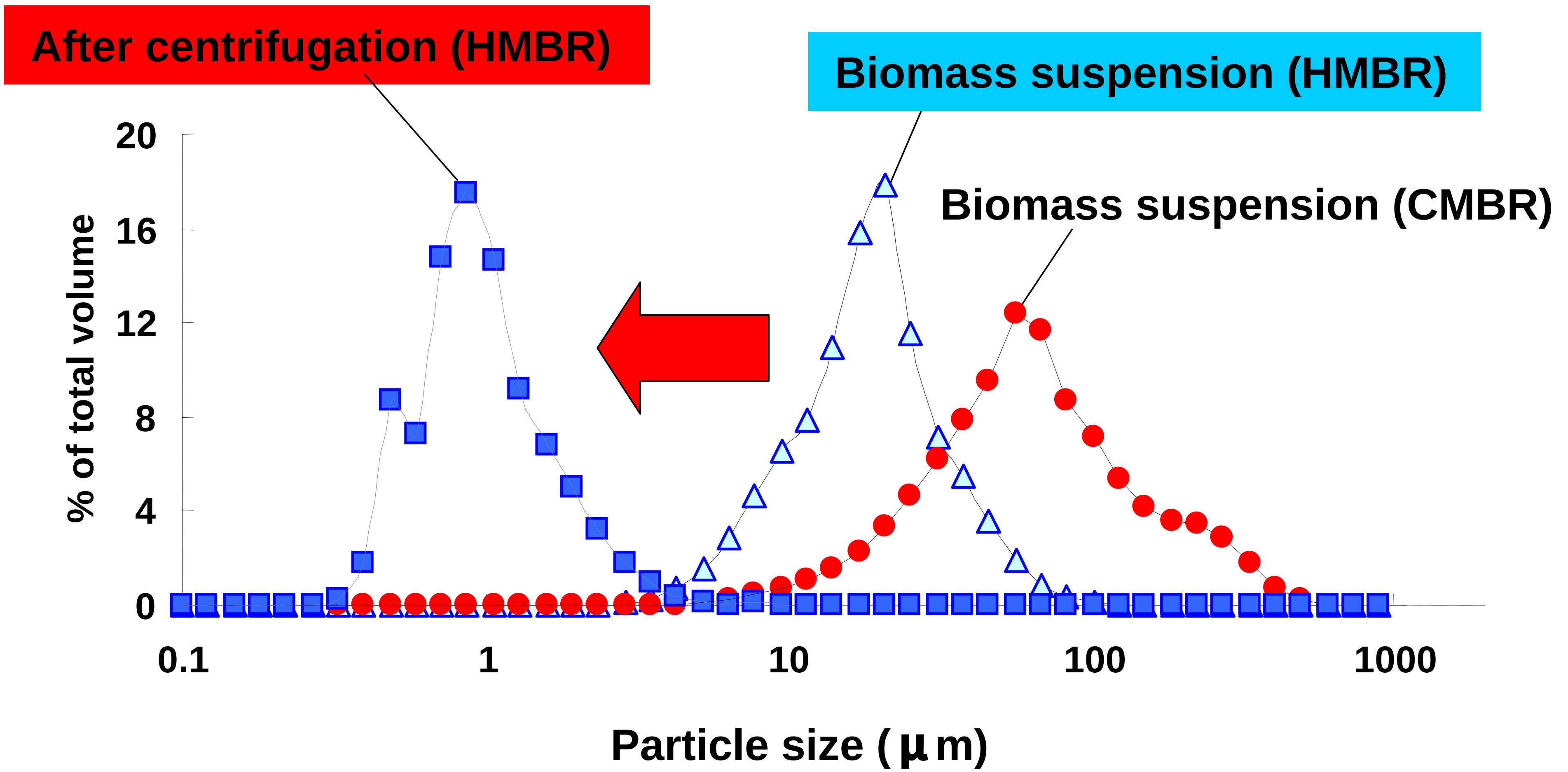
	Biomass suspension		After centrifugation		After filtration	
	CMBR	HMBR	CMBR	HMBR	CMBR	HMBR
SS	9,400	10,420	-*	148	-*	-*
TOC	-*	-*	21.1	83.8	6.2	11.9
Carbohydrate	1444	1995	13.5	89.1	6.4	21.2
Protein	4250	3726	13.5	94.8	0.0	7.0

unit (mg/L)

