Comparison of Pre-concentration Technology for Domestic Sewage to Enhance the Performance of Anaerobic Digestion

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Graphical Abstract

Domestic Sewage

COD
0.14 ± 0.05 g/L

Pre Concentration

Energy Recovery

COD
8.1 ± 0.96 g/L

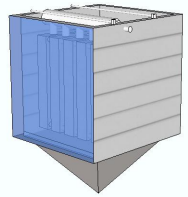
Anaerobic Digestion

Technology Comparison

Performance

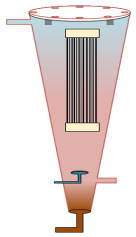
1 Woven Fiber Microfiltration (WFMF)

COD (g/L)	5 LMH	7.5 LMH
	5.4 ± 0.72	8.1 ± 0.96



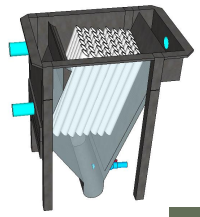
2 Conical Membrane Tank (CMT)

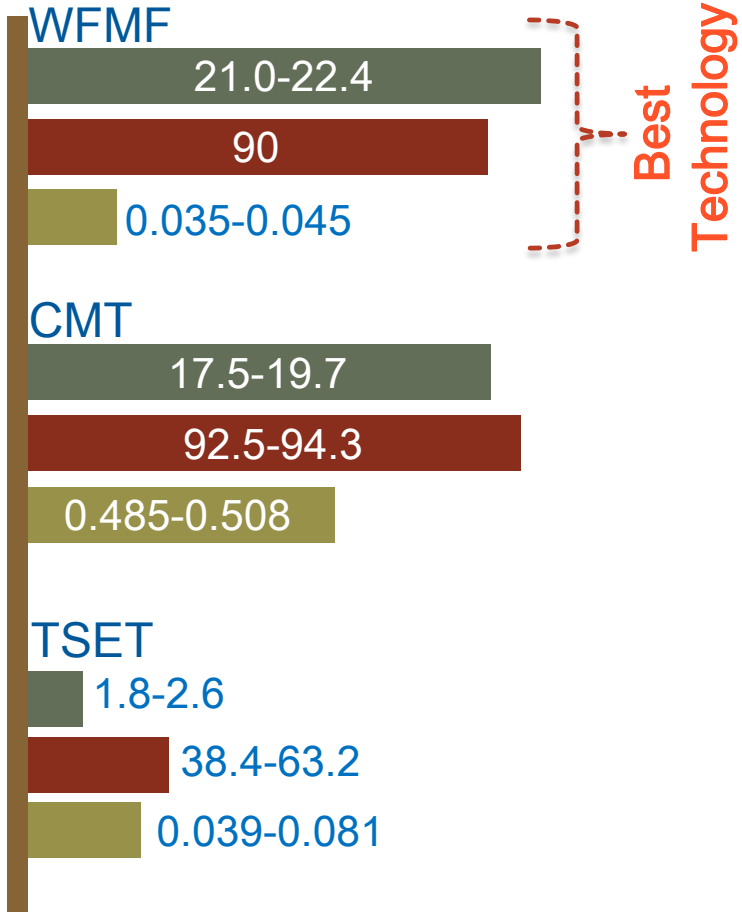
COD (g/L)	5 LMH	7.5 LMH
	13.9 ± 0.86	18.1 ± 2.68



3 Tube Settler (TSET)

COD (g/L)	0.005 m/h	0.01 m/h
	1.6 ± 0.55	5.5 ± 0.00





Presentation Outline

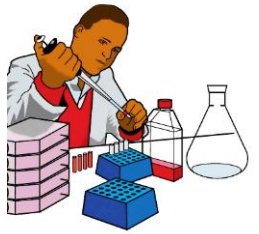
1. 
Rational

2. 
Objectives of the Study

3. 
Methodology

4. 
Results and Discussions

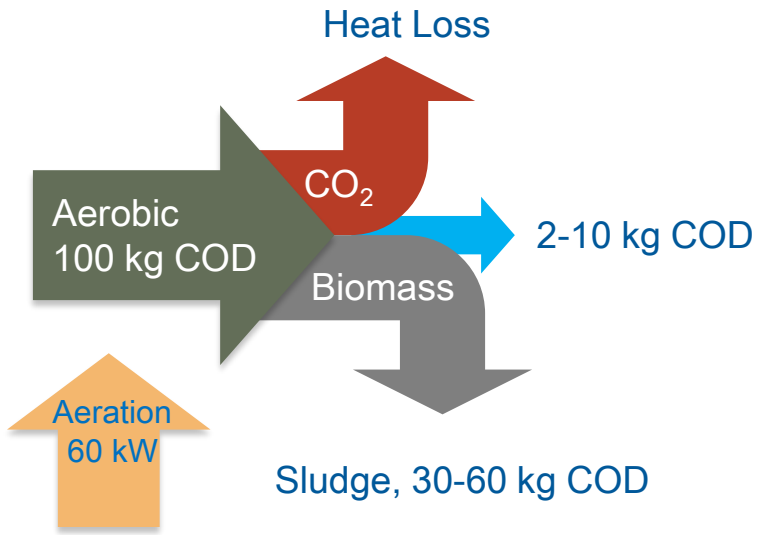
5. 
Conclusions

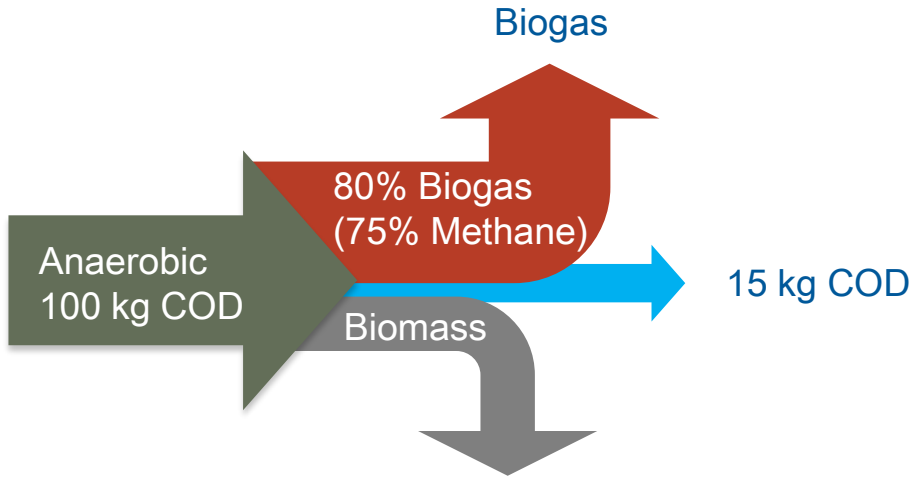
6. 
Recommendations for the Future Works

Rational

- Wastewater treatment services exerts a huge operational cost on public financial resources.
- A substantial portion of the operational budget is made up of carbon-intensive energy costs.
- Energy is consumed in this sector in pumping, aeration, motor drives, transportation and in the manufacture of chemicals such as polyelectrolyte, disinfectants.
- The high energy consumption exerts added pressure on the environment.

Aerobic vs Anaerobic Wastewater Treatment



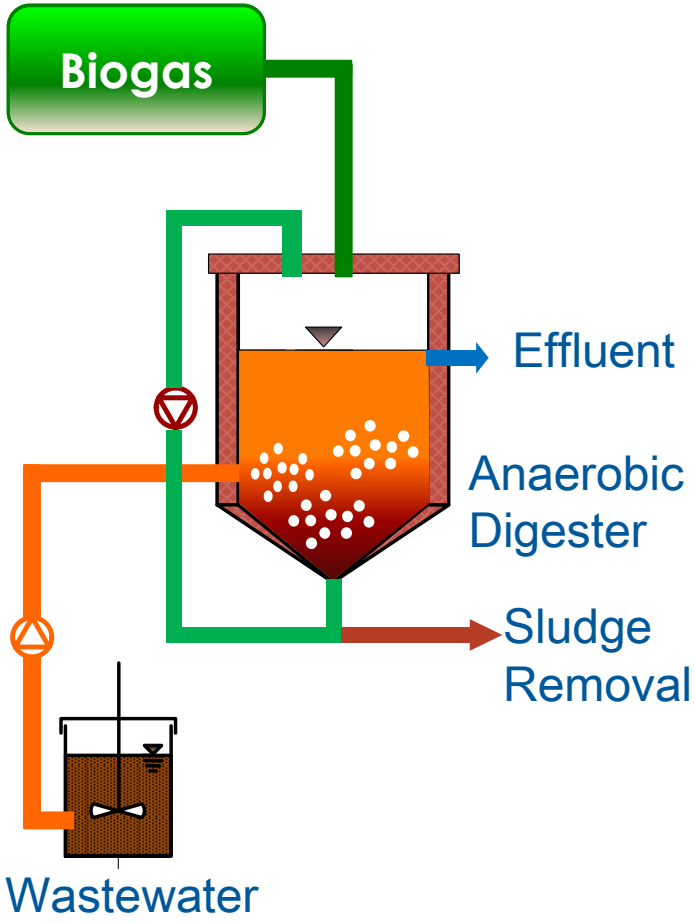


1 kg COD removed → 0.35 m^3 CH_4 → 3.8 kWh

Source: Chetty, S., & Pillay, K. (2015)

Anaerobic Digestion for Domestic Sewage

- Anaerobic Digestion (AD) → Widely using for wastewater and sludge treatment



Advantages

- Low sludge production
- Less energy requirement
- Reduce greenhouse gas outflow through use of methane gas
- Cost effective and sustainable technology

Treatment Efficiency Depends On

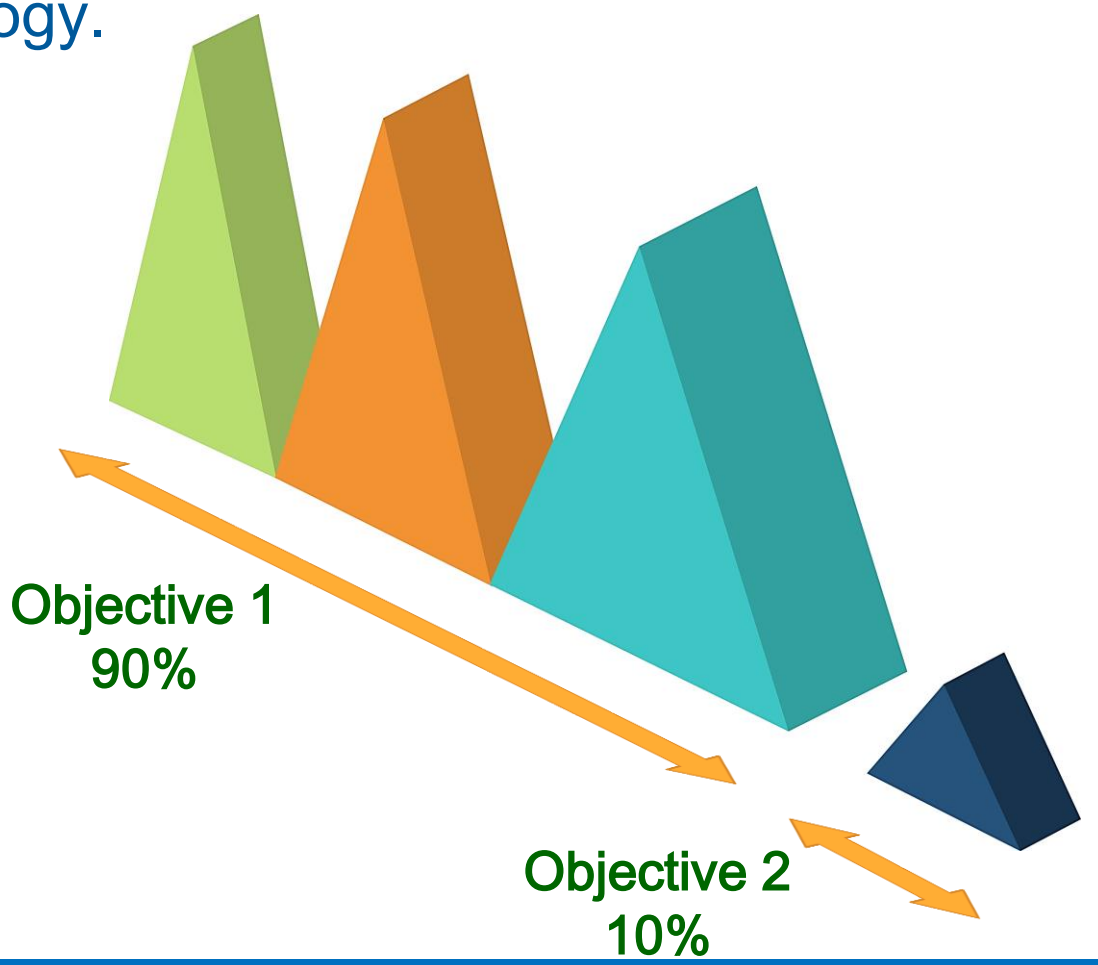
1. Extensive variety of microorganisms
2. Biological activity, pH, etc
3. Biomass concentration
4. Organic portion of the wastewater

How to Apply AD for Diluted Domestic Wastewater

Domestic Sewage → **Increase** → Increase Efficiency of AD

Research Objectives

1. To study pre-concentration, efficiency of domestic sewage with woven fiber microfiltration, tube settler and conical membrane tank applications.
2. To evaluate the performance of anaerobic digestion, with best performing pre-concentration technology.



