Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants "SMART-Plant"

SmartPlant: Biogas recovery in primary treatment with a polyfoam biofilter Advanced Anaerobic Treatment (AAT)

Evaluation and simulation at a pilot-scale system

Isam Sabbah

The Galilee Society

Webinar on "Biogas Technologies": October, 30th 2020

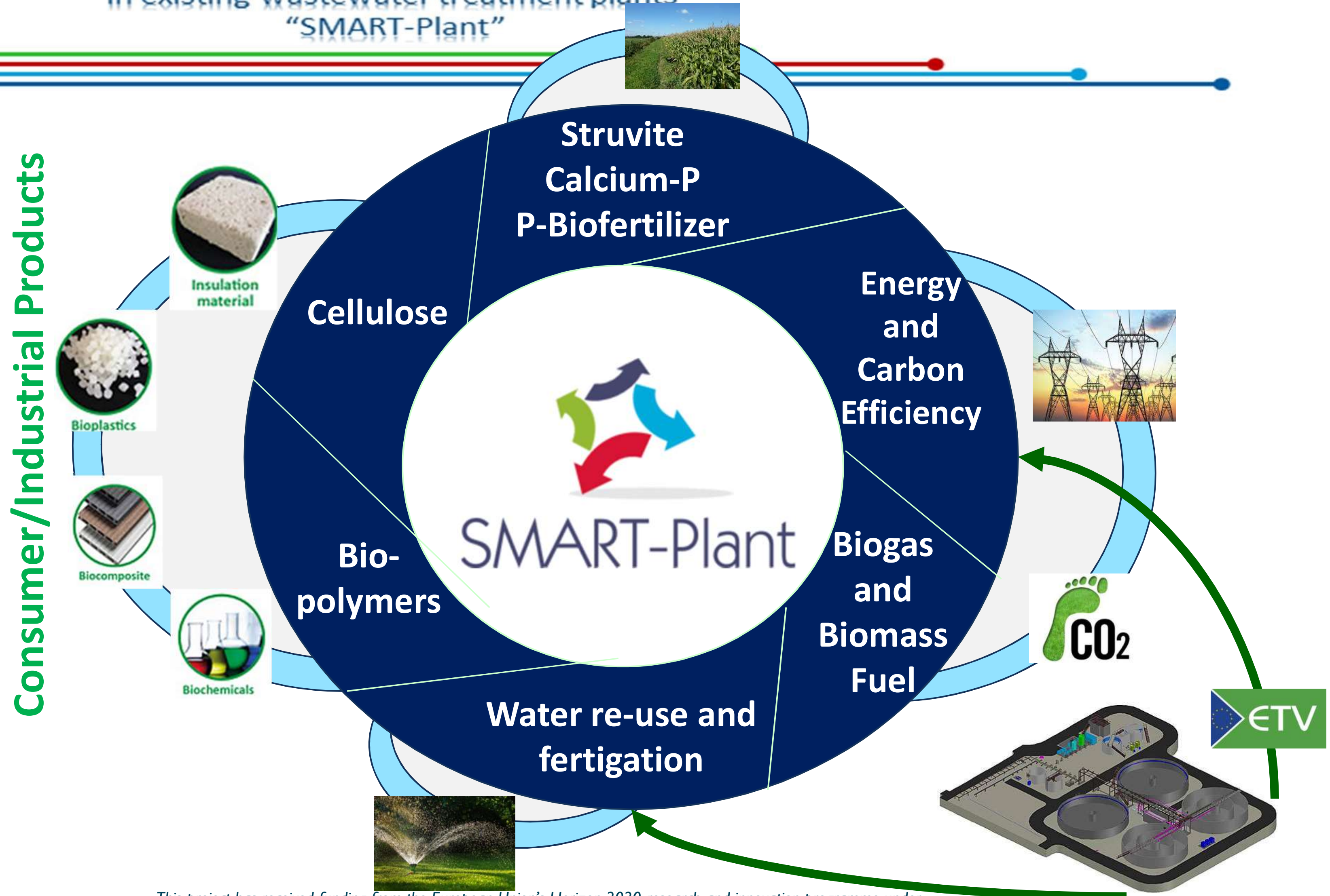
Introduction

OBJECTIVE:

Pilot scale evaluation of the start-up and operation of the Advanced Anaerobic Treatment (AAT) reactor receiving real municipal wastewater and the recovery of biogas as sub-product.