-* not determined

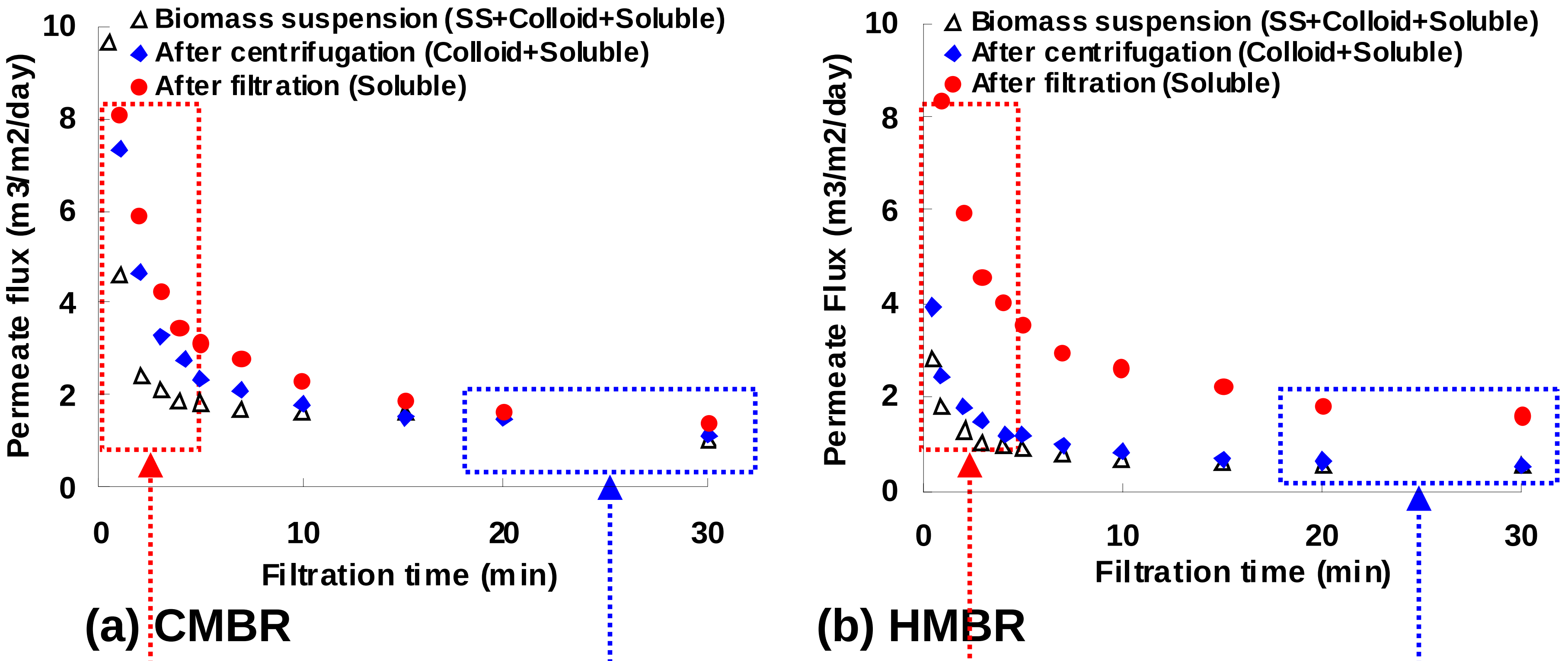
- * * not detected

Particle size distribution



***Particle size distribution in the supernatant collected from CMBR could not be determined due to the detection limit of the analyzer (particle concentration was too low).**

Changes in the permeate flux



Rapid decrease in permeate flux were observed at initial stage.

Permeate flux reached a stable value within filtration time of 30 min.

For all the test, fouling resistances were determined by Darcy' law. (30 min. of filtration)

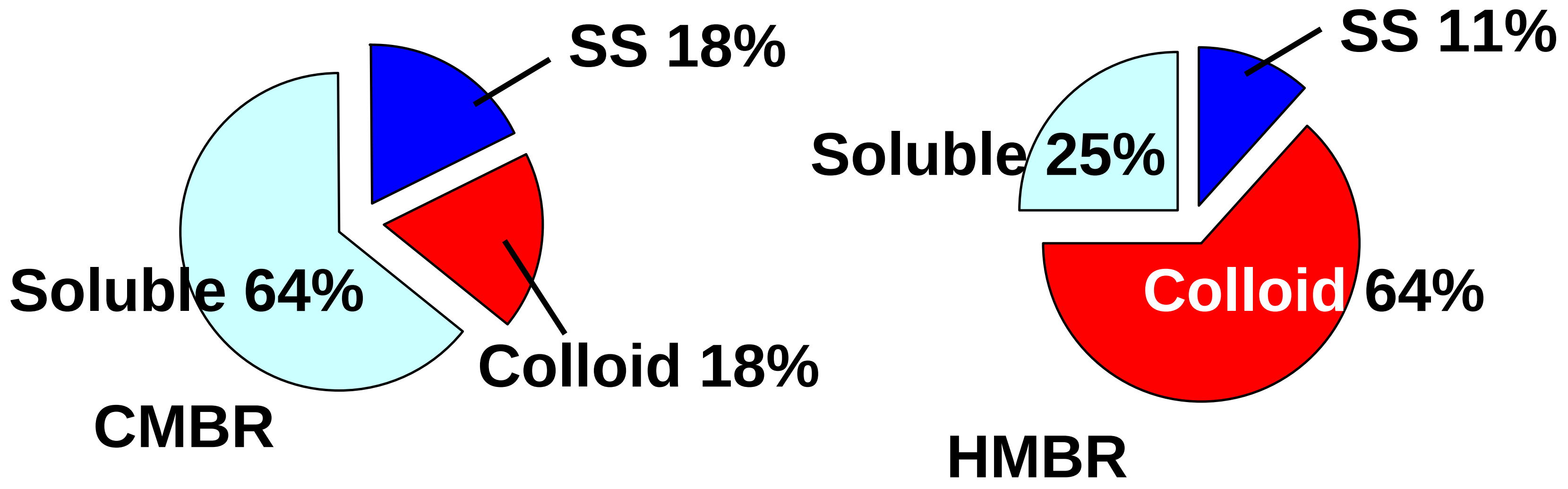
Role of SS, colloidal matter and soluble matter in membrane fouling