Methodology

Research Framework

Domestic Sewage

Biological Treatment

Aerobic Treatment

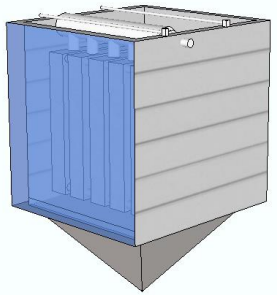
Anaerobic Treatment

Research Focus → Pre Concentration

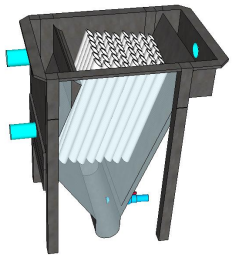
Pre Concentration Options

Stage 1

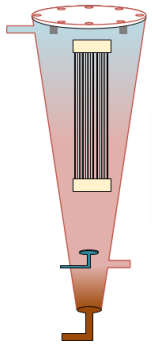
Woven Fiber Microfiltration

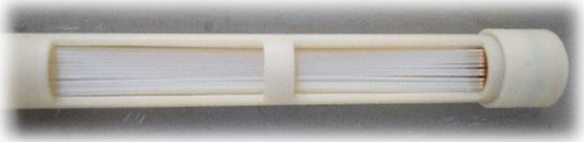


Tube Settler Application



Conical Membrane Tank Application

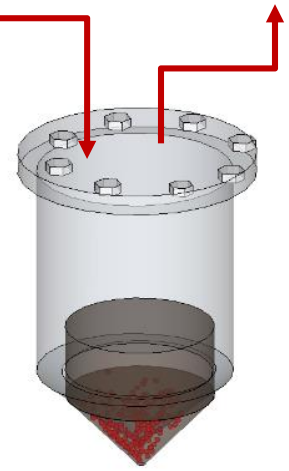




Pre Concentrated Wastewater From the best technology

Stage 2

Anaerobic Digestion

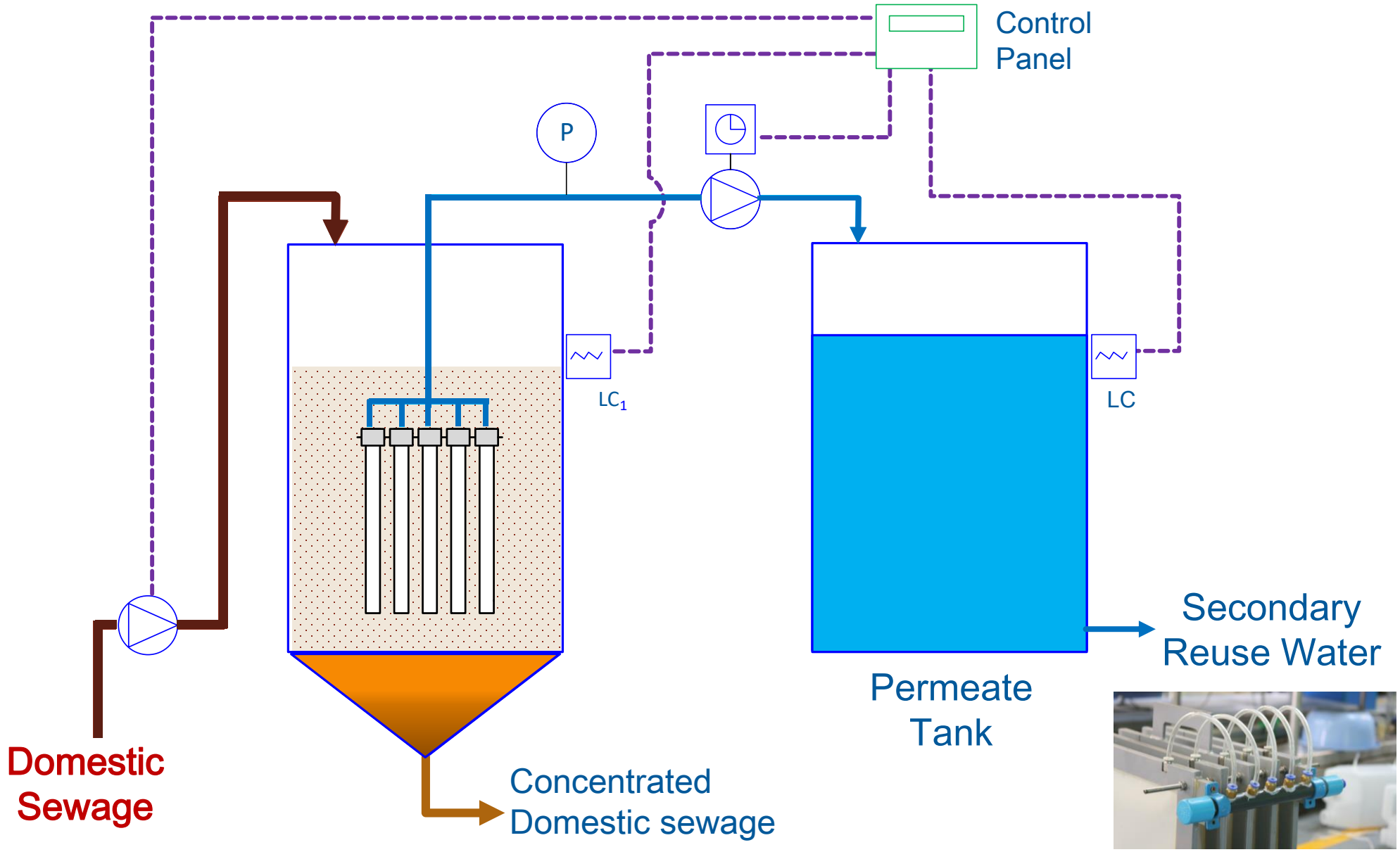


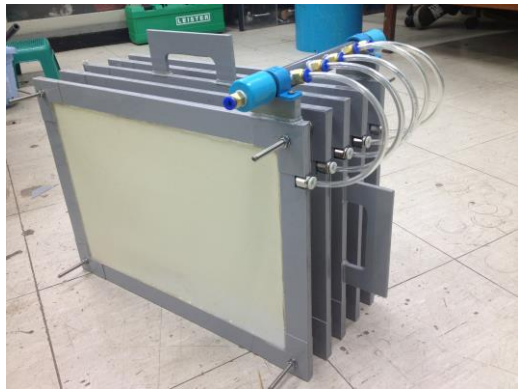
Bio Gas

Digested Sludge

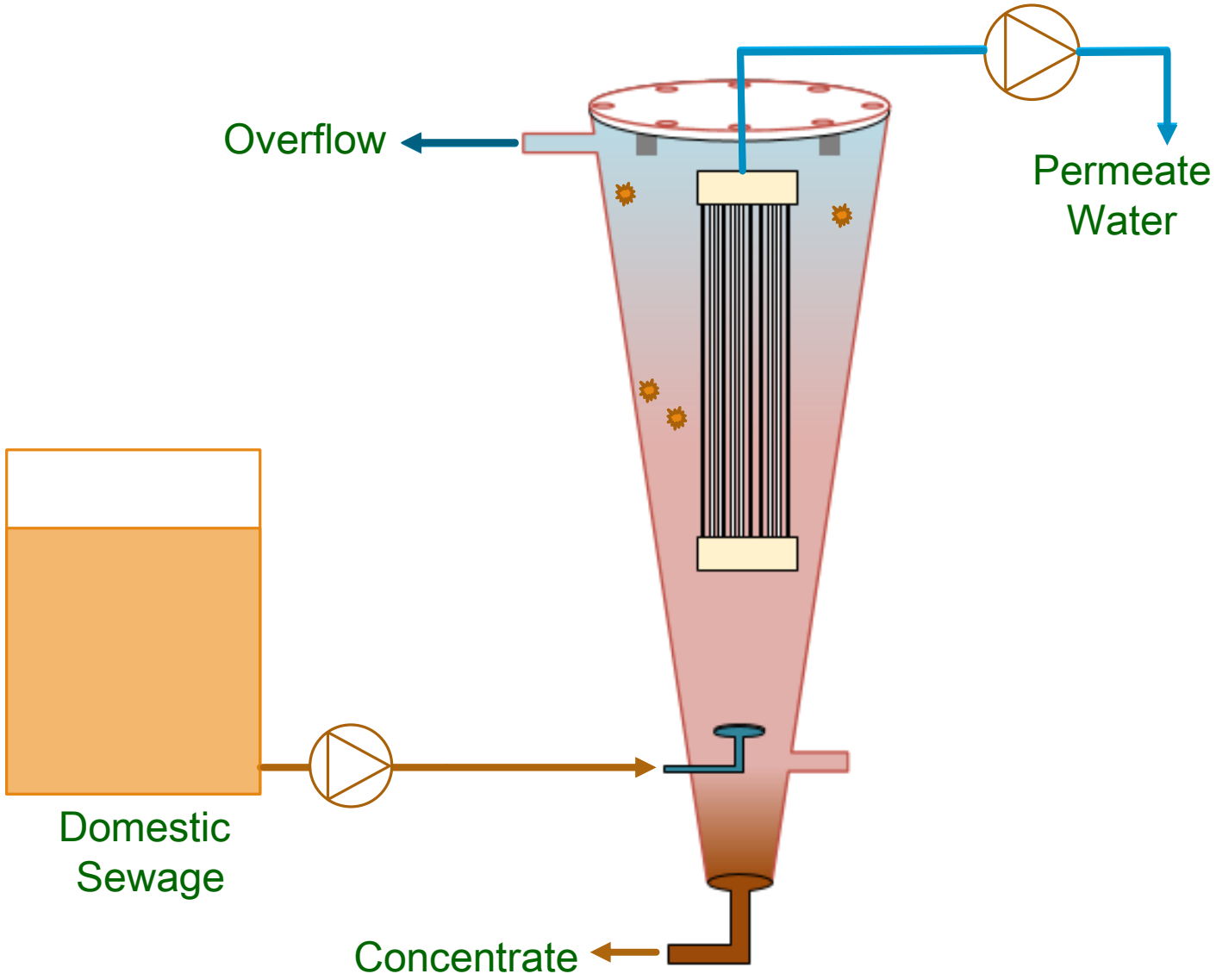
Stage 1: Pre-concentration Technologies

Woven Fiber Microfiltration (WFMF)





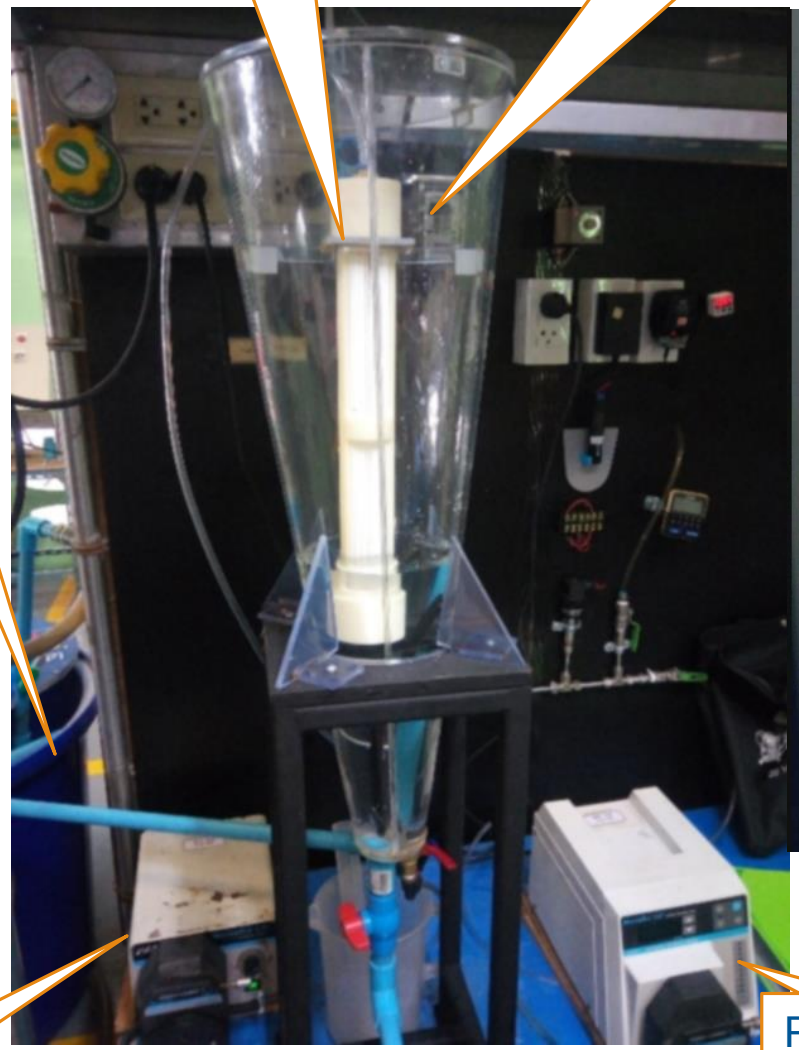
Conical Membrane Tank (CMT)

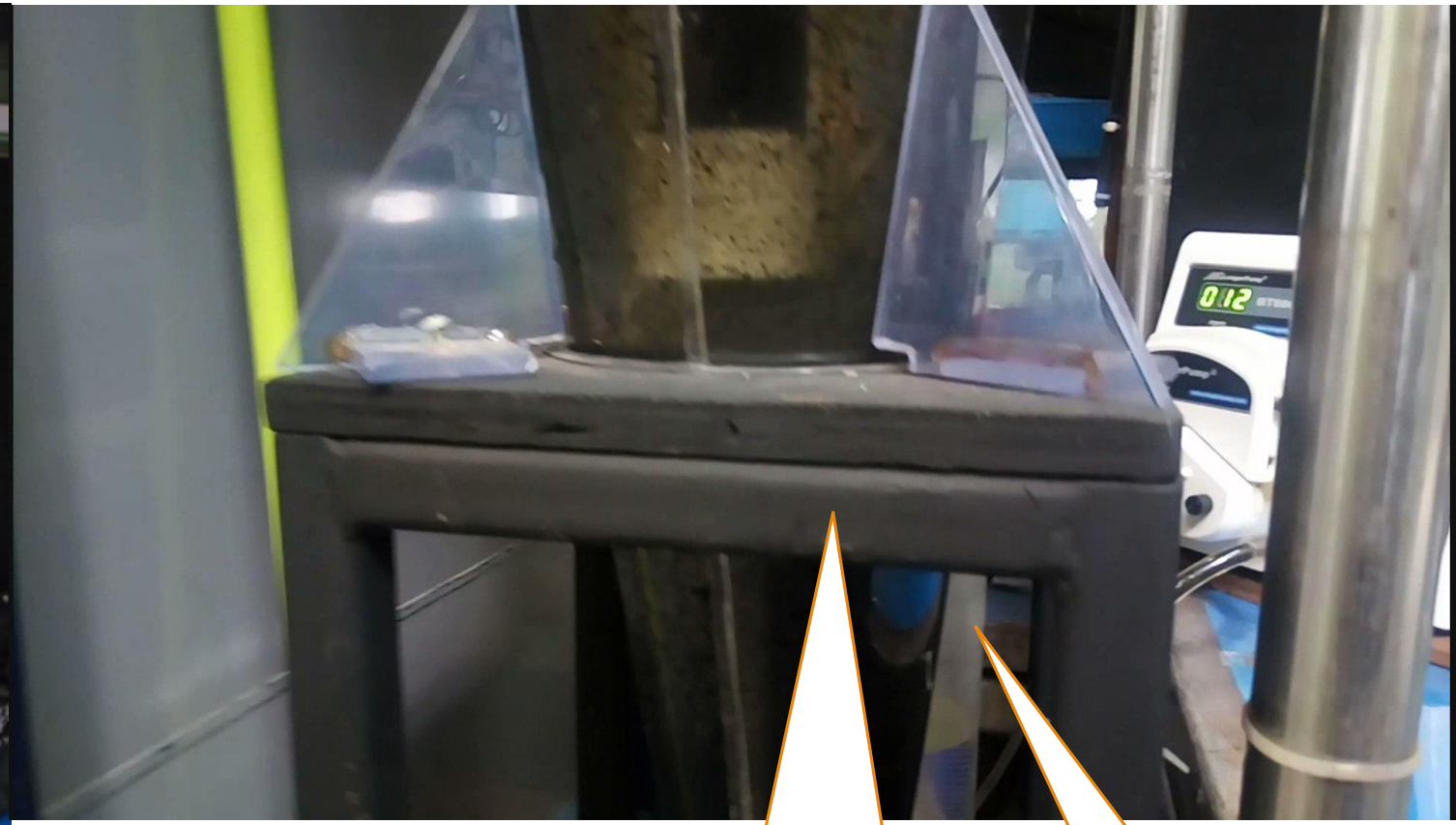


PTFE Hollow Fiber Membrane

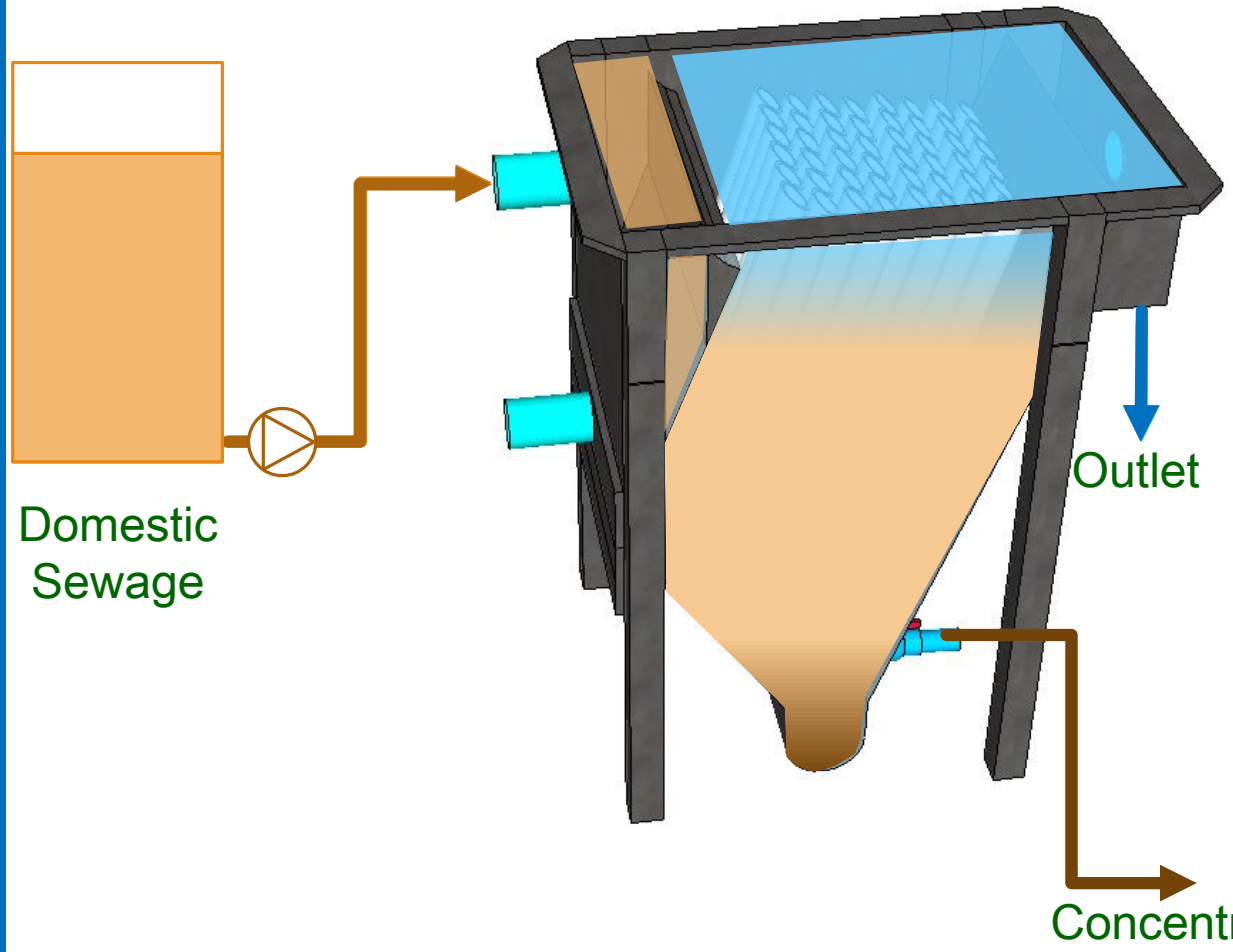
Description	Specification
Manufacturer	Sumitomo, Japan
Material	PTFE
Membrane configuration	Hollow fiber membrane
Membrane area	0.1 m^2 / module
Flux (PWF)	12-42 $L/m^2.h$
Pore size	0.1 µm
Tube diameter	0.8 mm
TMP (filtration)	< 60 kPa

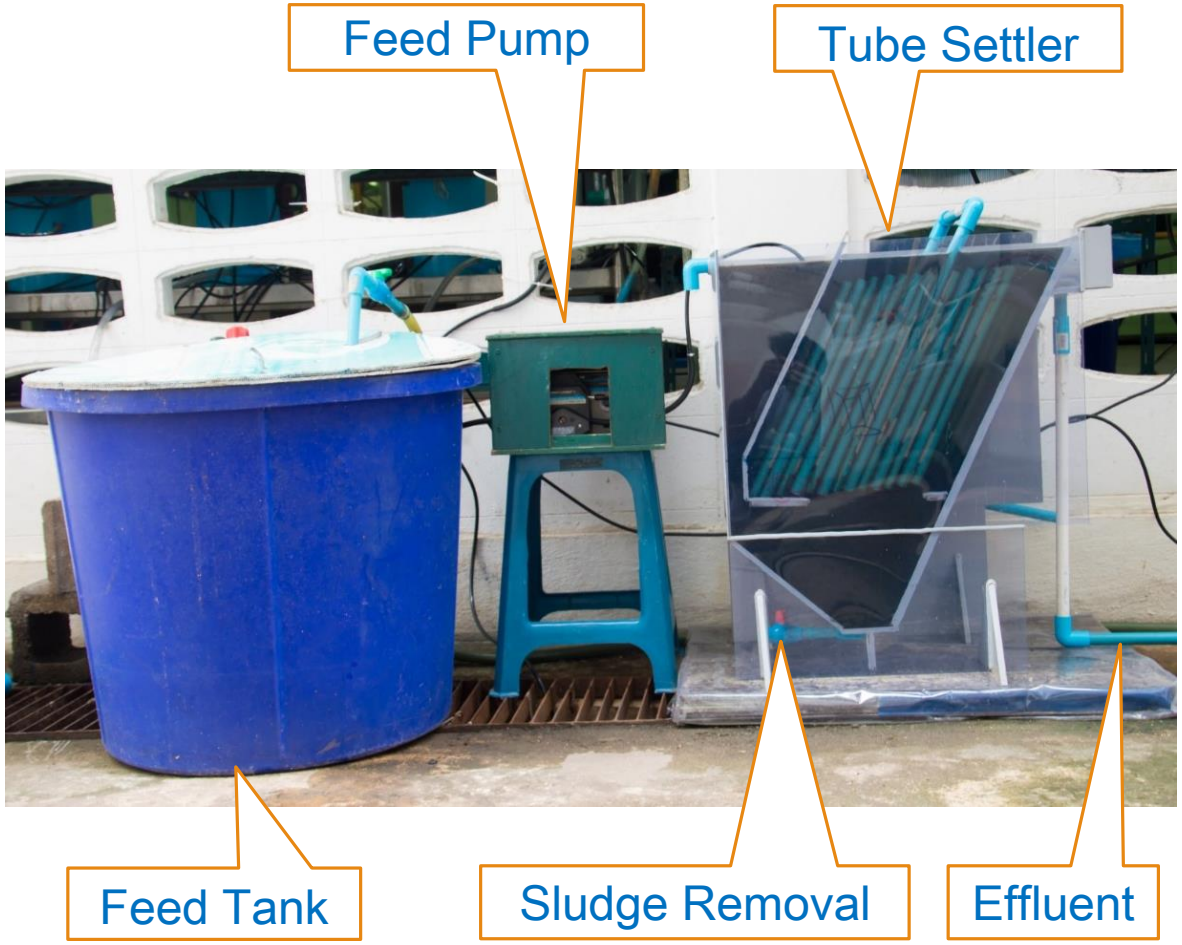
Conical Membrane Tank (CMT)