- ***Applied*** *before secondary biological treatment units to reduce organic loads and consequently operational costs (e.g. O_2 supply); shaving peaks of illegal agro-industrial discharge streams;*
- ***Completely different approach*** *to traditional UASB reactors due to the "bio-stabilized", polymer-based matrix impregnated with anaerobic microorganisms;*
- ***More stable operation*** *because the matrix provides physical protection for the microorganisms and therefore resulting in no biomass washout;*
- ***Recovery of CH_4*** *as a bioproduct with a high potential for energy generation;*
- ***The aim*** *is the implementation of this robust, affordable, and environmentally sound process guarantees sustainable wastewater treatment adhering to existing and future effluent quality requirements and energy-saving approaches.*

Scale-up of low-carbon footprint MAterial Recovery Techniques in existing wastewater treatment PLANTs



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Demostration Sites

ALL SITES

- Geestmerambacht
- Karmiel
- Manresa
- Cranfield
- Carbonera
- Psyttalia
- Carbonera (b)
- London
- Manresa (b)

http://smart-plant.eu/index.php/map

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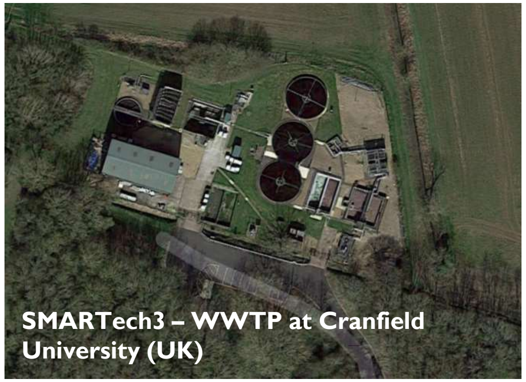
SMARTechs integrated in existing WWTPs (transformed in WRRFs)


SMARTech1 - Geestmerambacht WWTP (NL)


SMARTech2a – Karmiel WWTP (IL)


SMARTech2b and Downstream SMARTech B - Manresa WWTP (Spain)


SMARTech3 – WWTP at Cranfield University (UK)


SMARTech 4a and SMARTech 5 Carbonera WWTP (Italy)


SMARTech 4b - Psyttalia WWTP (Greece)

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ACHIEVEMENTS OF SMART-PLANT

Mainstream

SMARTech n.	Integrated municipal WWTP	Key enabling process(es)	SMART-product(s)
ETV	Geestmerambacht (Netherlands)	**Upstream dynamic fine-screen** and post-processing of cellulosic sludge	**Cellulosic sludge, refined clean cellulose**
ETV	Karmiel (Israel)	Mainstream polyurethane-based **anaerobic biofilter**	**Biogas, Energy-efficient water reuse**
2b	Manresa (Spain)	Mainstream **SCEPPHAR**	**Struvite, PHA**
3	Cranfield (UK)	Mainstream **tertiary hybrid ion exchange**	**Nutrients**
ETV 4a	Carbonera (Italy)	**Sidestream SCENA**	**P-rich sludge, VFA**
4b	Psyttalia (Greece)	**Sidestream Thermal hydrolysis – SCENA**	**P-rich sludge**
5	Carbonera (Italy)	**Sidestream SCEPPHAR**	**PHA, struvite, VFA**

Sidestream

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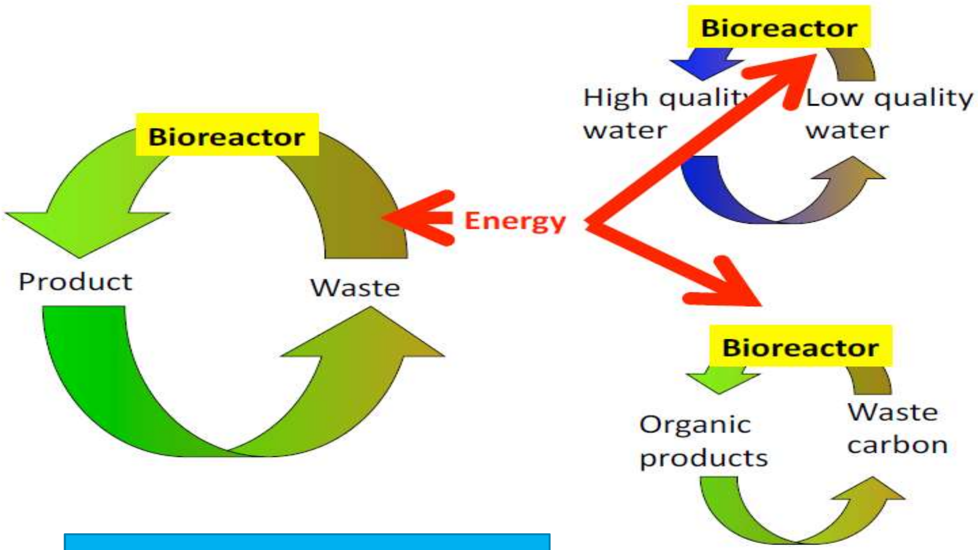
Circular Economy:

The talk is about resources recovery from wastewater by biological technologies, where **Anaerobic** treatment plays the main role within the concept of **circular economy**.