- **Resistance caused by membrane fouling for each sample**

	CMBR	HMBR
Biomass suspension (SS+colloid+soluble)	2.8	6.0
After centrifugation (colloid+soluble)	2.3	5.3
After filtration by 0.5 μm (soluble)	1.8	1.5

unit (10^{12}/m)

- **Contributions of each fraction in the total membrane fouling**



Conclusions Ⅰ

Water quality of whole system

		Activated sludge process	CMBR	HMBR	HMBR (N removal)
Turbidity	(NTU)	< 10	0	0	0
TOC	(mg/L)	< 10	< 6	< 4	< 4
T-N	(mg/L)	< 15	< 18	< 16	< 10
NH_4^+-N	(mg/L)	< 3.0	< 1.0	< 3.0	< 1.0
T-P	(mg/L)	< 0.5	< 1.0	< 0.1	< 0.1

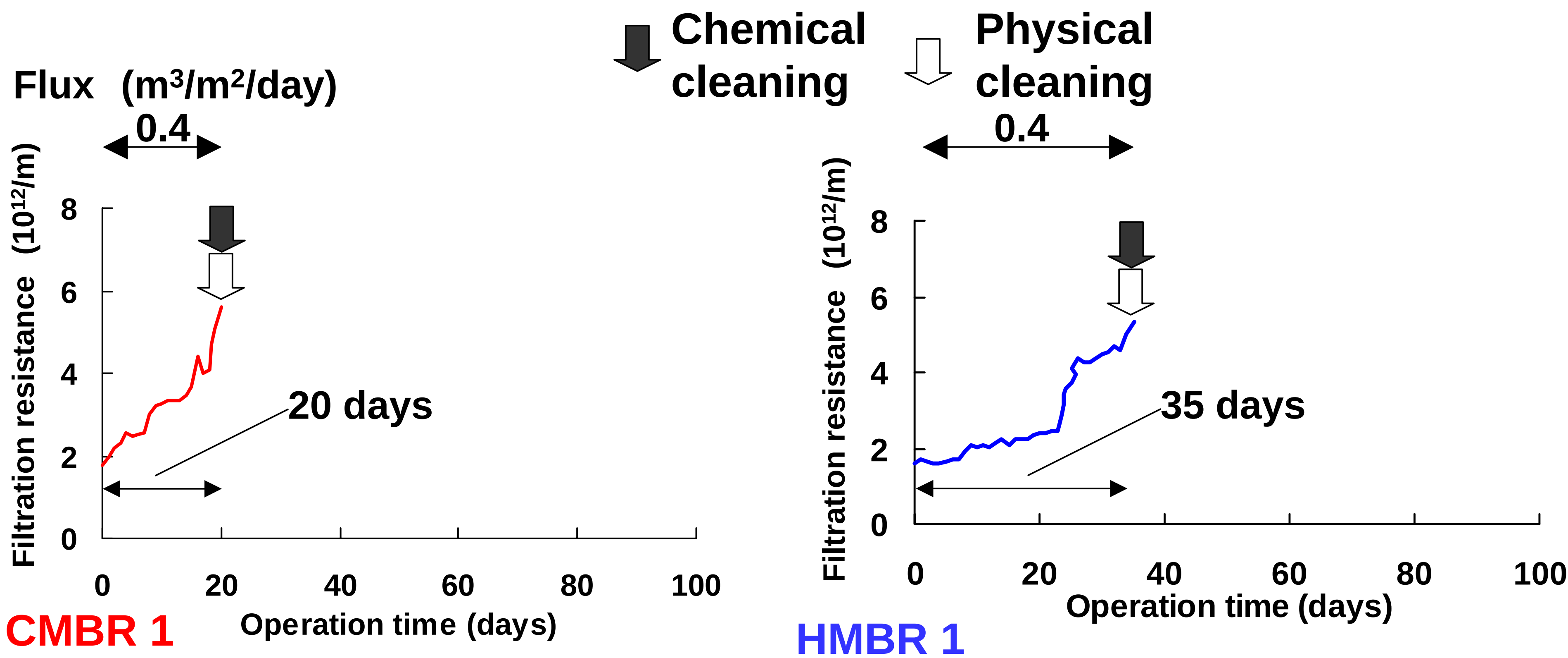
•Hybrid MBR : DOC concentration was less than 4.0 mg/L. BDOC concentration was almost zero. Total phosphorus concentration was less than 0.1 mg/L.

Conclusions II

Pilot scale experiments were carried out to examine membrane fouling occurring in MBR with or without pre-coagulation/sedimentation. The influence of suspension viscosity and DOM on membrane fouling was investigated.