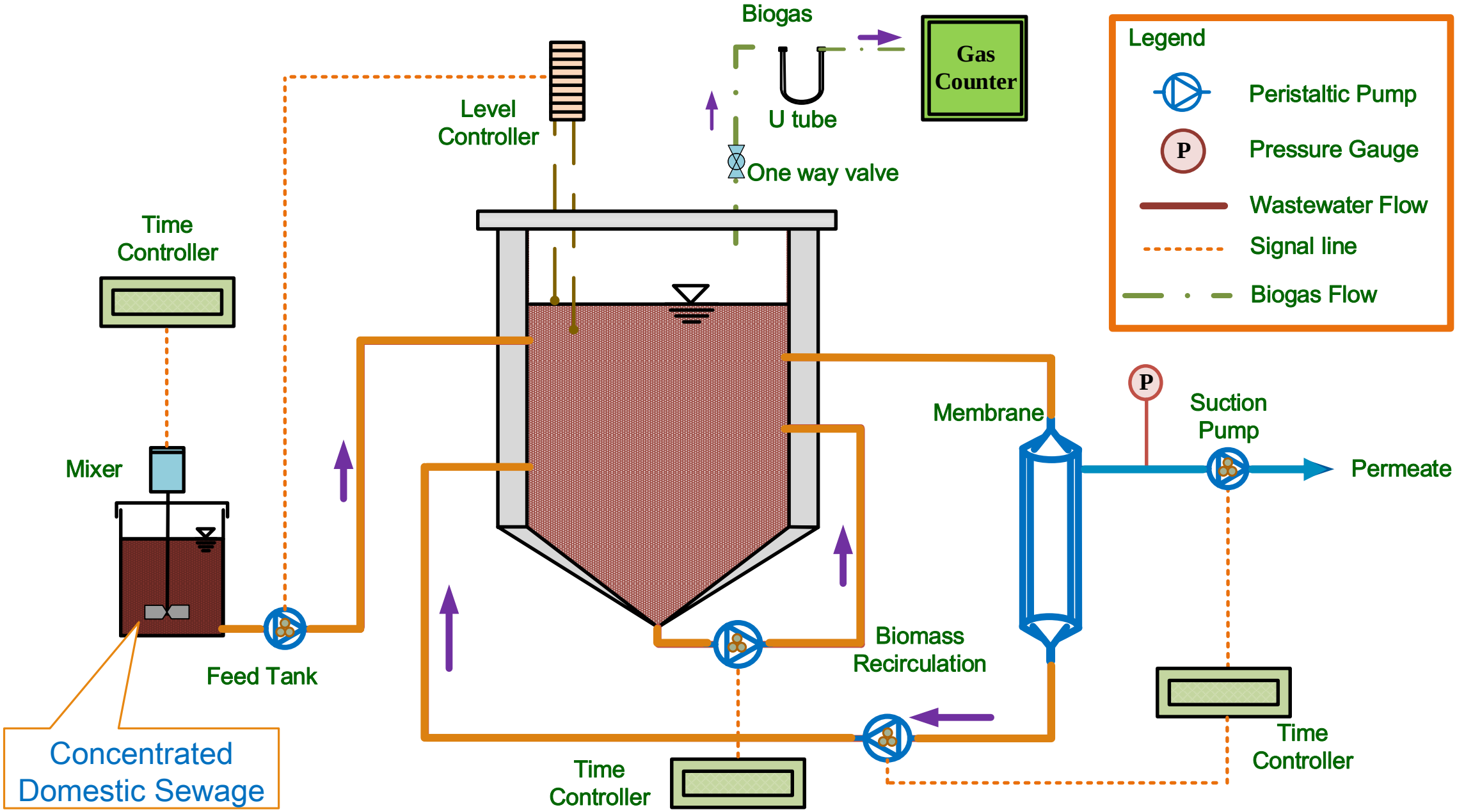
Tube Settler Application



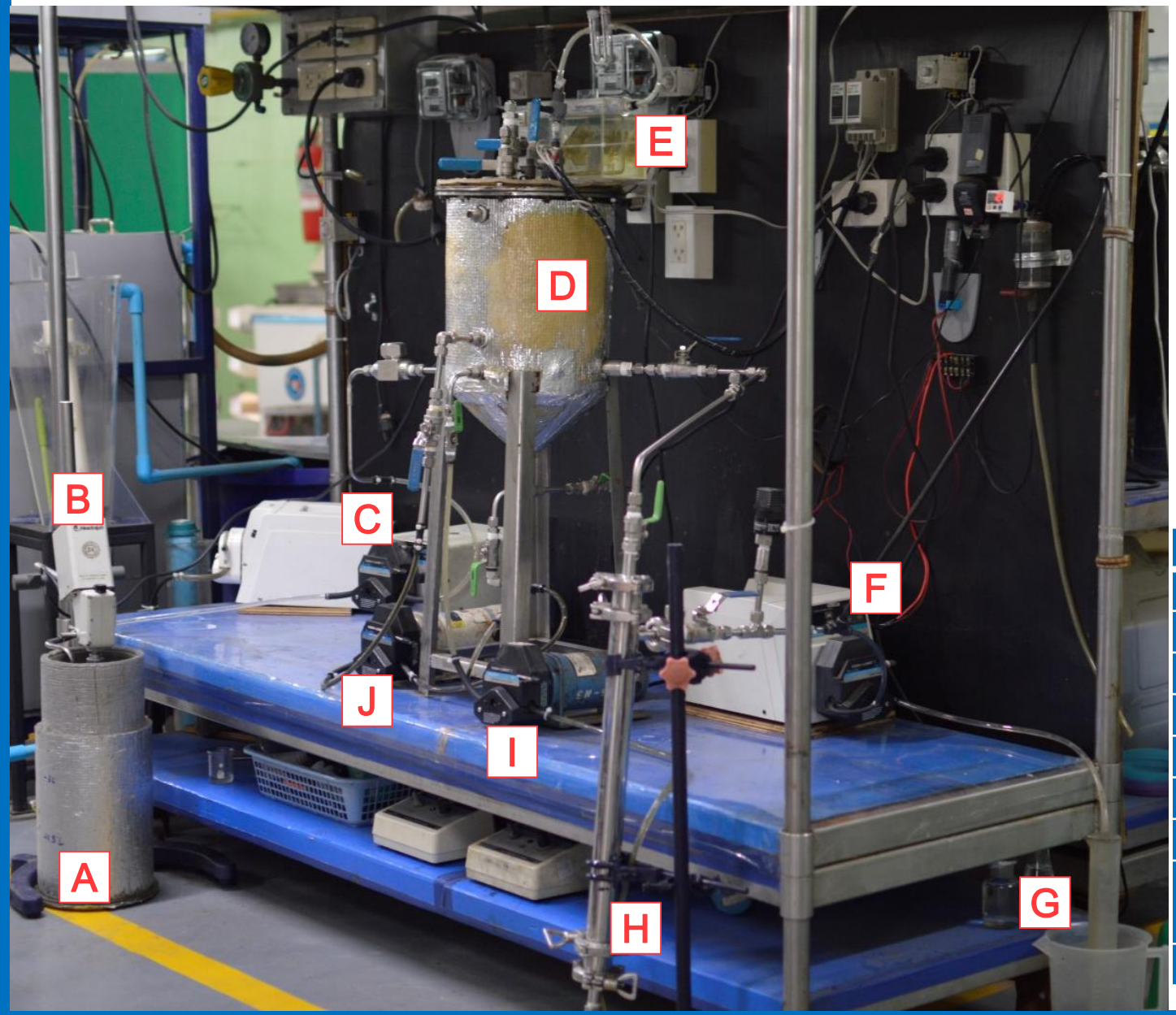


Stage 2: Anaerobic Membrane Bioreactor

Anaerobic Membrane Bioreactor



Anaerobic Membrane Bioreactor

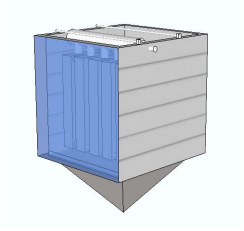


A. Feed Tank
B. Mixer
C. Feed Pump
D. Anaerobic Reactor
E. Gas Counter
F. Permeate Pump
G. Effluent
H. Ceramic Membrane Module
I. Cross-flow Pump
J. Mixing Pump

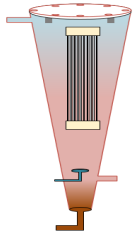
Operating Conditions

Parameters	Unit	Overall
Temperature	°C	26-30
Influent COD	g/L	6-7
Loading rate	Kg COD/m^3.d	3.2
HRT	d	2.18
SRT	d	∞
Flow rate	L/d	2.74
Working volume	L	6
Biomass retention	-	Ceramic membrane filtration
Permeate flux	L/m^2.h	0.63

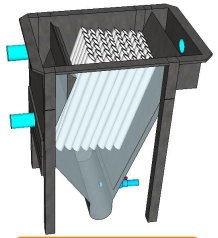
Results and Discussions- (Objective 1)



(WFMF)



(CMT)



(TSET)

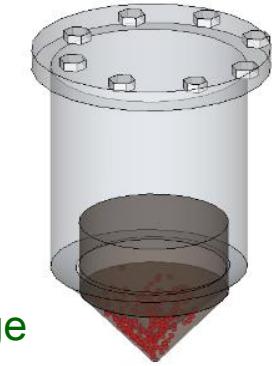
Technology Comparison

Individual Performance

1. Membrane Flux
2. COD Pre-concentration Ability
3. TSS Accumulation
4. Cleaning Performance
5. Energy Consumption

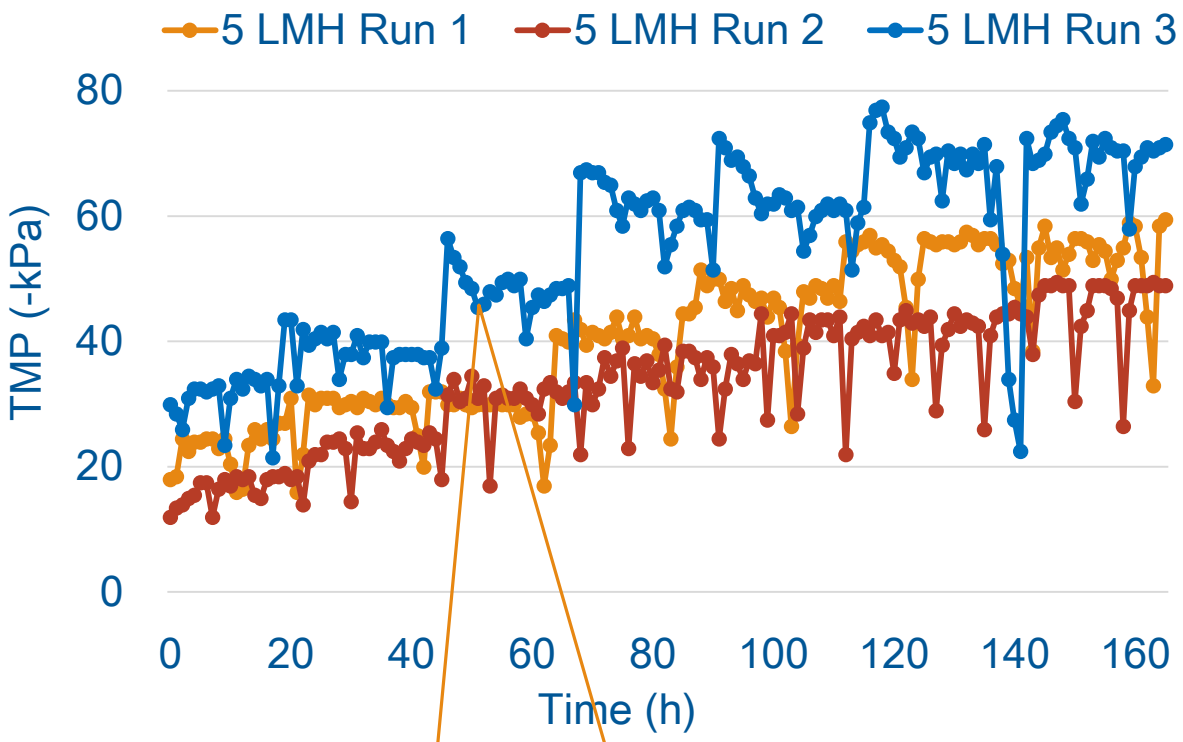
Concentrated Domestic Sewage

AnMBR



Woven Fiber Microfiltration System (WFMF)- Membrane Flux

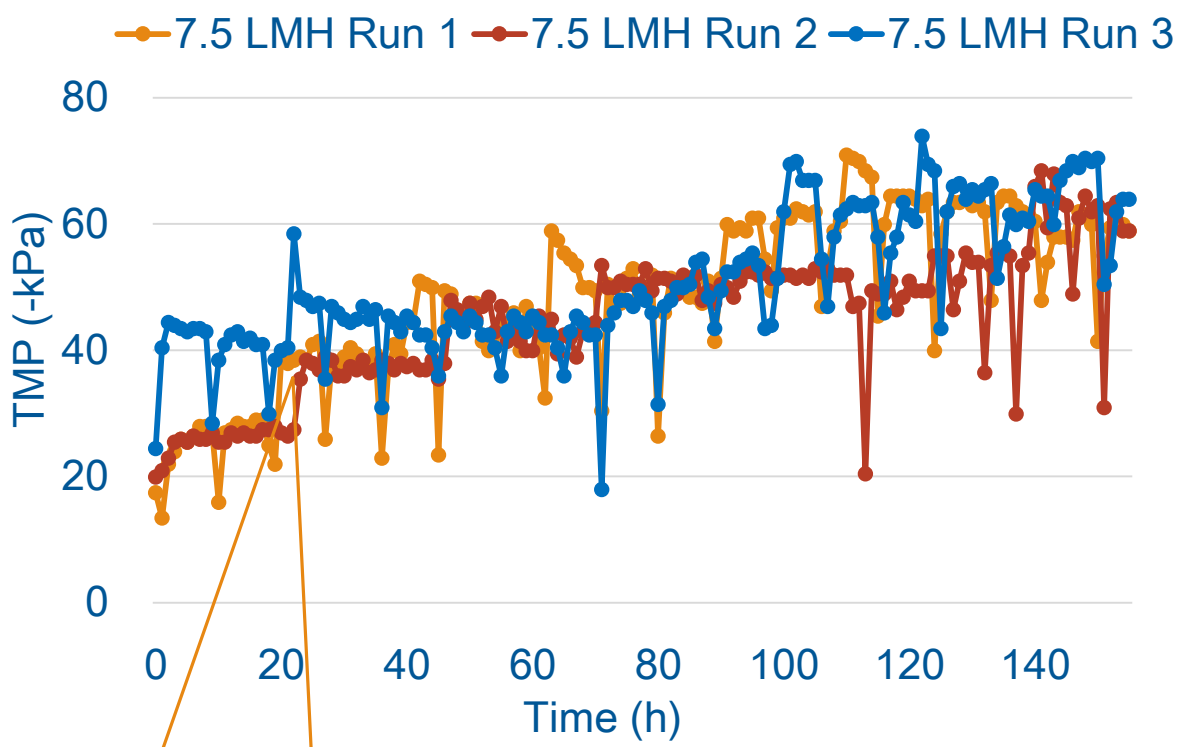
5 LMH Flux- Compilation of the Triplicates



Inorganic Fouling Accumulation

This indicates that this system could be operated with higher filtration rate with proper chemical cleaning.

7.5 LMH Flux- Compilation of the Triplicates

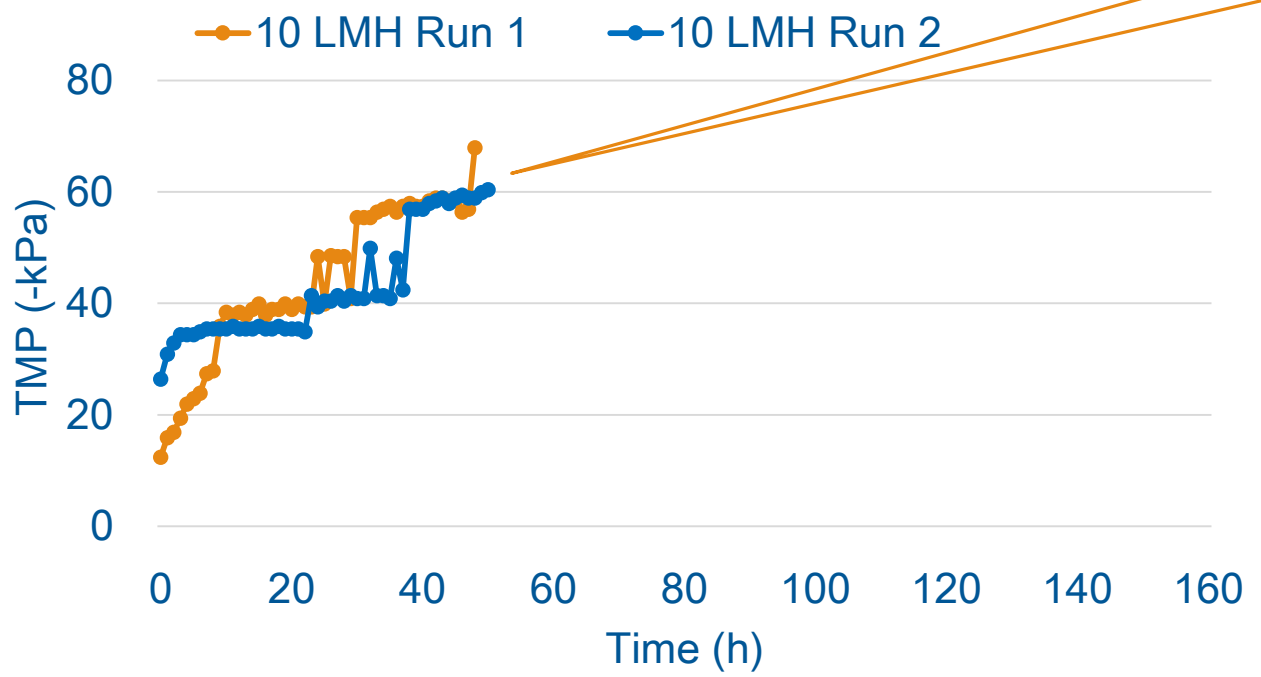


Same Trend for All the Test

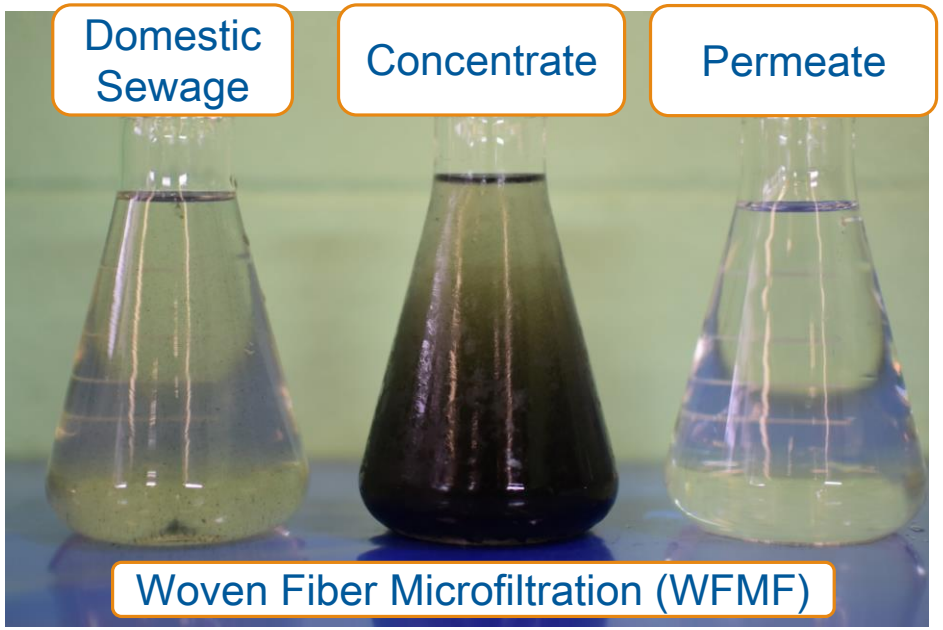
7.5 LMH – Sustainable flux up to this point.

Woven Fiber Microfiltration System (WFMF))- Membrane Flux

10 LMH Flux



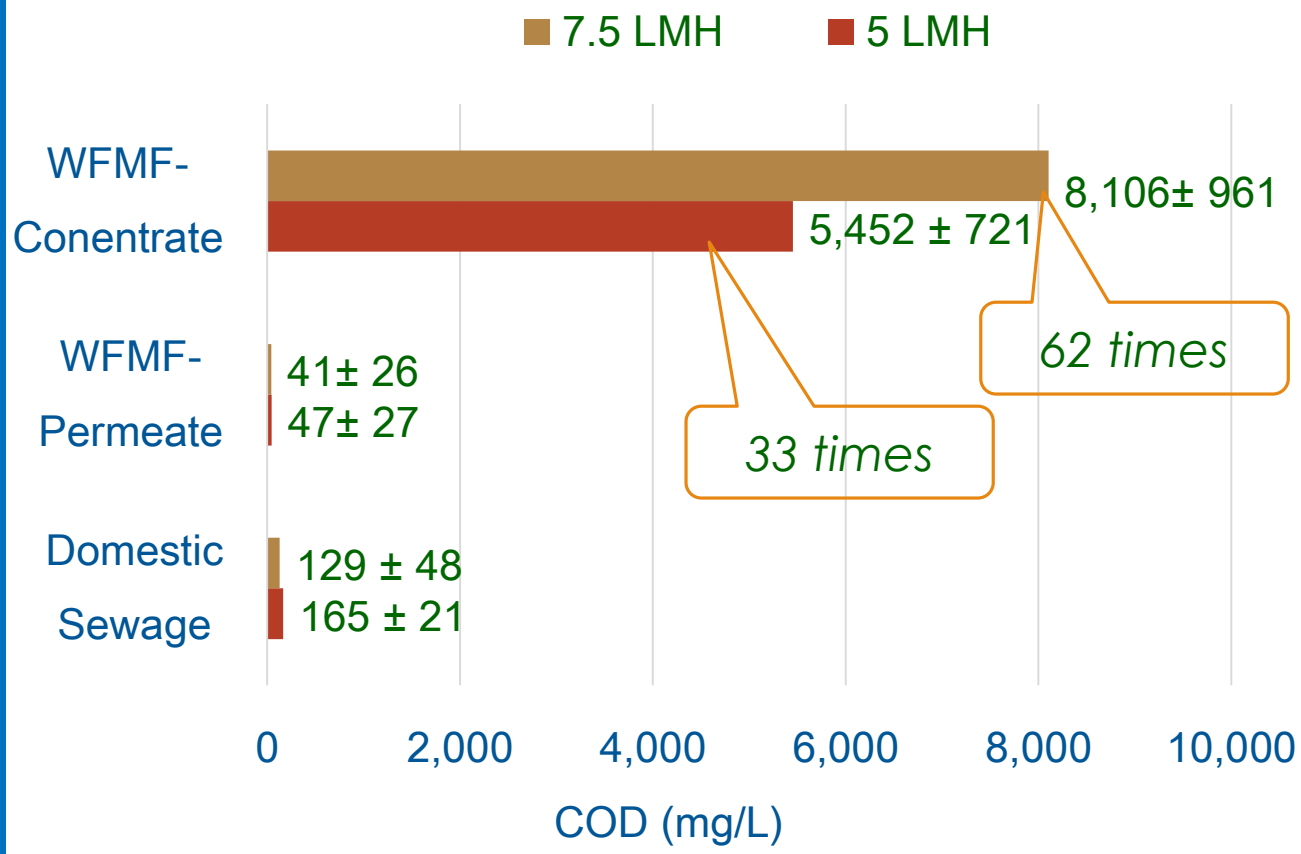
Pressure reached to the cleaning point with a short time period.



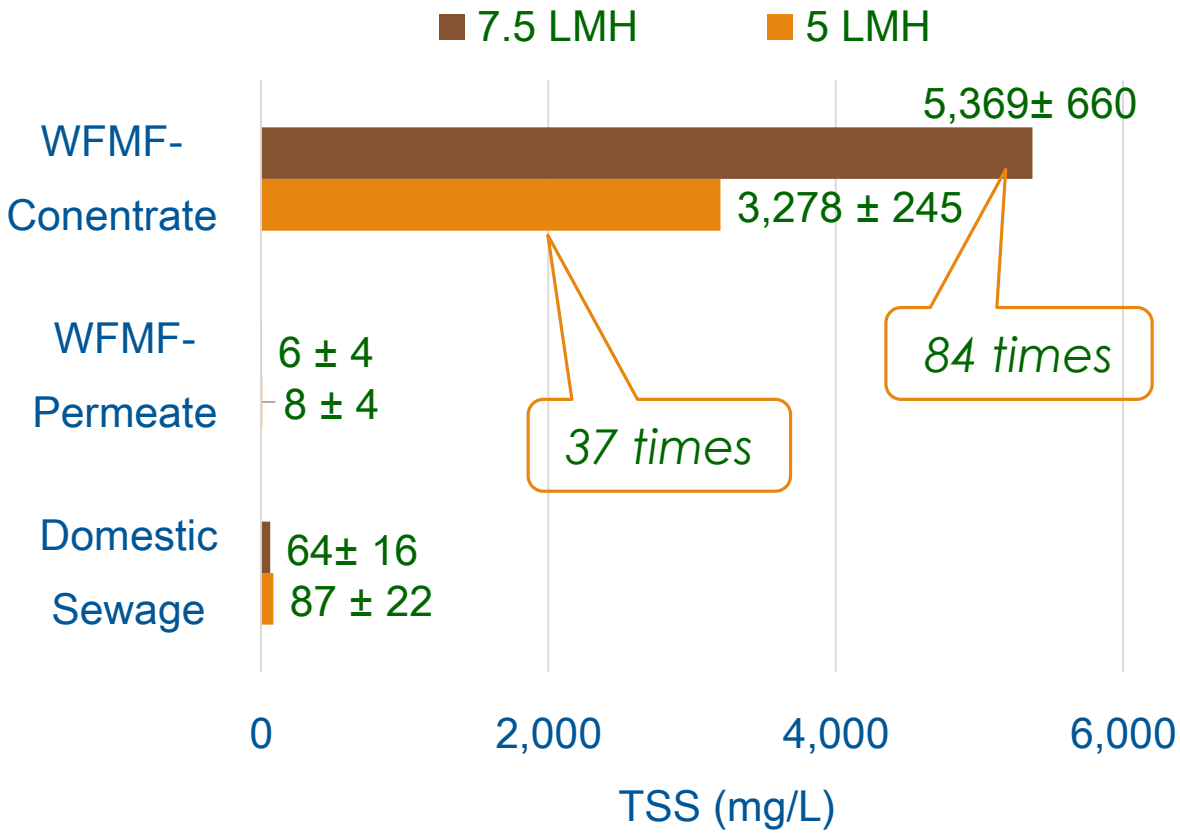
After comparing the three different flux, the 7.5 LMH was found to be the best in terms of the operation.

Woven Fiber Microfiltration System (WFMF) - COD & TSS Pre-concentration

COD Pre-concentration performance



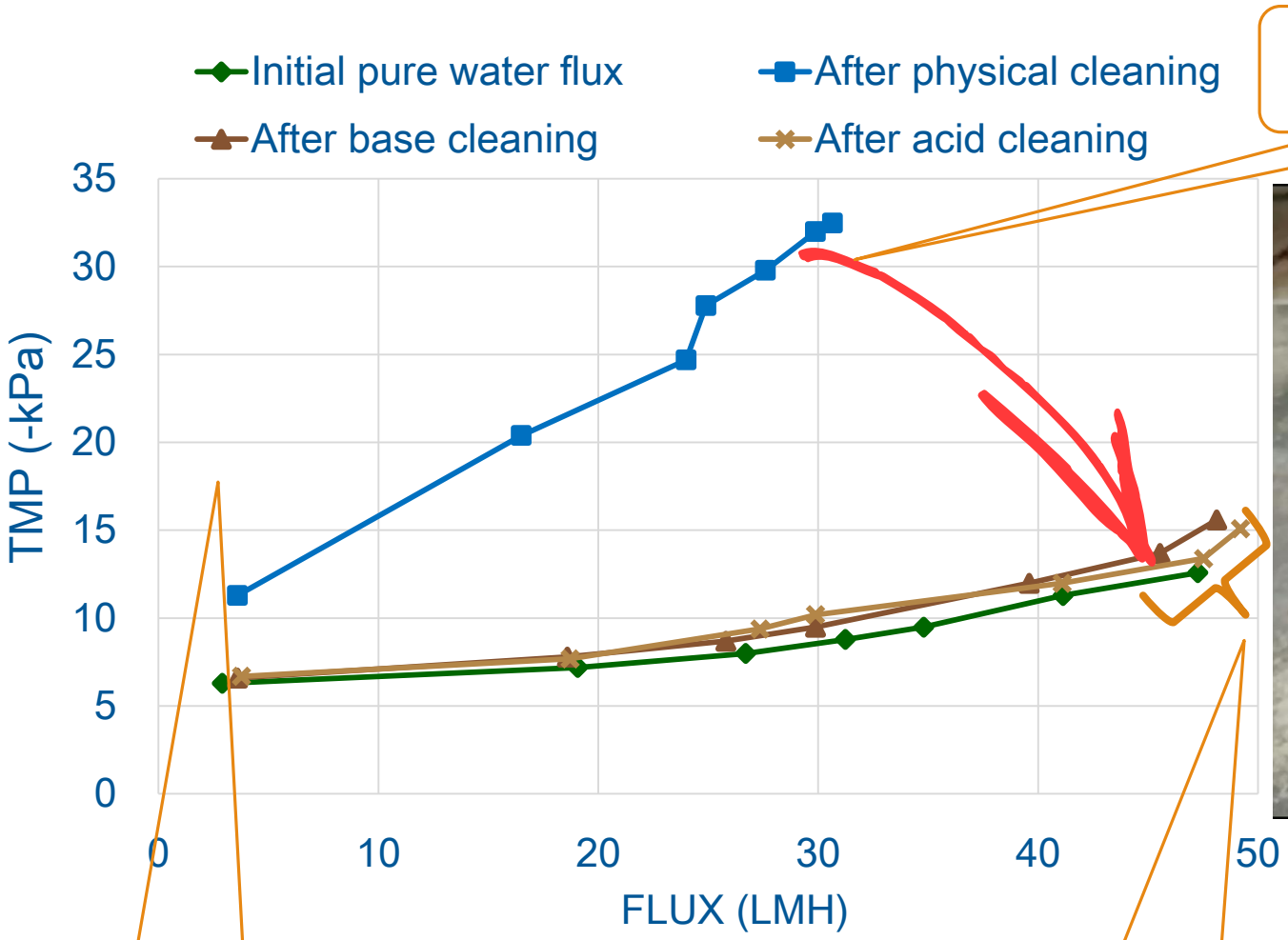
TSS Accumulation



COD has a positive relationship with TSS.

TSS accumulation resulting the higher COD concentrations of the concentrate.