- **Pre-coagulation/sedimentation process improved the performance of MBR by reducing both reversible fouling and irreversible fouling.**
- **In order to efficiently operate a MBR, suspension viscosity in the membrane chamber should be maintained as low as possible. Suspension viscosity was controlled by MLSS concentration and floc size.**
- **DOM such as carbohydrate and protein seemed to be not important in interpreting membrane fouling in MBRs.**
- **Colloidal fraction in biomass suspension played an important role in membrane fouling.**

Membrane permeability (MLSS conc. 2 - 4 g/L)

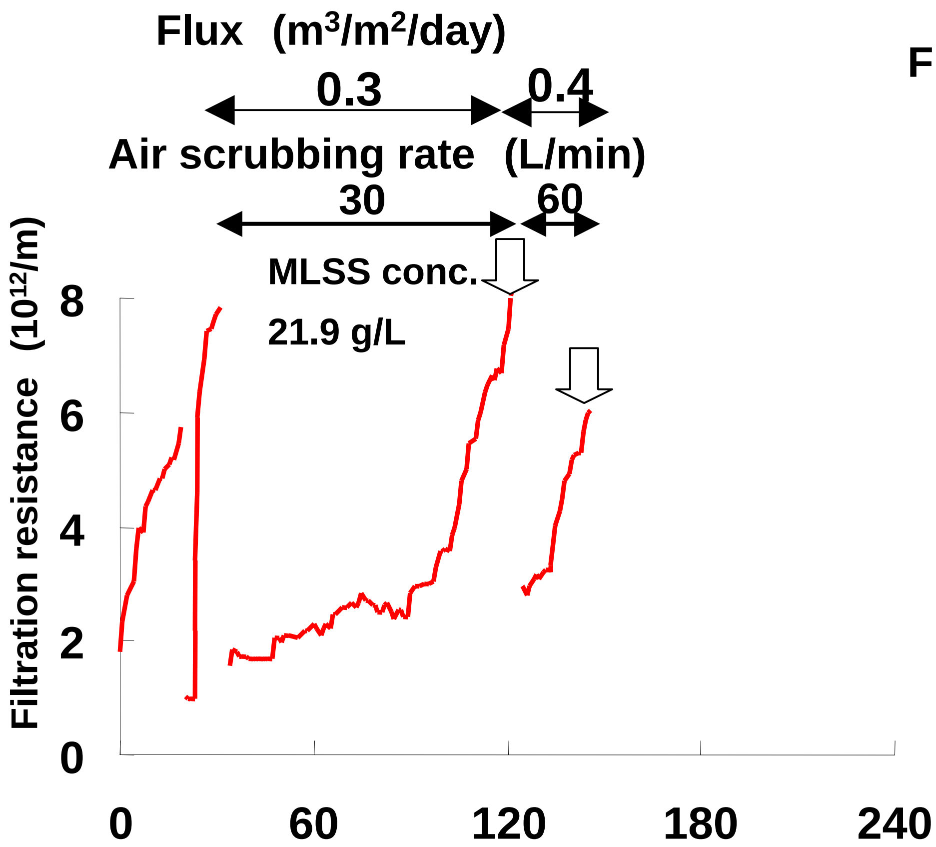


•When deterioration in membrane permeability became significant, deposition of biomass suspension on the membrane surface was not recognized and chemical cleaning was needed.