Woven Fiber Microfiltration System (WFMF)- Cleaning Performance



Resistance due to organic fouling

57 %

Resistance due to cake layer

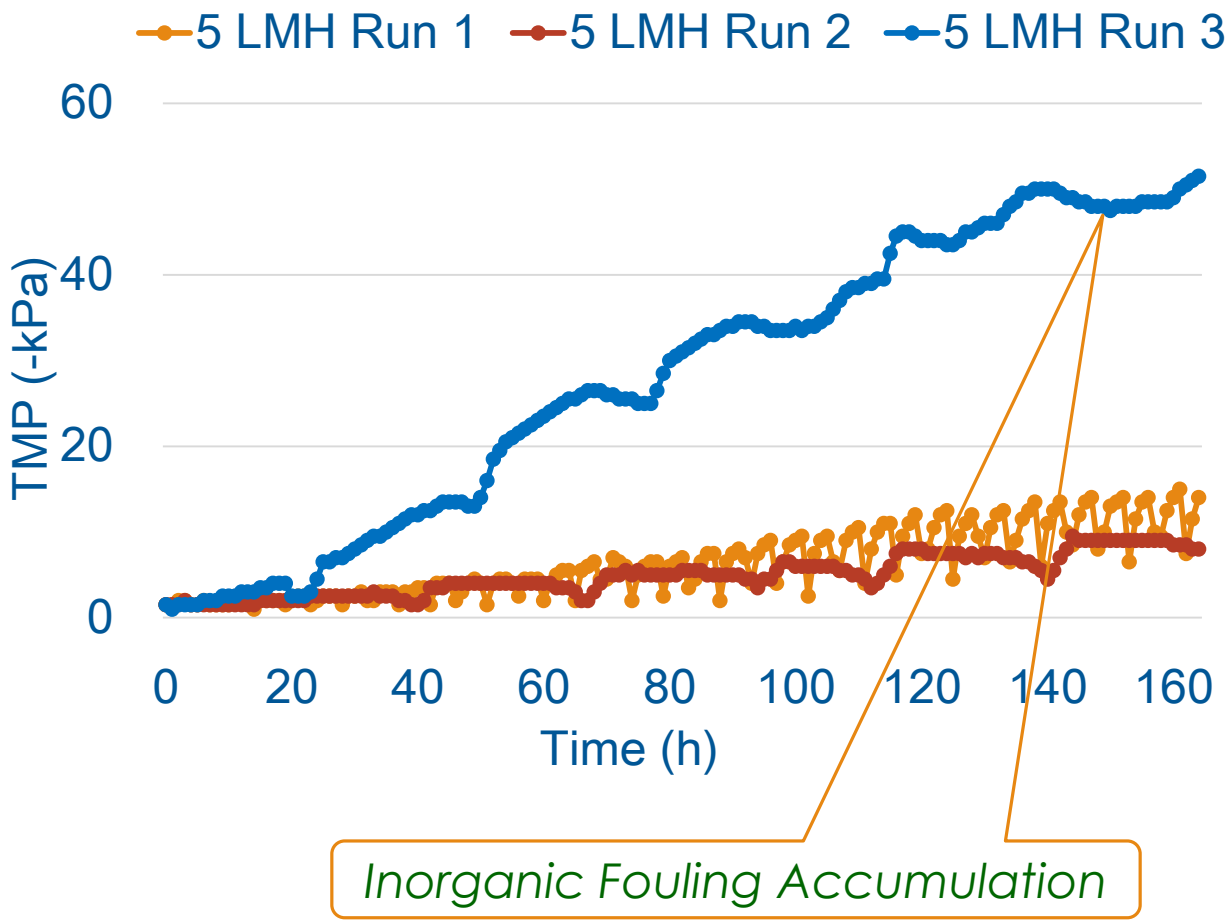
32 %

Inorganic fouling

1 %

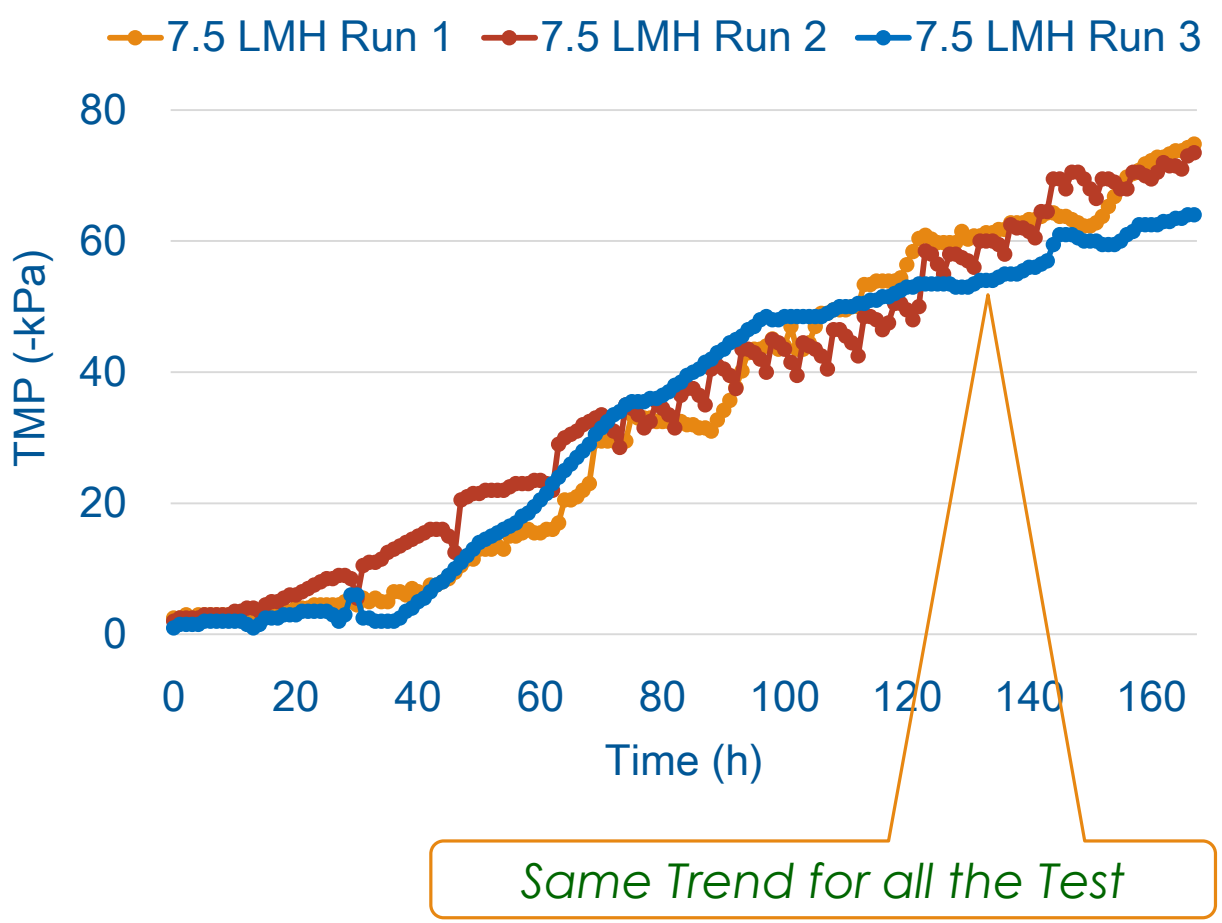
Conical Membrane Tank (CMT)- Membrane Flux

5 LMH Flux- Compilation of the Triplicates



Flux can be increased with the proper cleaning method

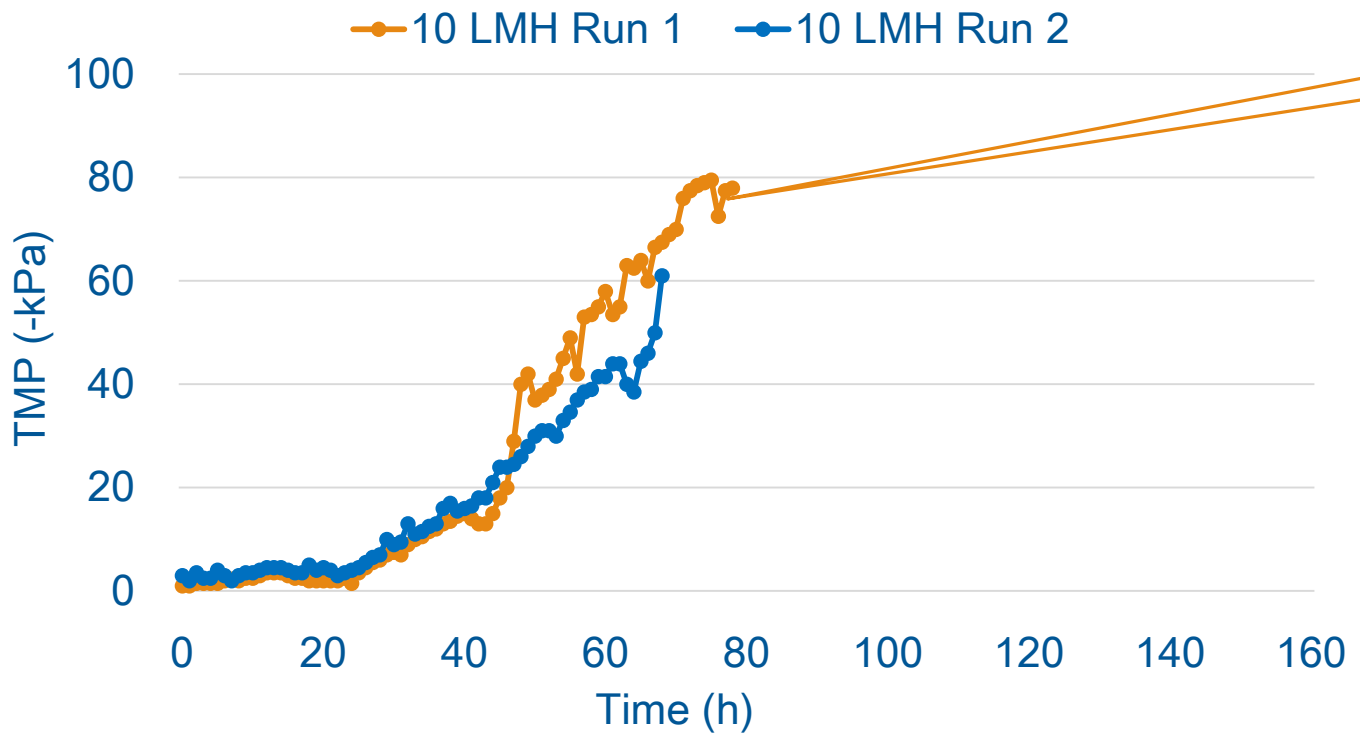
7.5 LMH Flux- Compilation of the Triplicates



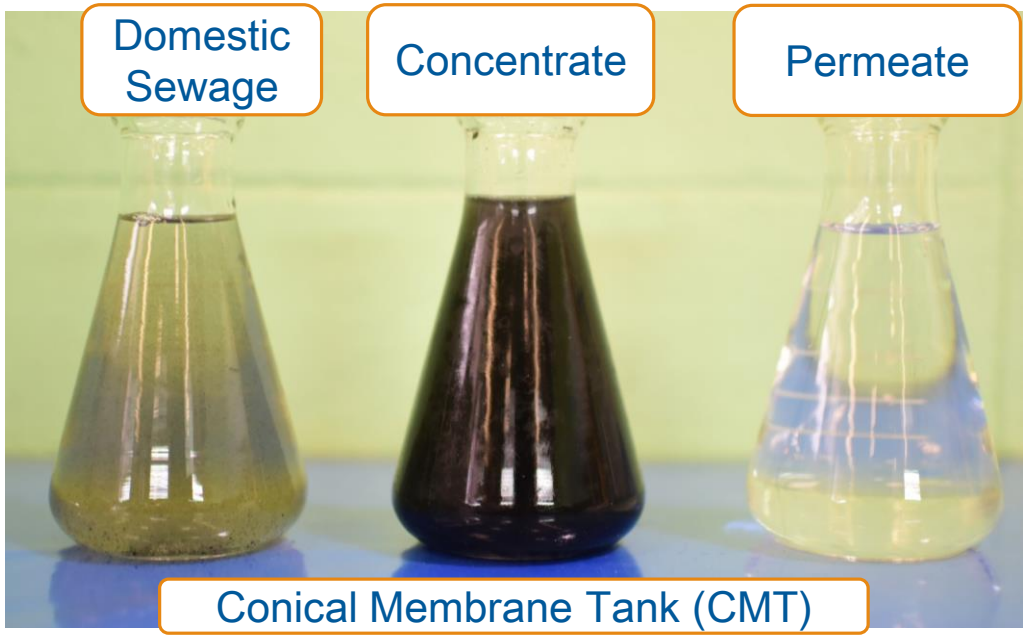
7.5 LMH – Sustainable flux up to this point

Conical Membrane Tank (CMT)- Membrane Flux

10 LMH Flux



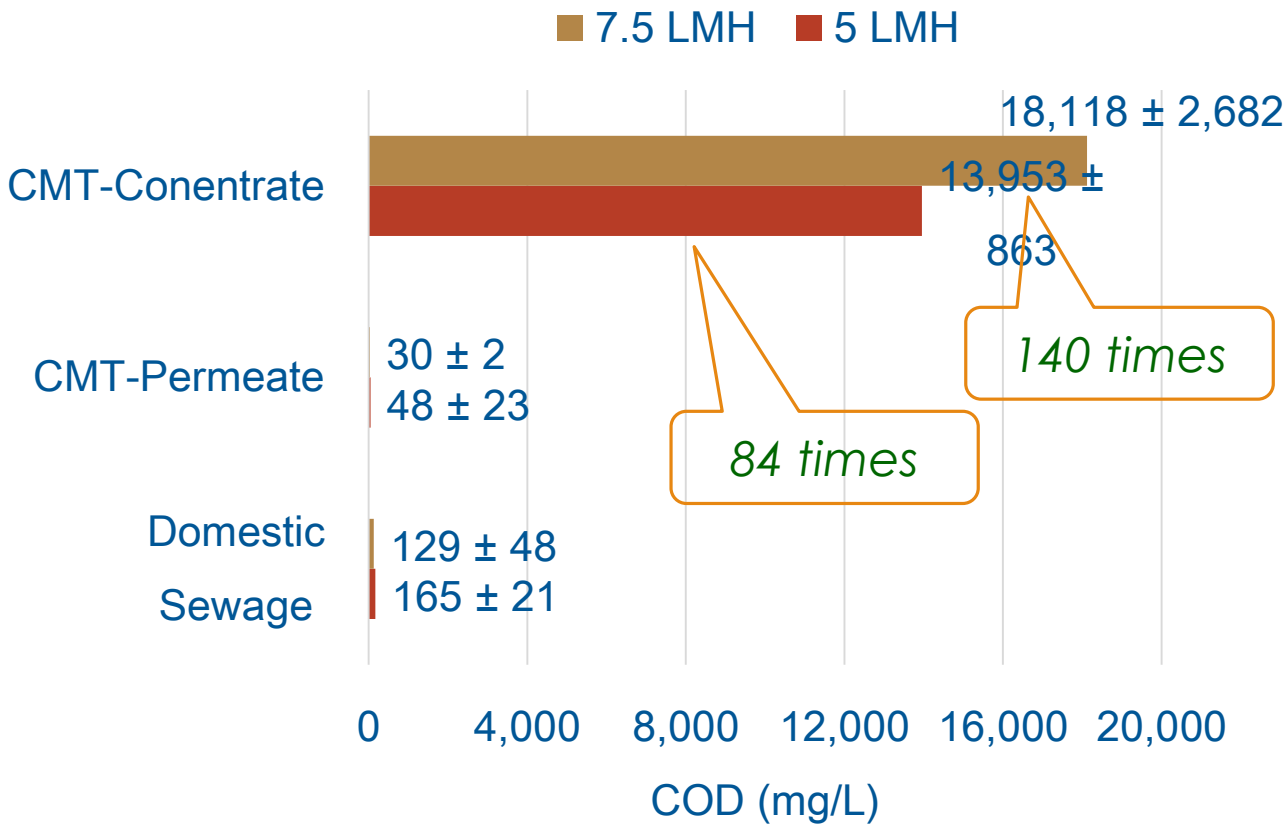
Pressure reached to the cleaning point with a short time period.



After comparing the three different flux, the 7.5 LMH was found to be the best in terms of the operation.

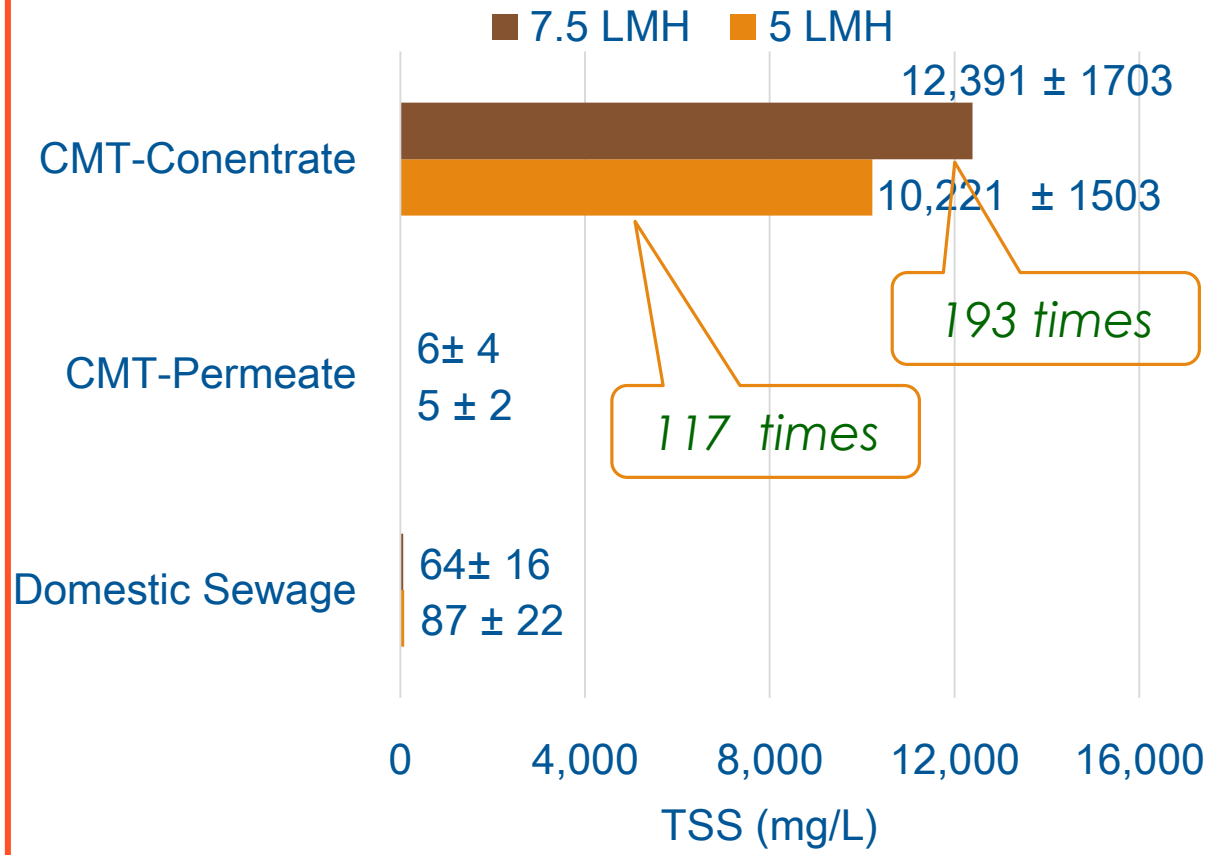
Conical Membrane Tank (CMT)- COD & TSS Pre-concentration

COD Pre-concentration performance



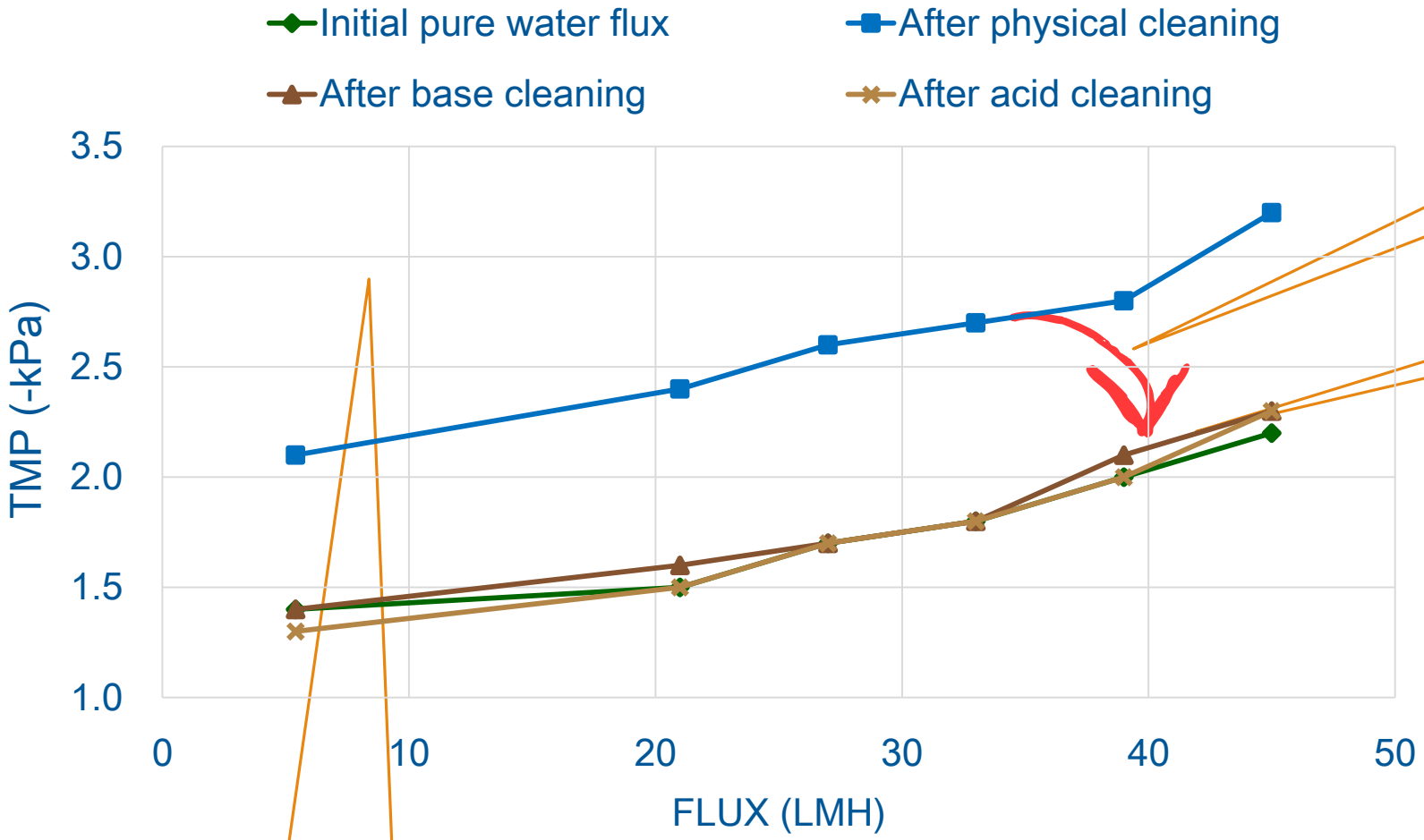
COD has a positive relationship with TSS.