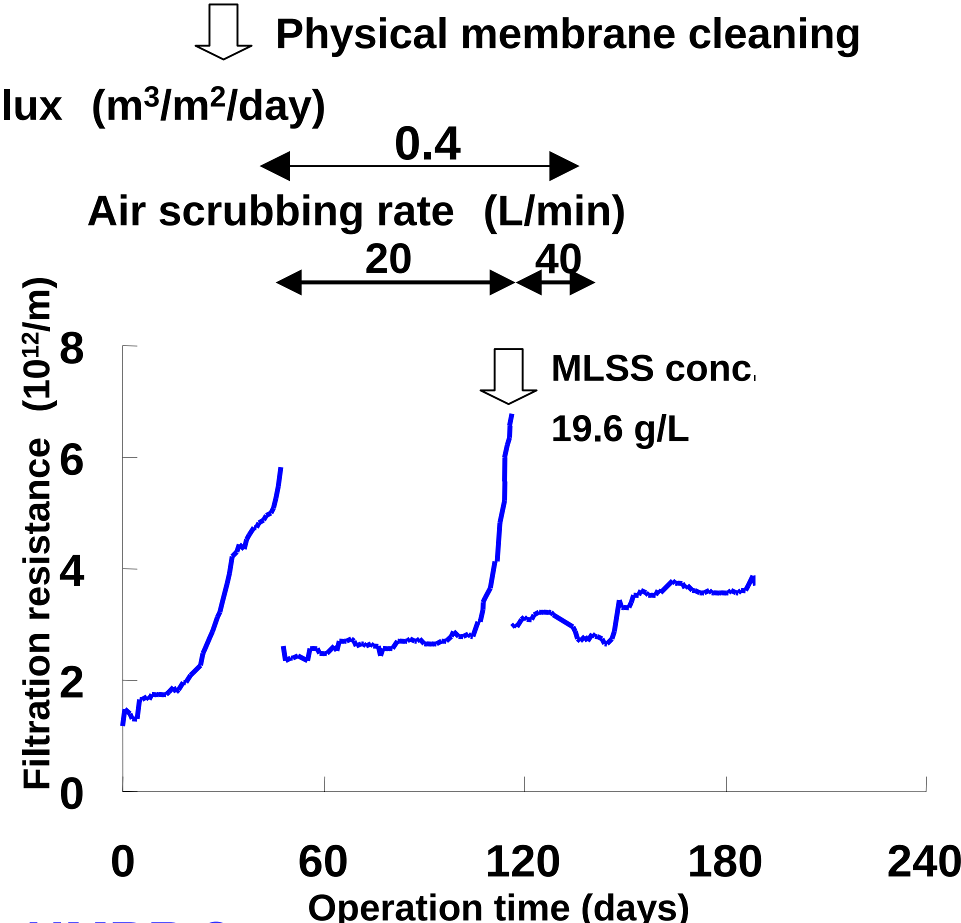
→ Irreversible fouling

•In contrast with the results with CMBR1, relatively high membrane permeability was maintained with HMBR1.

Membrane permeability (MLSS conc. > 10 g/L)



CMBR 2

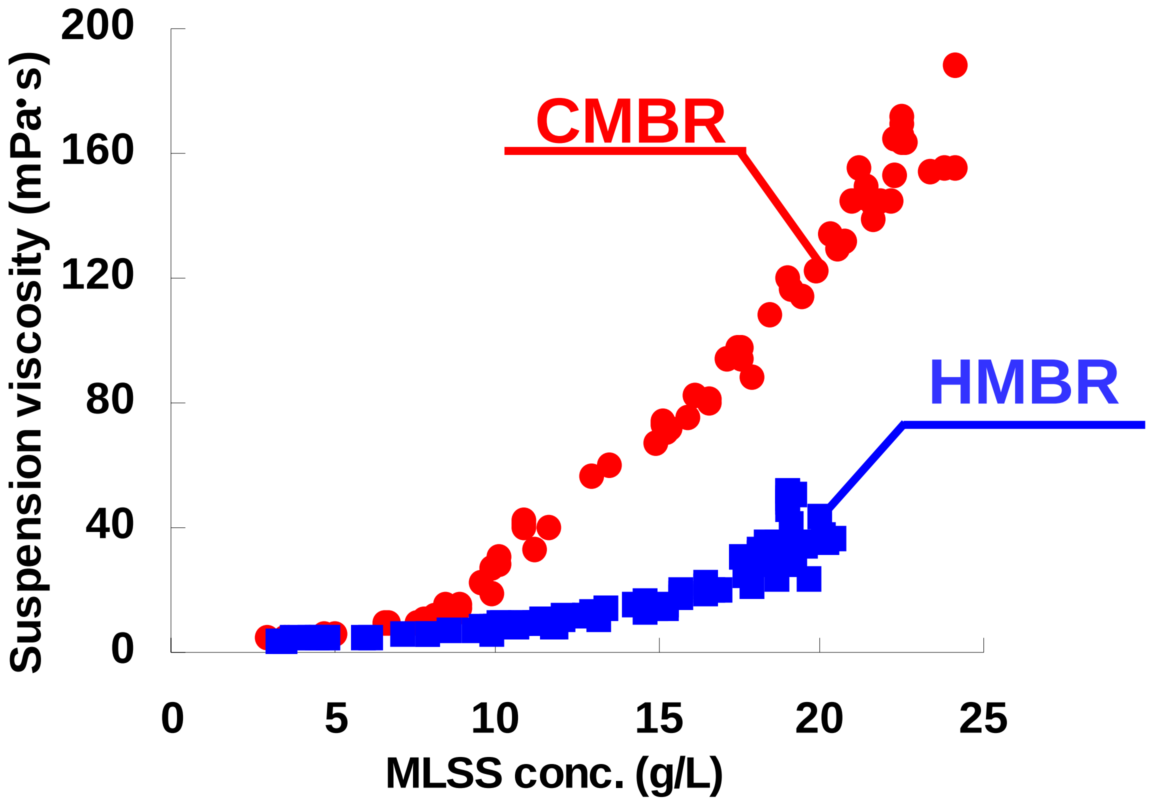


HMBR 2

Rapid increase of filtration resistance in CMBR2 was observed while that in HMBR2 was stable operation.

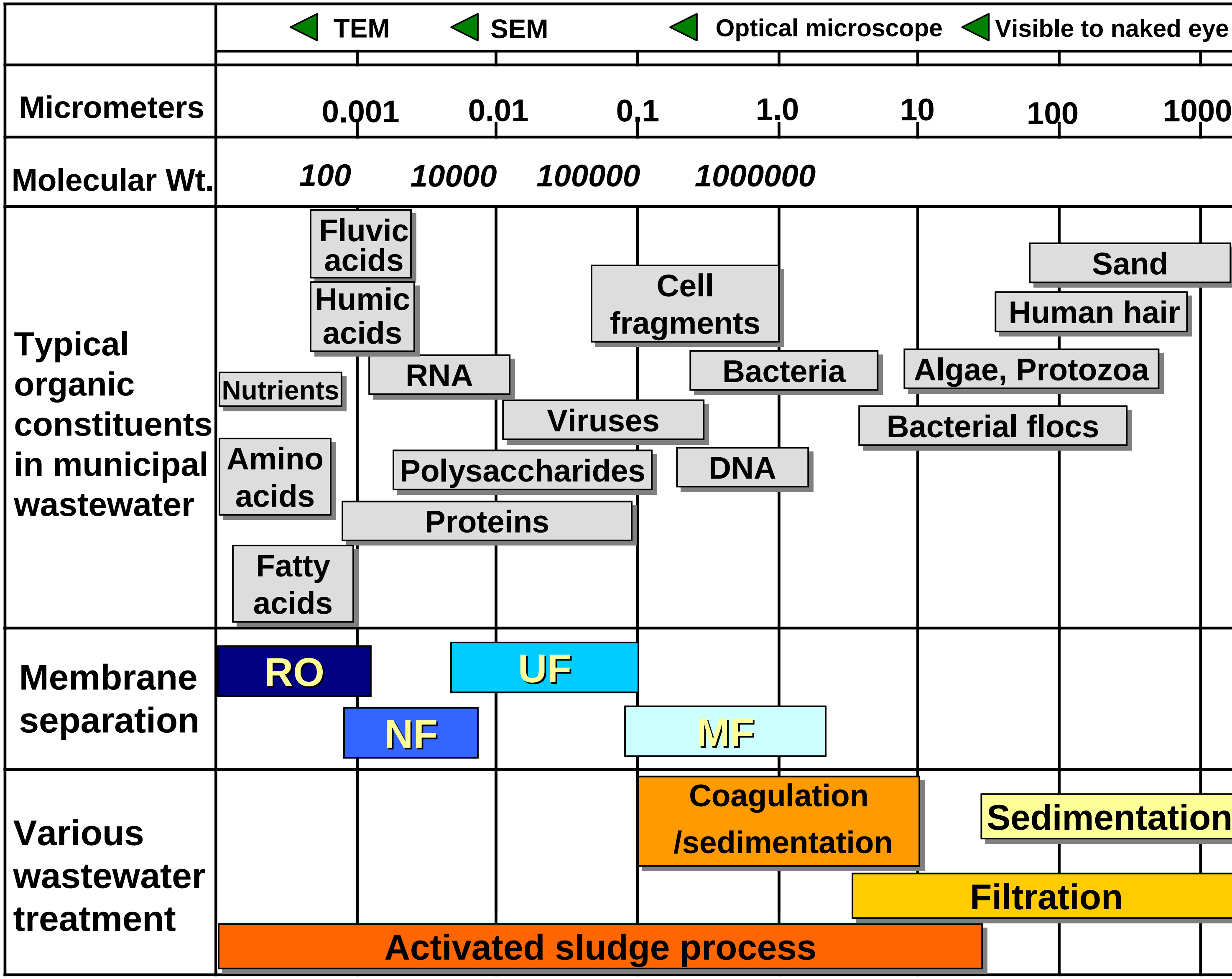
Relationship between MLSS conc. and suspension viscosity.

Suspension viscosity of CMBR was greater than that of HMBR



In order to efficiently operate a MBR, suspension viscosity in the membrane chamber should be maintained as low as possible.

Filtration spectrum



Classification of contaminants in wastewater

Size Range		Classification			
		Soluble <0.025µm	Colloidal 0.025-3µm	Supracolloidal 3-106µm	Settleable >106µm
BOD_5	(% of total)	17	16	46	21
COD	(% of total)	12	15	30	43
TOC	(% of total)	22	6	36	36
Tot P	(% of total)	63	3	12	22
Org.N	(% of total)	27	15	38	20

After Munch,R. et al. (1980)