TSS Accumulation



Conical shaped tank, enhancing the settlement of the suspended solid particles in an efficient way.

Conical Membrane Tank (CMT)- Cleaning Performance



Resistance due to organic fouling

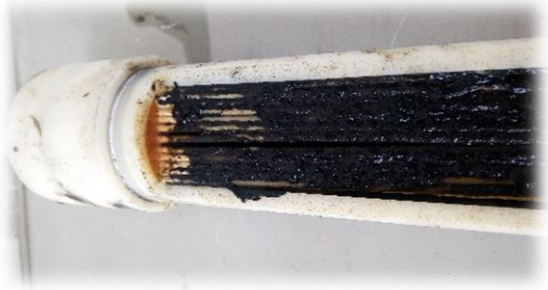
7-30 %

Inorganic fouling

1 %

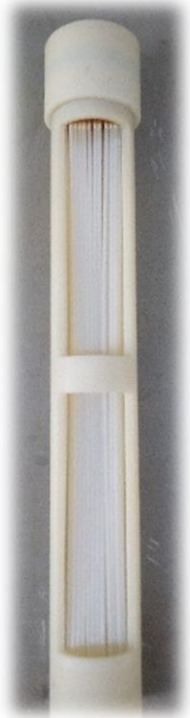
Resistance due to cake layer

86-90 %



Fouled Membrane

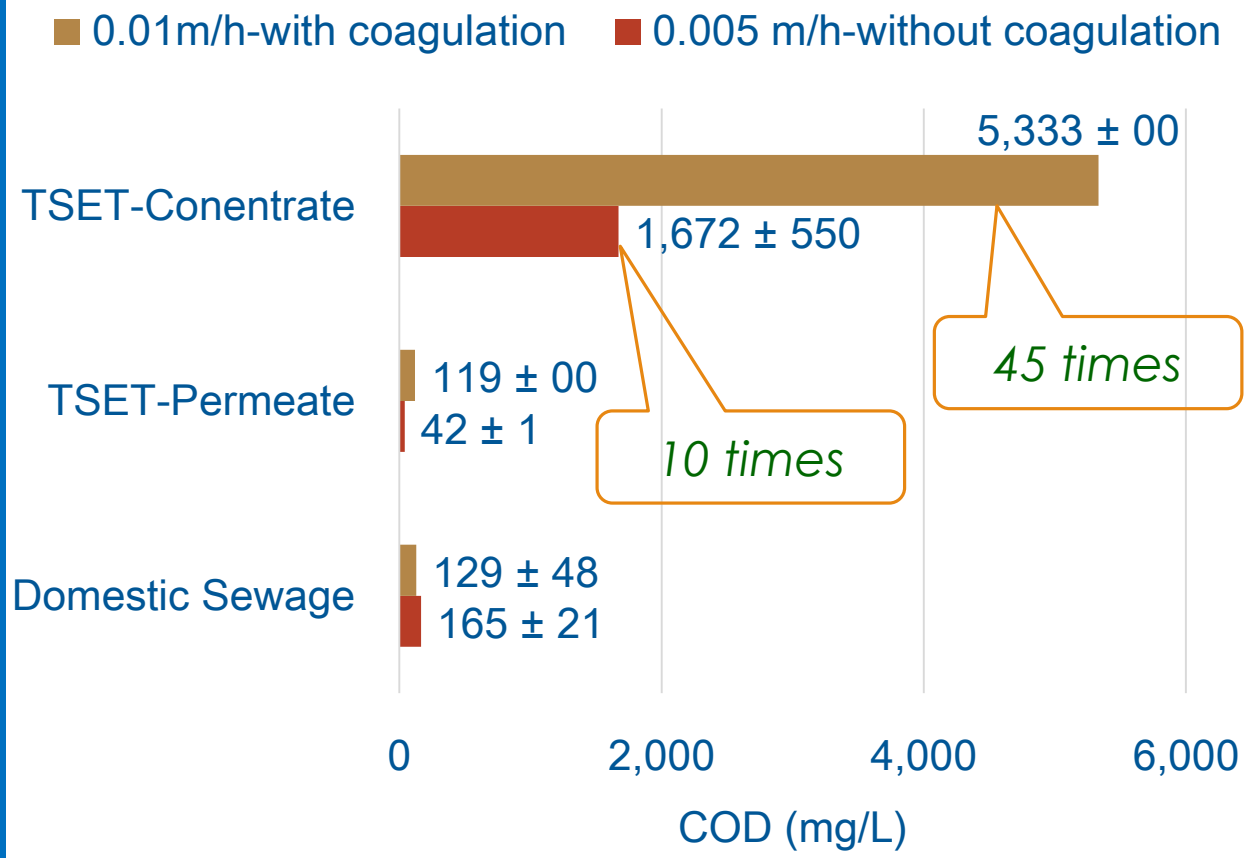
After Physical Cleaning



After Chemical Cleaning

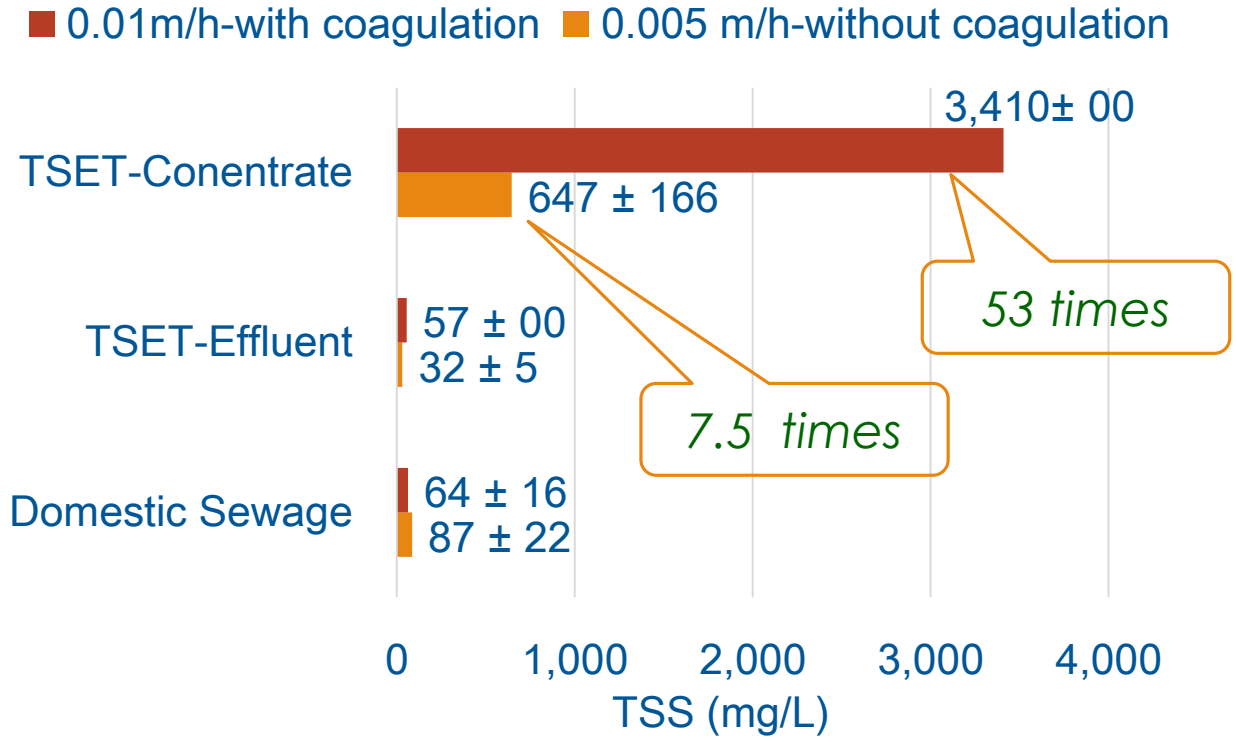
Tube Settler (TSET)- COD & TSS Pre-concentration

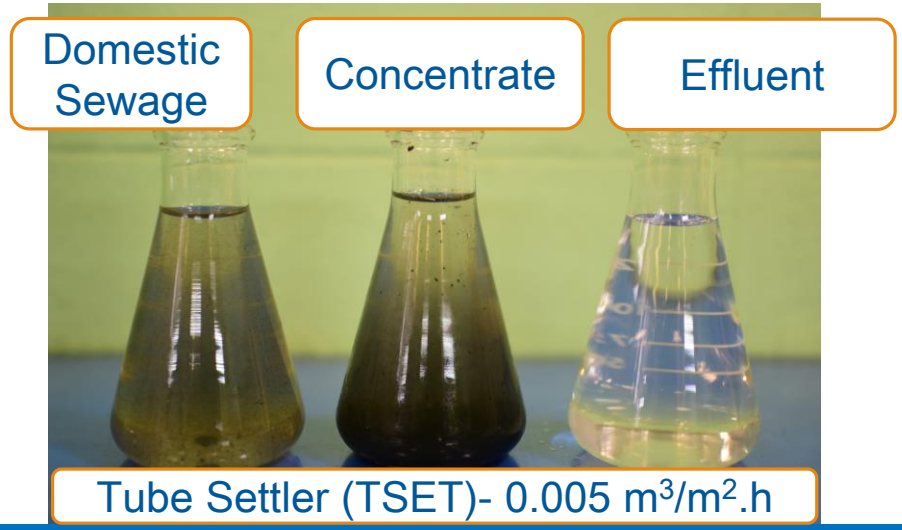
COD Pre-concentration performance



$m^3/m^2.h \longrightarrow m/h$

TSS Accumulation





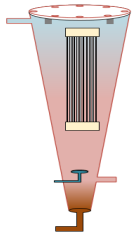
Tube Settler (TSET)- 0.005 $m^3/m^2.h$

Overall Comparison of the Pre-concentration Technologies

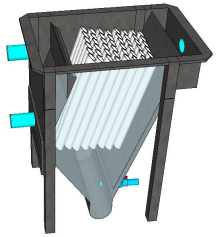
COD Pre-concentration- Concerned Factors

1 Common Unit

(WFMF)



(CMT)



(TSET)

Different technologies

Different system volumes

Different sludge cone volumes

Common unit that comparable

1. g COD
2. Filtered volume
3. Time duration

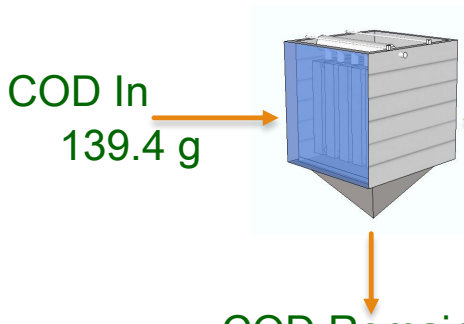
COD Pre-concentration Evaluation → **g COD/m³.d**

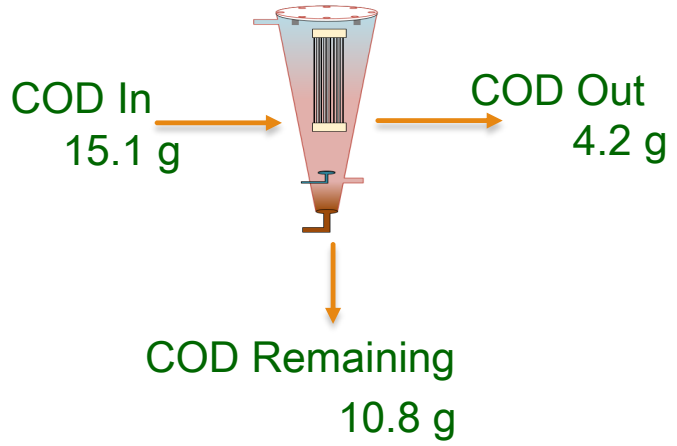
2 Sludge Cone Volume

	WFMF	CMT	TSET
Total Volume(L)	130	23	72
Sludge Cone Volume (L)	23.5	0.9	18.0

Example

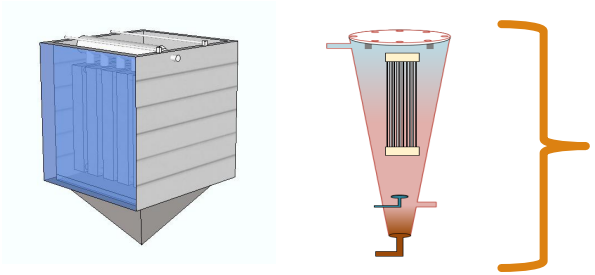
Theoretical mass balance- For 5 LMH Flux



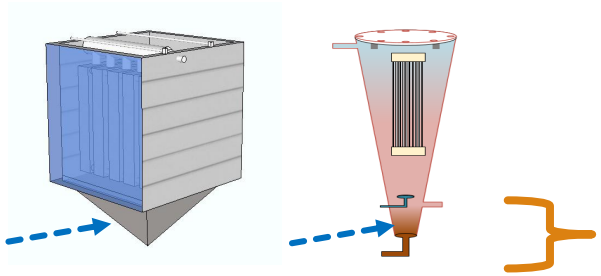


COD Pre-concentration- Concerned Factors

Example



	WFMF	CMT
Full tank volume (L)	130	23
COD concentration (mg/L)	96,600/130 = 743	10,829/23 = 470



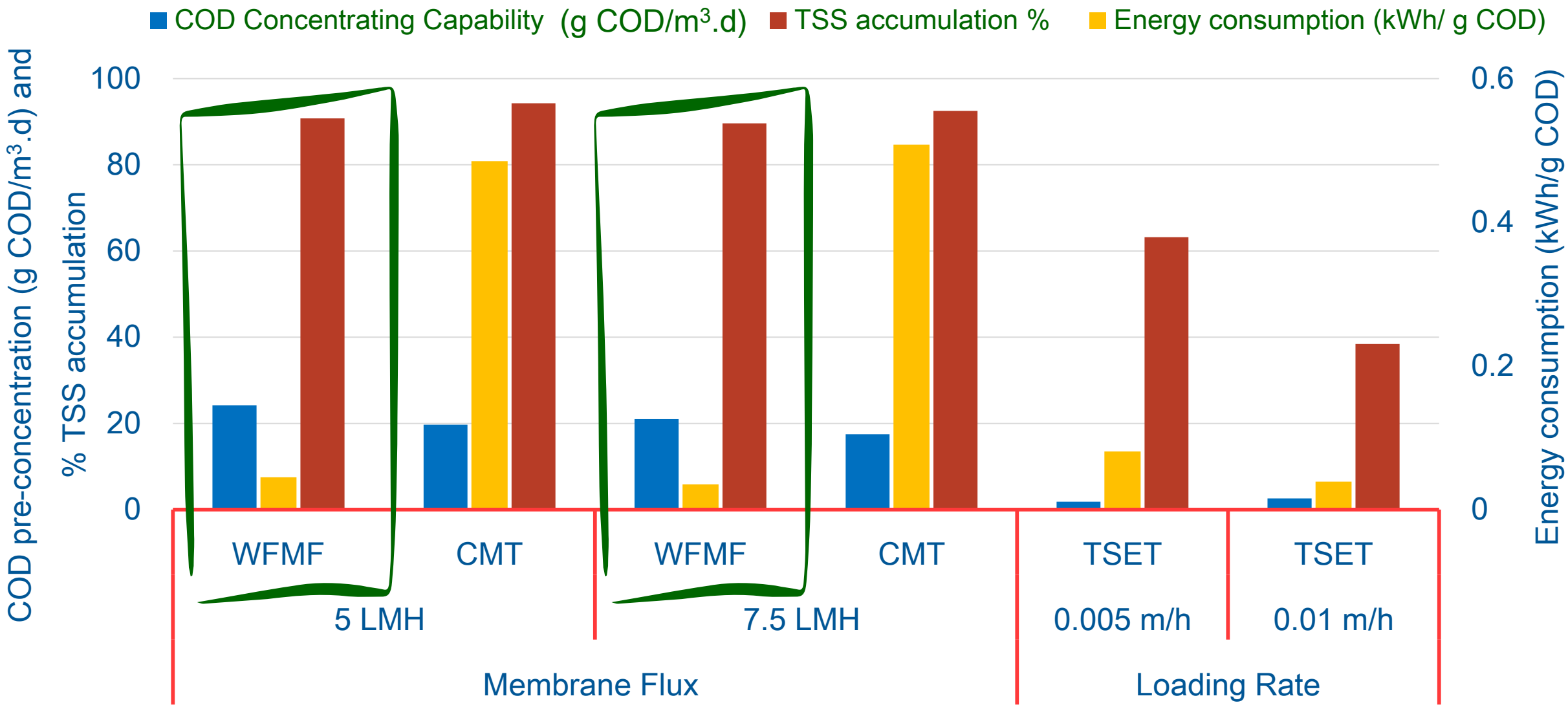
	WFMF	CMT
Sludge cone volume (L)	23.5	0.9
COD concentration (mg/L)	96,600/23.5 = 4,110	10,829/0.9 = 12,032