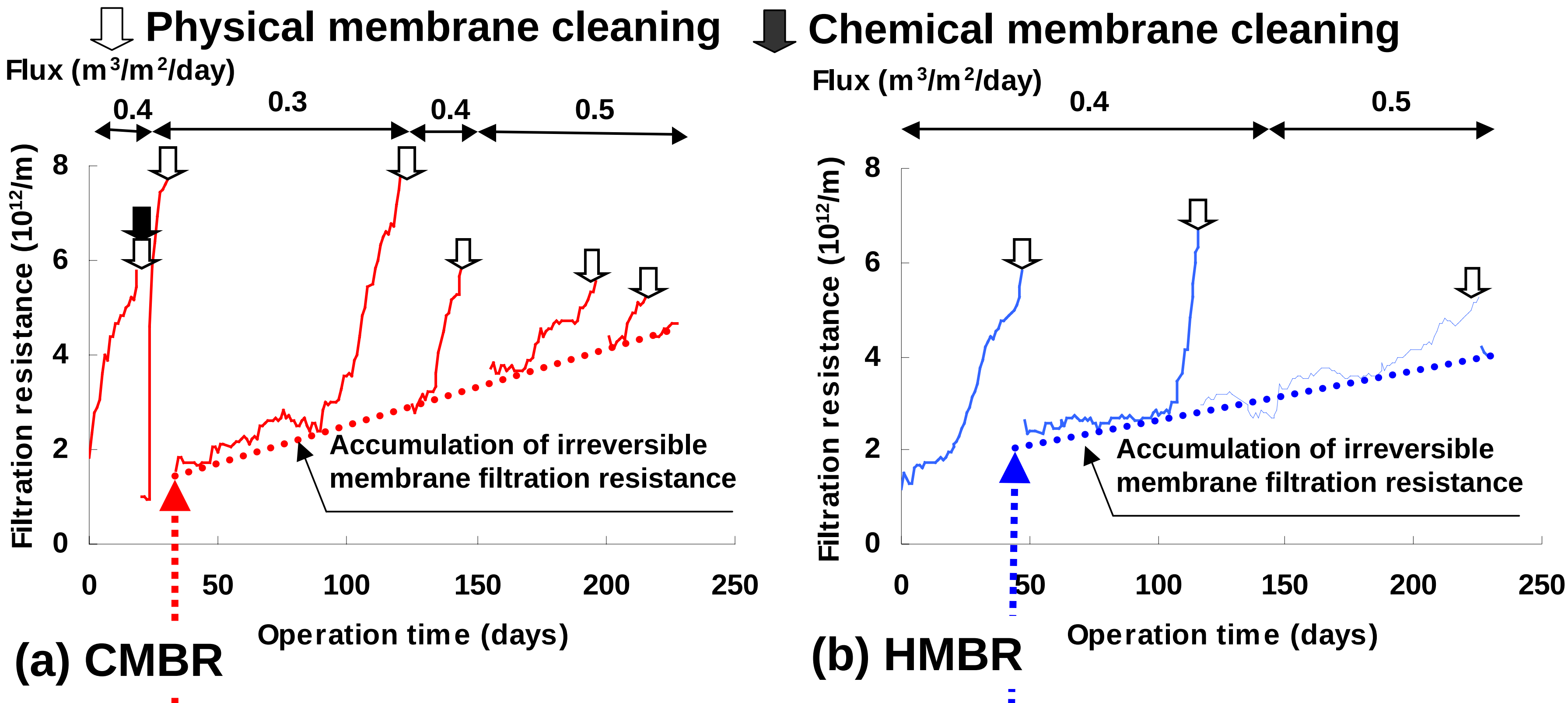
Percentage of total associated with suspended solids in the raw water at the Eskilstuna wastewater treatment plant in Sweden

Metal	Zn	Cu	Ni	Cr	Pb	Cd
%-suspended	51	48	13	71	71	82

After SWEP (1985)

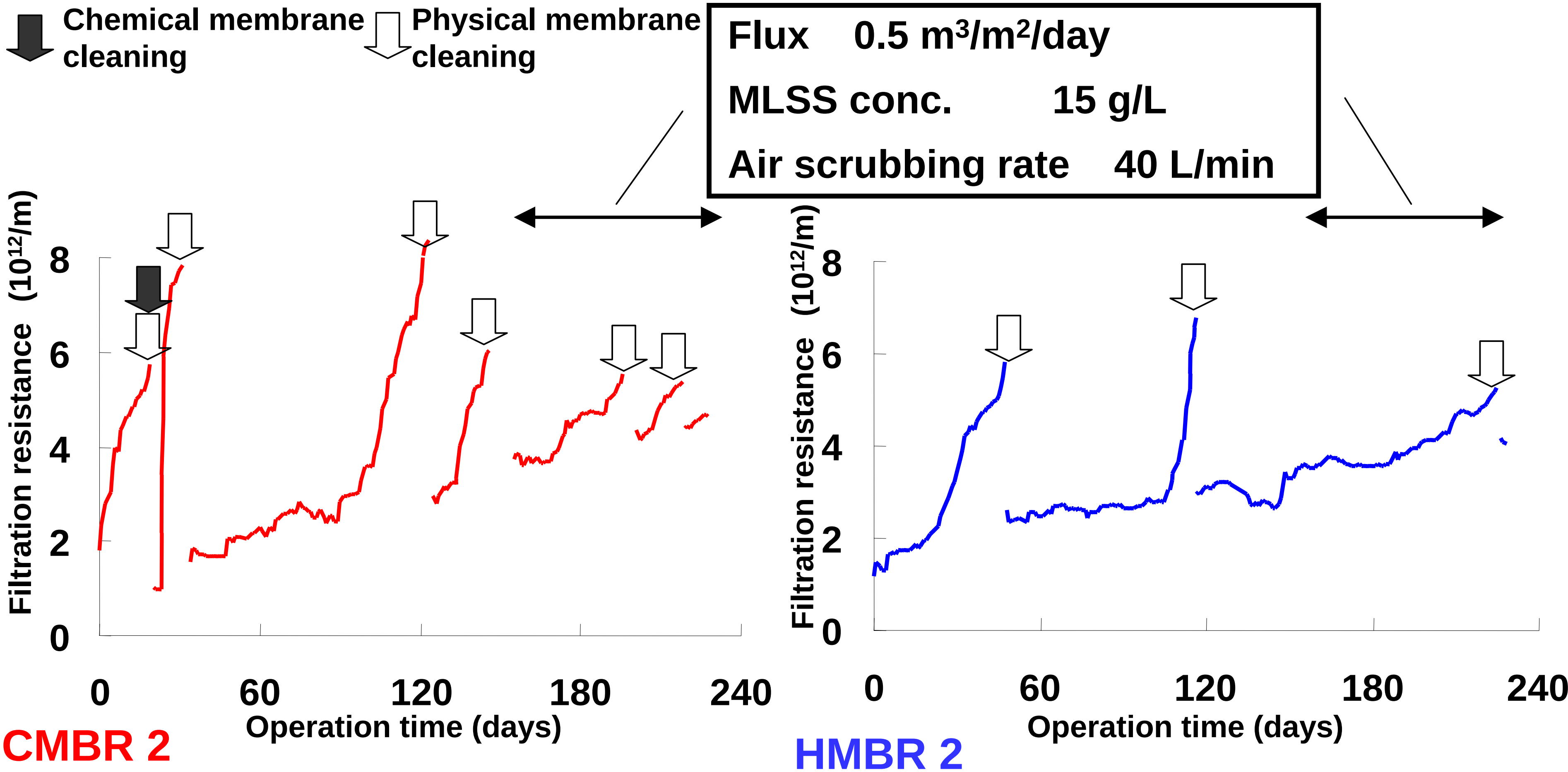
Direct particle separation is effective way of lowering the wastewater contaminant level

Membrane permeability (MLSS conc. > 10 g/L)



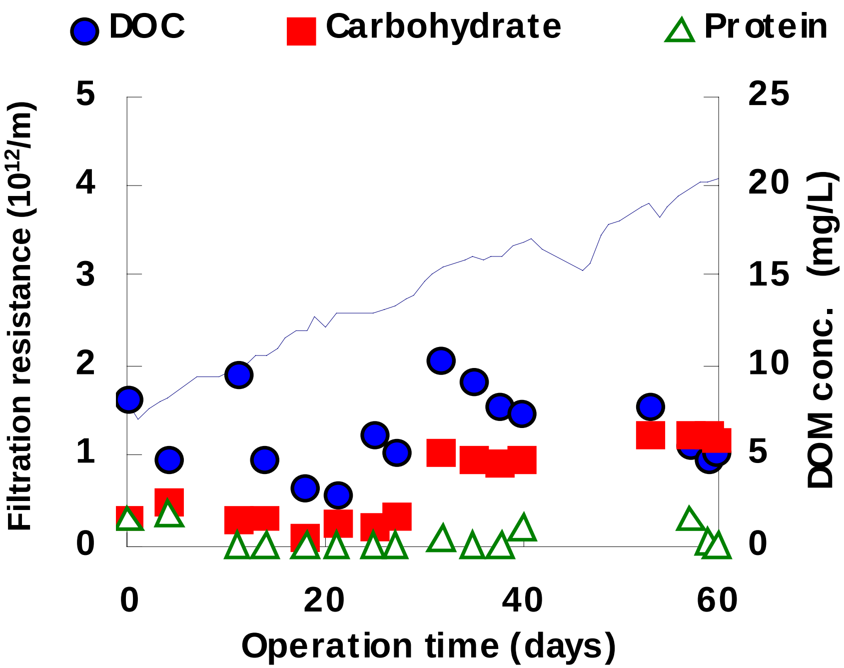
Accumulation of irreversible resistance observed in HMBR was 40 % less rapid than that in CMBR.

Membrane permeability (MLSS conc. > 10 g/L)

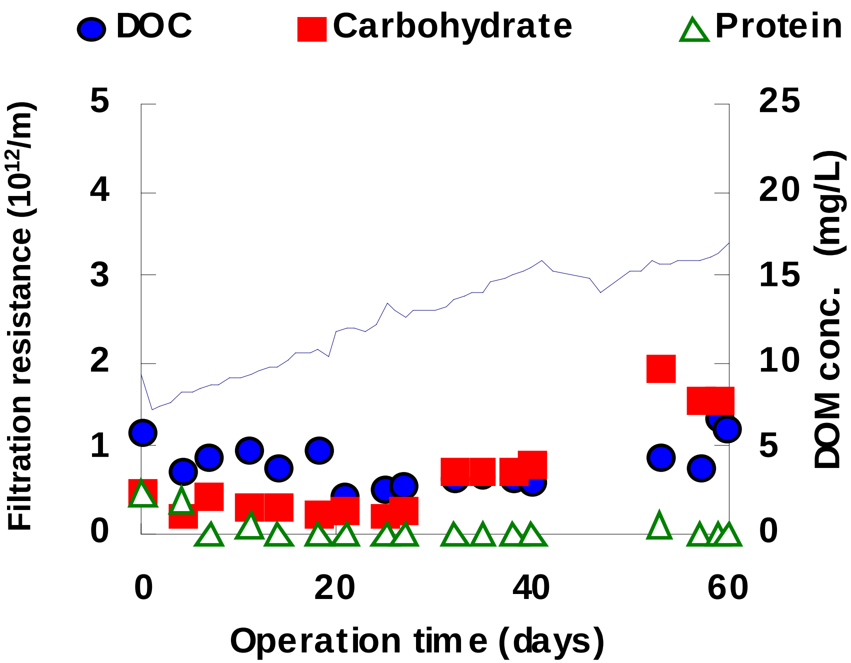


Rapid increase of filtration resistance in CMBR2 was observed while that in HMBR2 was stable operation.

Influence of DOM such as carbohydrate and protein on membrane fouling



(a) CMBR



(b) HMBR

DOM = Carbohydrate + Protein + etc…..

No clear relationship between DOC and DOM was indicated.

DOM such as carbohydrate and protein would not be concerned with membrane fouling.