vs

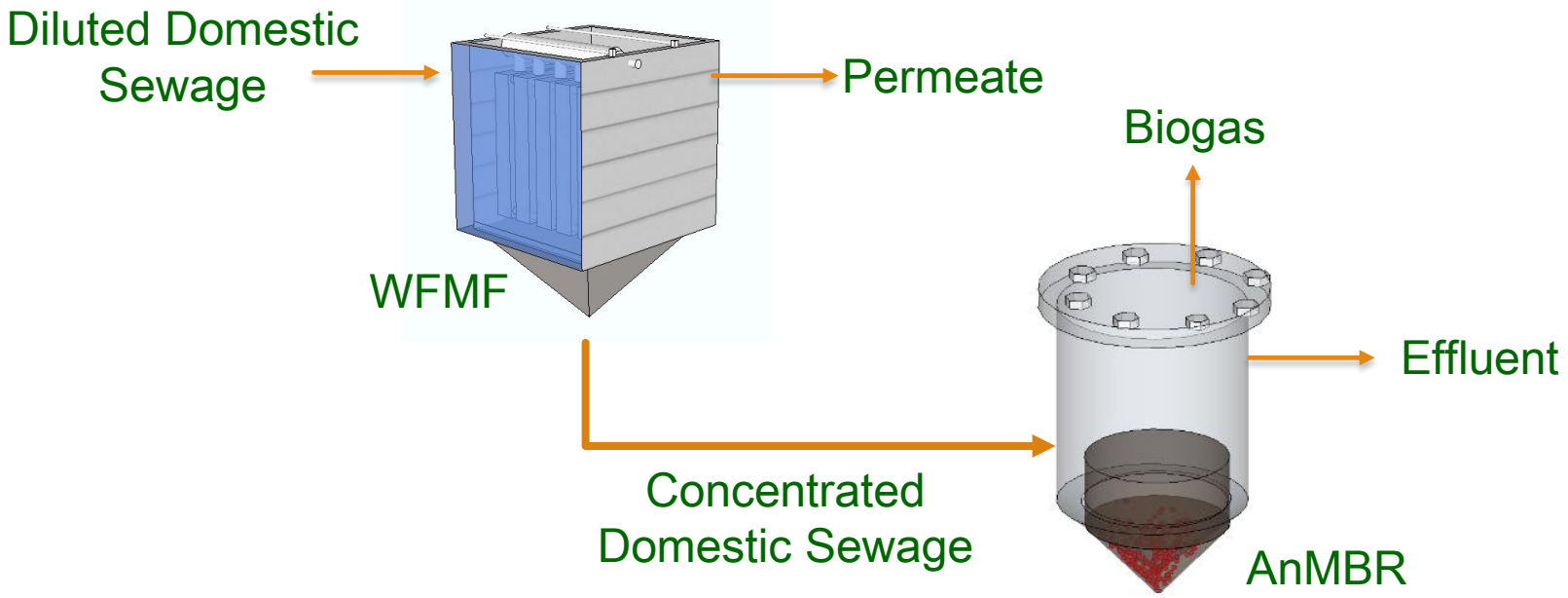
	Theoretical COD (mg/L)	Practical COD (mg/L)
WFMF	4,110	6,047
CMT	12,032	13,953

In mass balance approach, considers the sludge cone volume is more suitable than full tank volume.

Overall Comparison of the Pre-concentration Technologies

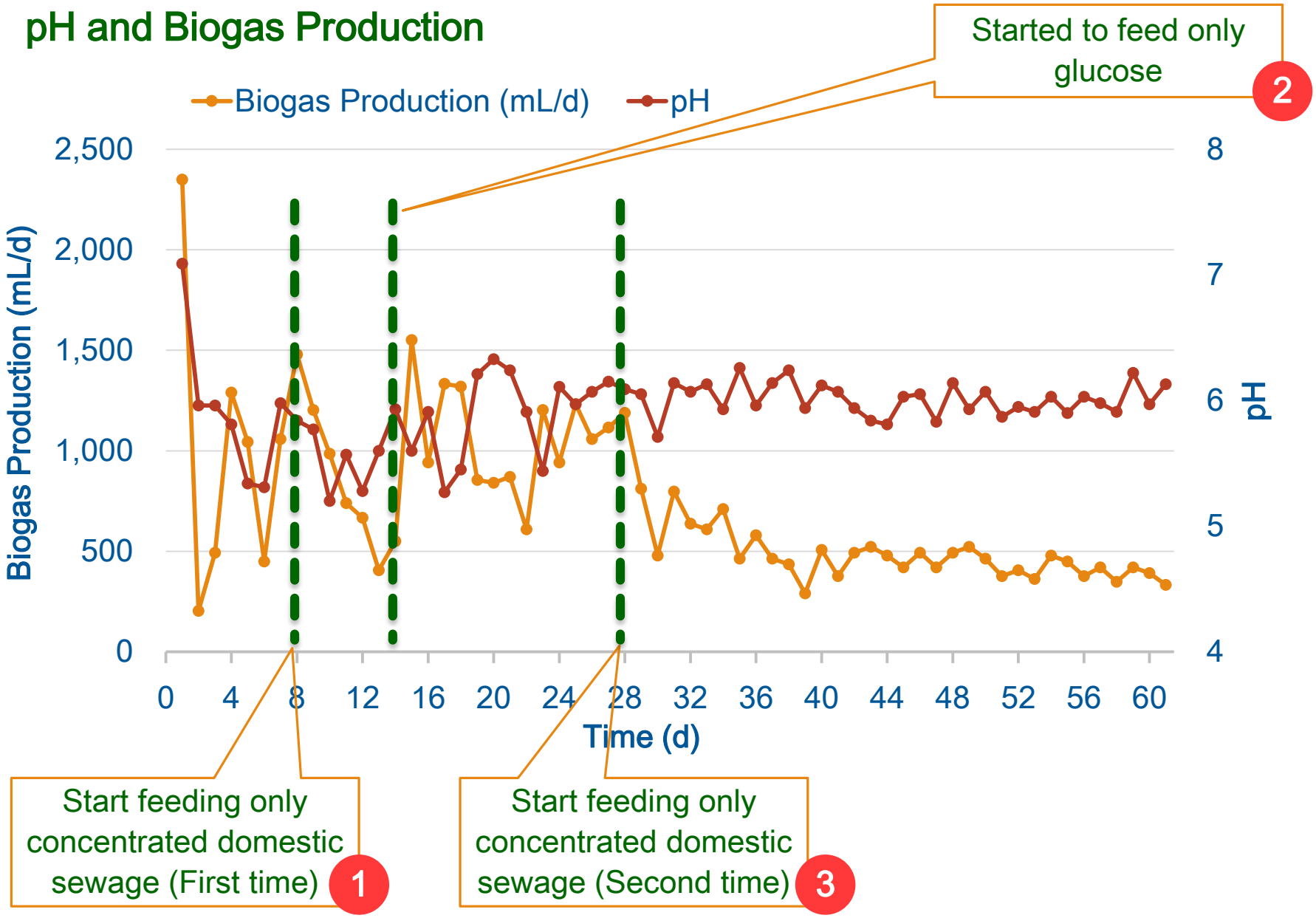


Results and Discussions- (Objective 2)



Performance of the AnMBR

pH and Biogas Production



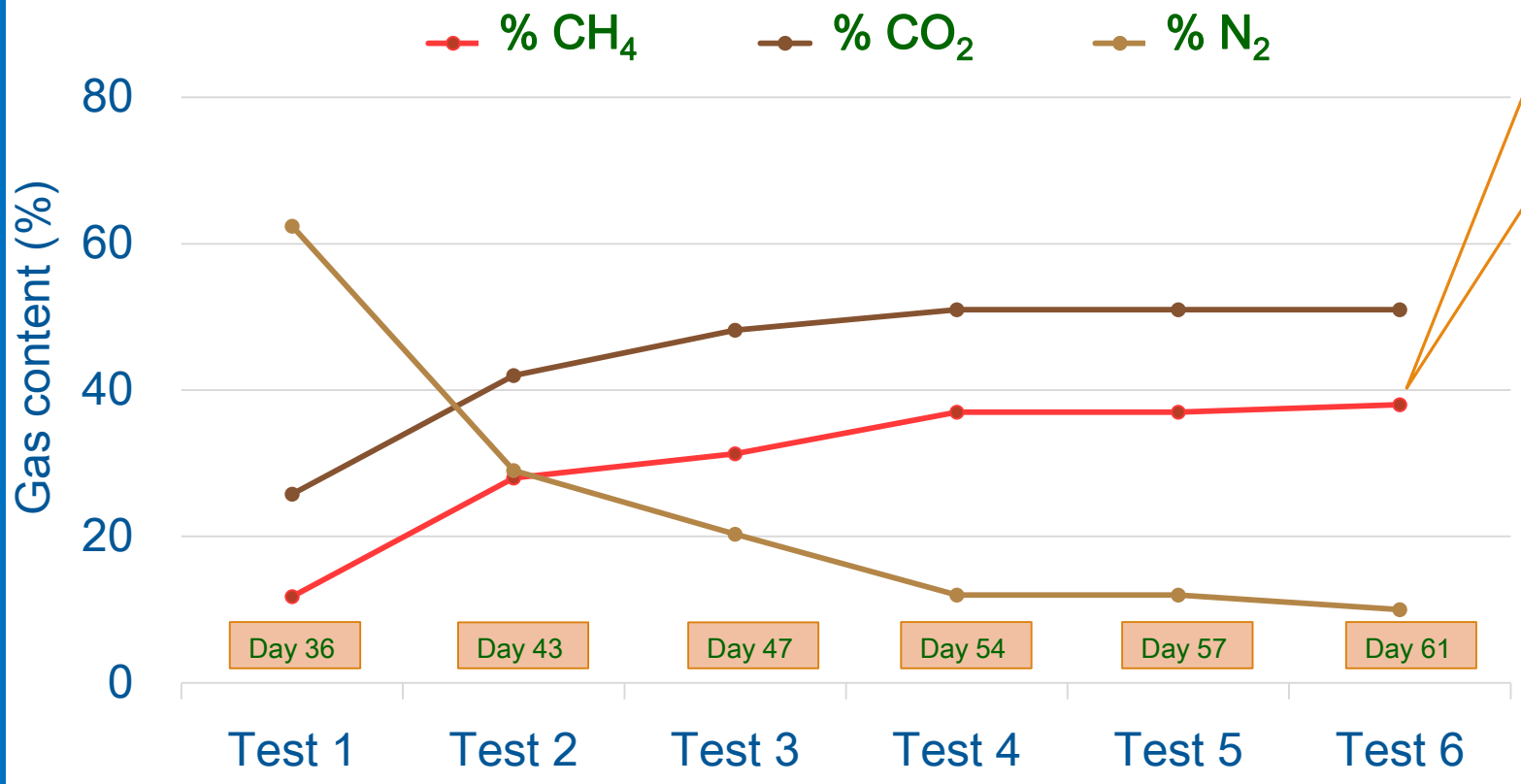
Average Gas yield for Concentrated Domestic Sewage

28.3 L/kg COD

pH Range = 6 ± 0.2

Performance of the AnMBR

Methane Content

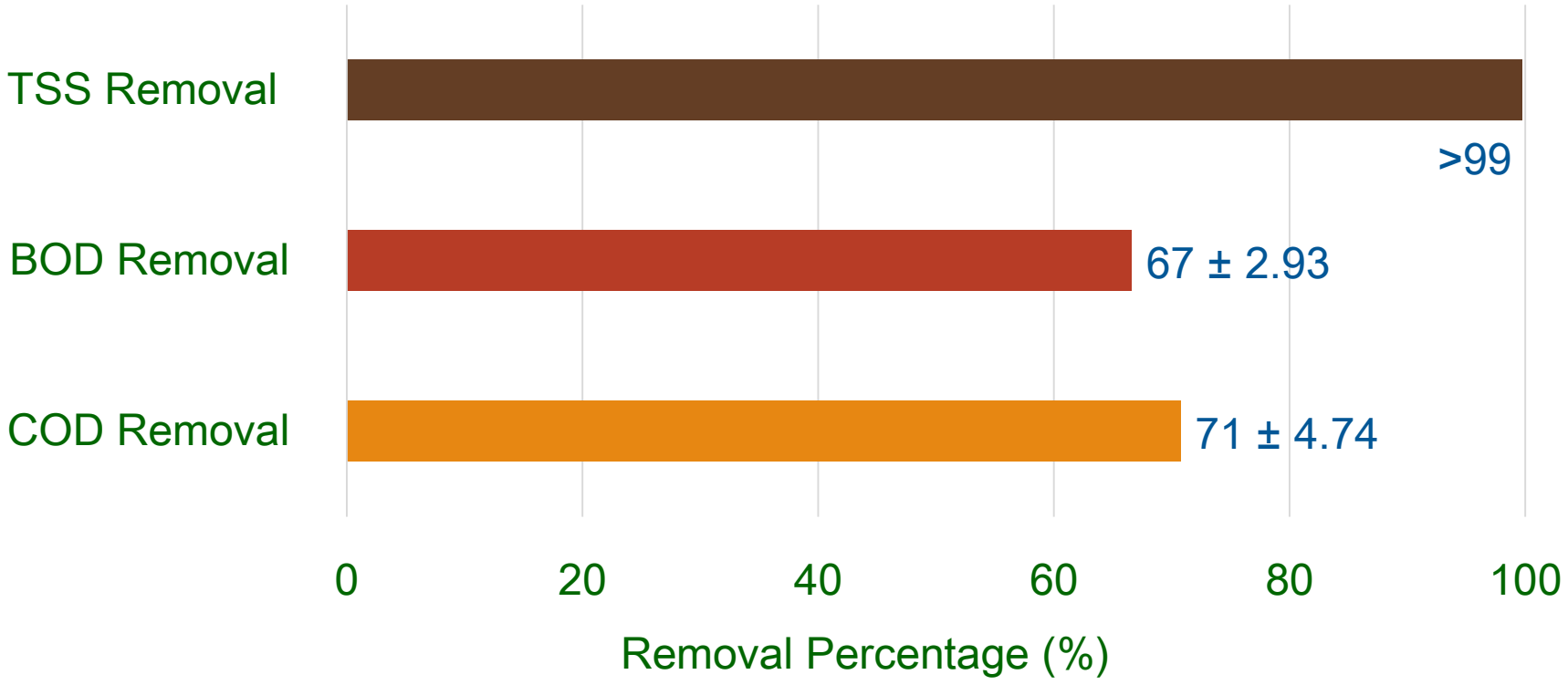


38 % of CH_4

- Gradual increment of the **% CH_4** over the study period and stable after, day 54.
- **% CH_4** showed the stabilized value as 38% in the final stage of the study period.
- **% CO_2** stabilized at 51% at the final stage of the study period.

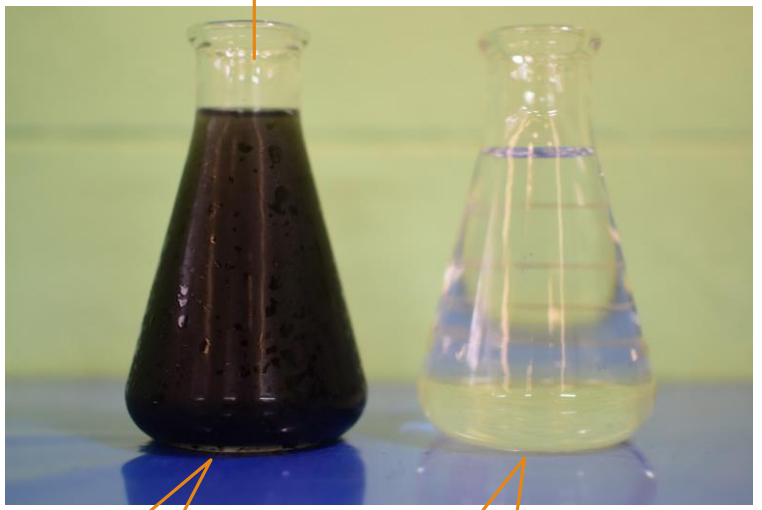
Performance of the AnMBR

Removal Efficiencies of the AnMBR



COD: 6,360 ± 300
BOD: 3,850 ± 350
TSS: 4,716 ± 384

mg/L

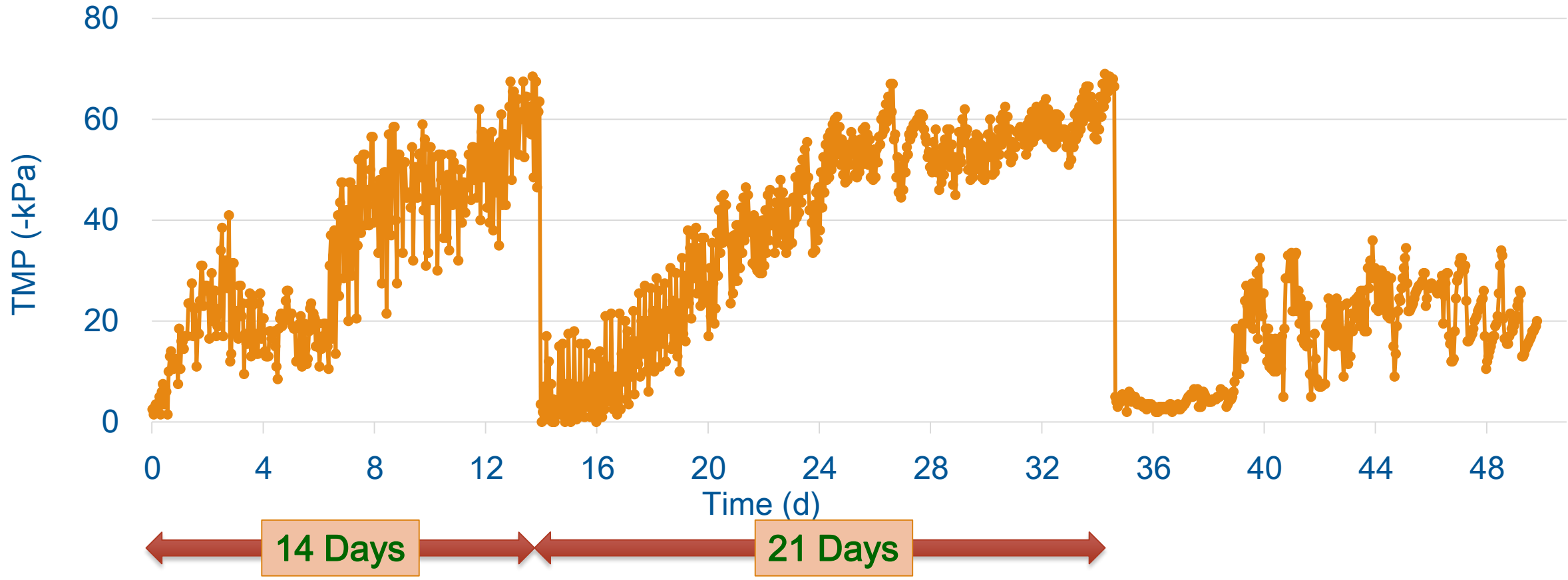


Concentrated Domestic Sewage

AnMBR Effluent

Performance of the AnMBR

Membrane Performance of the AnMBR



Effluent Removal Intervals

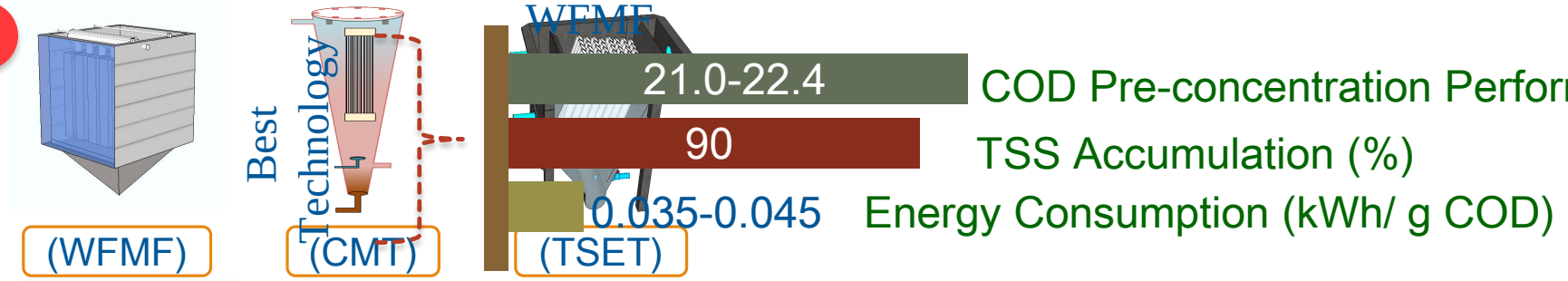
Filtration	10 min	5 min
Sedimentation	30 min	15 min

Further optimization can leads to a better performance.

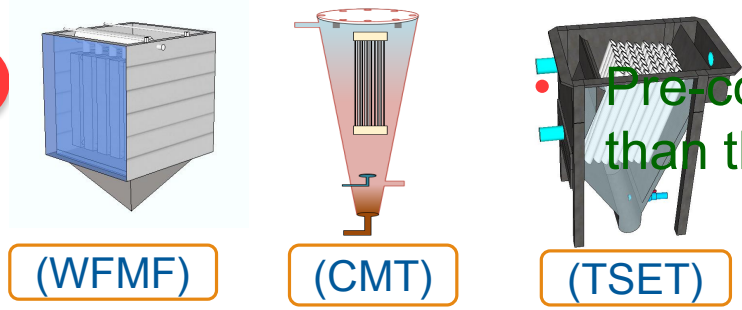
Conclusions

1. Capturing solid fraction from the domestic sewage can leads to generate the higher COD concentrations that can be effectively used for the anaerobic digestion process.

2. To compare the different technology performance, the comparable factors needed to bring it to the same level that can be compared. To make the common comparable unit, the amount of the COD, filtration time and volume was considered. → g COD/ m^3. d

3. 

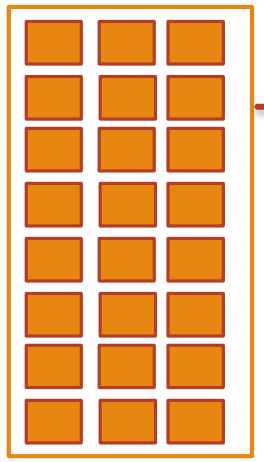
COD Pre-concentration Performance (g COD/ m^3.d)
TSS Accumulation (%)
Energy Consumption (kWh/ g COD)

4. 

Pre-concentration capability of the WFMF and CMT systems were better than the tube settler application.

5. Only the physical cleaning methods are not suitable for the membrane cleaning while it operate with the domestic sewage at it contains organic and inorganic foulants.

Overall Picture



AIT Campus

AIT Wastewater Treatment Plant

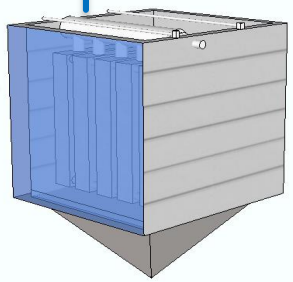
Permeate

COD 41 ± 26
TSS 6 ± 4
TKN 16.8
NH_4-N 18
(mg/L)

Potential of Agricultural Use

COD
0.14 ± 0.05 g/L

Diluted Domestic Sewage

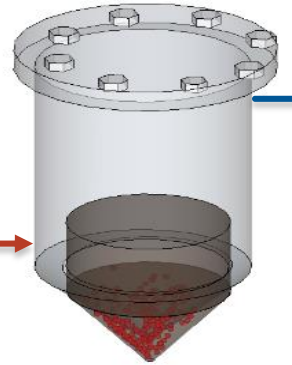


Concentrate

COD
8.1 ± 0.96 g/L

This study, covered this section

Biogas



Effluent

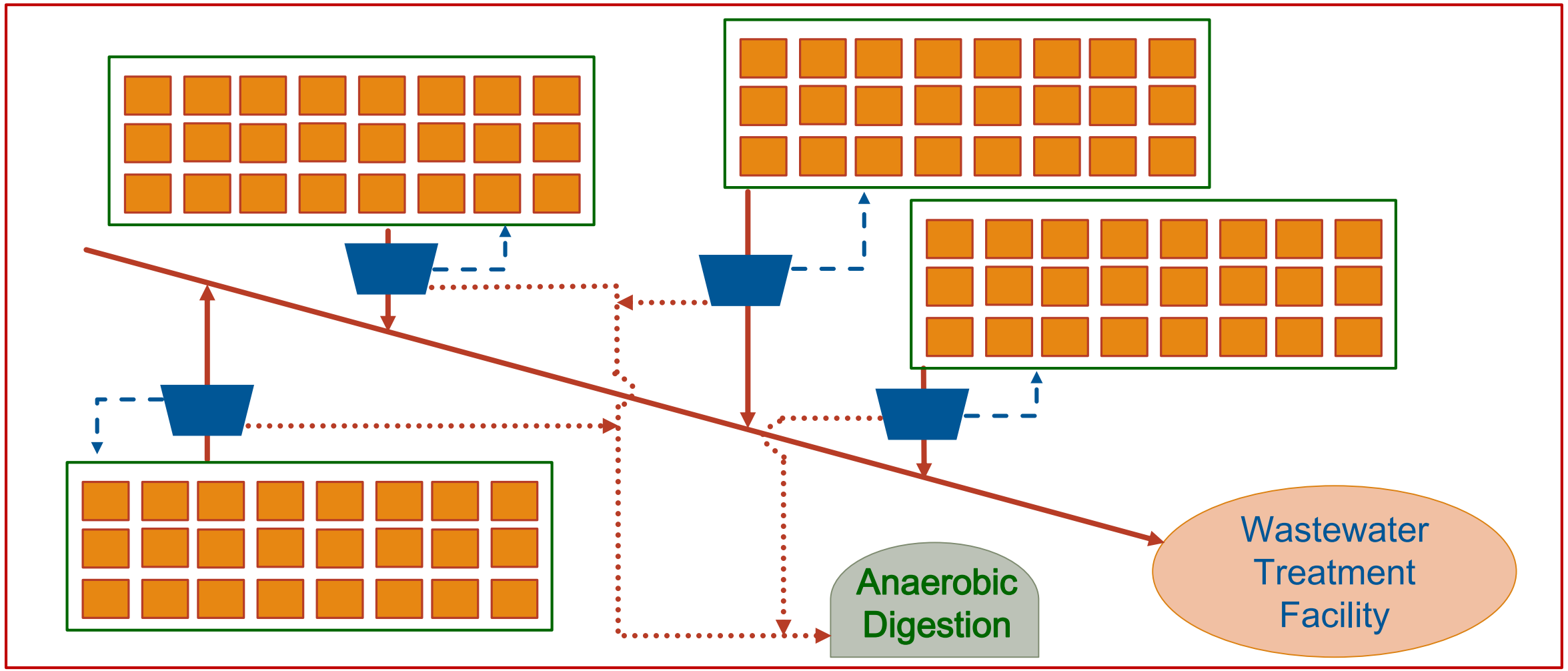
Sludge

Optimization of Anaerobic Process

Co-digestion

This segment, need more study

Potential Application



Suggestions for the Future Work

- AIT's domestic sewage has BOD of 65 ± 8 mg/L and COD of 140 ± 50 mg/L which is compared to lower than the typical domestic sewage characteristics.

  Better to study further with the domestic sewage which represent the typical concentrations.

- This study focused on the concentrating options.

  It need to be study the effluent water reuse potential with different contest to higher the advantages of this concept.

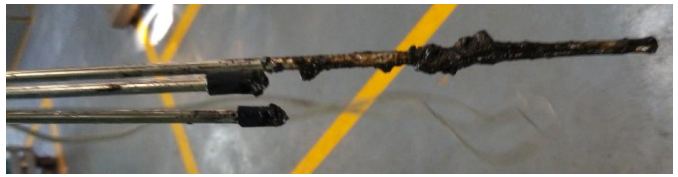
- Optimizing the AnMBR for concentrated domestic sewage

  I. Propeller mixing can be more attractive than the pump recirculation due to the negative effect on bio-flocs while pump circulation.

  II. It is important to use sonar level sensors than the typical electrode type. Electrode type level sensors can be easily clogged inside and finally have an issue to control the exact working volume.

  III. It is important to operate the membrane separation, in external mode. Moreover, it is important to use bigger diameter tubular ceramic membrane as small diameter tubes can easily block with the biomass settlement.

  IV. Inline measurement of pH and temperature can be more attractive to observe and control the pH fluctuation in the anaerobic reactor.



Achievements

Title

Pre-concentration technology comparison of domestic sewage for enhancing the performance of anaerobic digestion.

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Summary

This study compares the performance of three different pre-concentration technologies; woven fiber microfiltration (WFMF), tube settler (TSET) and conical membrane tank (CMT) that can apply to, concentrate the domestic sewage prior to the anaerobic treatment. The main goal of the pre-concentration is to concentrate as much as possible of the wastewater organic matters in a separate stream, which can later be used for energy recovery. Pre-concentration, performance was evaluated in terms of chemical oxygen demand (COD), suspended solid (TSS) concentration and the energy consumption. WFMF was able to concentrate 21 to 24.2 g COD/ m^3. d of COD, while CMT had 17.5 to 19.7 g COD/ m^3. d. TSET indicated that the lower COD pre-concentration, performance with 0.005 m/h and 0.01 m/h loading rates as 1.8 and 2.6 g COD/ m^3. d. In terms of TSS accumulation, WFMF and CMT indicated more than 90% while TSET had 63%. Thus, the WFMF was found to perform better among the three technologies in terms of domestic sewage pre-concentration.

Keywords: Pre-concentration, Domestic sewage, Membrane filtration

Introduction

Domestic sewage contains the detritus of our daily lives-faeces, leftover food particles, detergents and pharmaceuticals and many other contaminants. Over the past years, domestic sewage has been treated using activated sludge process, which remains the popular wastewater treatment process. This is because, the activated sludge system is simple yet effective in removing organic pollutant from wastewater. However, this comes with high energy consumption and the carbon footprint. To overcome this issue, wastewater treatment sector is currently moving to another economical process, namely anaerobic digestion. Anaerobic digestion is a procedure in which microorganisms extract energy and develop by metabolizing organic matter in a non-oxygen environment resulting in the generating of methane. Applying anaerobic practices directly to domestic wastewater could generate an excess of energy, but it is not currently possible with low concentrations of organics (Smith et al., 2014). The anaerobic treatment plant can make a use of methane, that produces electricity than consume it. The efficiency of the anaerobic digestion shows the highest values when the wastewater is concentrated. Pre-concentration of the domestic sewage can lead to minimize the carbon footprint treatment cost as well as the digester volume. Moreover, it can help to maximize the water reuse potential, energy and nutrient recovery. Pre-concentration of domestic sewage produces an organically rich wastewater stream that is suitable for the anaerobic digestion process (Verstraete and Vlaeminck, 2011).

Material and Methods

WFMF and CMT membrane systems operated in a submerged mode with dead-end outside-in configuration. WFMF system consists of 1-3 µm pore size flat sheet membrane with a surface area of 1 m^2. The CMT system operated with Polytetrafluoroethylene (PTFE) hollow fiber (HF) membrane of 0.1 µm pore size and the area of 0.1 m^2. Both the membrane applications were tested with 5.0, 7.5 LMH flux. Tube settler operated with the loading rate of 0.005 m/h without coagulants and 0.01 m/h with the coagulant dose of 20 ppm. All operations were conducted in triplicate test runs. The performance was then evaluated based on the COD concentration ability, total suspended solid accumulation, and the energy consumption by each of these three pre-concentration membrane technologies.

Results and Conclusions

The COD concentrating performance of the WFMF technology indicated 21 to 24.2 g COD/ m^3. d while CMT has 17.5 to 19.7 g COD/ m^3. d concentration ability. Tube settler application indicated the lower concentration capacity for the loading rate of 0.005 m/h, which was 1.8 g COD/ m^3. d. Moreover, even with the coagulation, tube settler could achieve only 2.6 g COD/ m^3. d for 0.01 m/h loading rate. **Table 1.1** summarizes the experimental results on pre-concentrating the domestic sewage.

Table 1.1 Performance comparison of the pre-concentration technologies.

	Membrane Flux				Loading Rate	
	5 LMH		7.5 LMH		0.005 m/h	0.01 m/h
	WFMF	CMT	WFMF	CMT	TSET	TSET
COD of domestic sewage (g/L)	0.14 ± 0.05					
COD of the concentrate (g/L)	6.0	14.0	7.9	17.9	1.8	5.3
Sludge cone volume (L)	23.5	0.9	23.5	0.9	18	18
Total COD in sludge cone (g)	142	13	186	16	33	96
Domestic sewage treated per run (m^3)	0.8	0.1	1.3	0.1	2.7	5.4
Test duration (days)	7		7		7	
Concentrating ability (g COD/ m^3.d)	24.2	19.7	21.0	17.5	1.8	2.6
TSS in domestic sewage (g/L)	0.08 ± 0.03					
TSS in concentrate (g/L)	3.20	10.22	5.51	12.07	0.60	3.41
TSS in permeate/ effluent (g/L)	0.008	0.005	0.007	0.01	0.032	0.06
TSS accumulation %	90.8	94.3	89.6	92.5	63.2	38.4
Power consumption (kWh/ g COD)	0.045	0.485	0.035	0.508	0.081	0.039

The CMT system shows the highest solid accumulation ratio, which is more than 92.5 % for 5.0 and 7.5 LMH flux. WFMF system also showed more than 89.6% of solid accumulation. Compared to the membrane systems TSET showed the lower solid accumulation percentage. TSET could only accumulate 63.2% of the TSS of 0.005 m/h loading rate. 0.01 m/h loading rate shows the lowest TSS accumulation due to washing out the particles even with the coagulation. TSET system's COD and TSS capture performance were lower among others. WFMF system showed the higher COD concentration ability and the nearly 10 times lower energy consumption compared to the CMT system. Thus, the performance of WFMF 7.5 LMH flux was the best among three technologies, in terms of its low energy consumption, higher COD concentration ability, and the higher TSS accumulation during domestic sewage pre-concentration.

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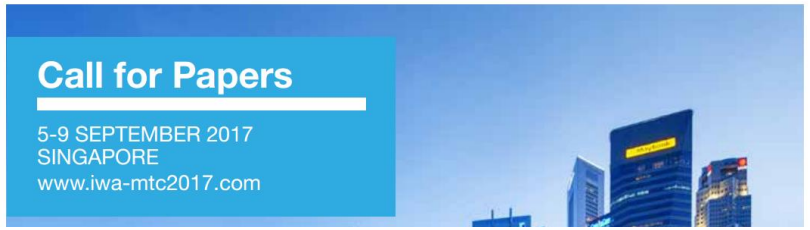

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Publishability

- Very few studies are reported using the technology for pre-concentration of domestic sewage.

Ex-

Jin, Z., Gong, H., Temmink, H., Nie, H., Wu, J., Zuo, J. & Wang, K. (2016). Efficient sewage pre-concentration with combined coagulation microfiltration for organic matter recovery. *Chemical Engineering Journal*, *292*, 130-138.

Diamantis, Melidis, P., Aivasidis, A., Verstraete, W. & Vlaeminck, S. (2011). Efficiency and sustainability of urban wastewater treatment with maximum separation of the solid and liquid fraction. Comprehensive Biotechnology, 6, 507-515.

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Thank You….

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