Circular economy is alternative for linear economy: make, use, dispose



From Crage Criddle, 2010

The economic value of the resource

Resource	Per m^3	US $ per m^3	US $ per 1000 gal
Organic soil conditioner	0.10 kg	0.026	0.10
Methane	0.14 m^3	0.065	0.25
Nitrogen	0.05 kg	0.065	0.25
Phosphorus	0.01 kg	0.013	0.05
Water	1 m^3	0.325	1.20

From Willy Verstraete (2008)

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History of Anaerobic Reactor

1881: First conventional anaerobic digester was used to liquidify the solid components of sewage

1891: First septic tank to retain solids in sewage

1905: Development of the 'Imhoff' tank in Germany

1930s: Digesters were started to be mixed and heated to improve the digestion of solids in the sewage

1955: Anaerobic contact process was developed to treat soluble organics and dilute wastewaters (**first high-rate system**)

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Scale-up of low-carbon footprint material recovery techniques in existing wastewater treatment plants

SMART

Anaerobic Waste Treatment Fundamentals

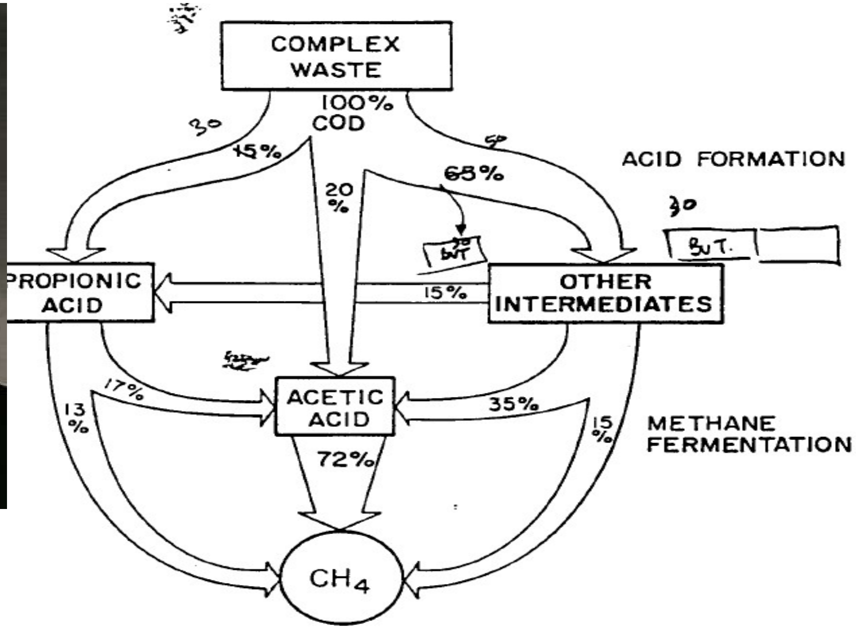
PART ONE | Chemistry and Microbiology

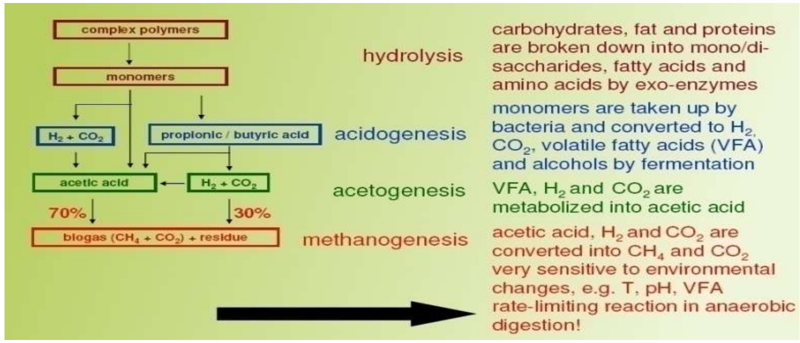
Public Work 1964

PERRY L. McCARTY
Associate Professor of Sanitary Engineering
Stanford University

portant parameters for design, operation, and control. This first article is concerned with a general description together with the chemistry

portion converted to cells is not actually stabilized, but is simply changed in form. Although these cells can be removed from the waste





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Scale-up of low-carbon footprint material recovery techniques
in existing wastewater treatment plants
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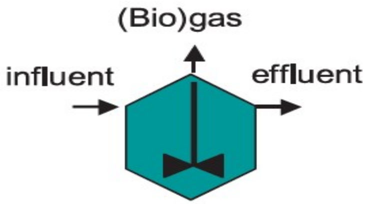
1955
(Schroepfer et al., 1955)

1960s
Young & McCarty 1966)

1970s &
Lettinga

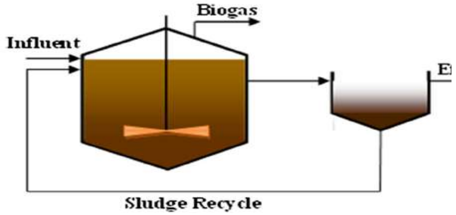
1980s
Lettinga

CSTR



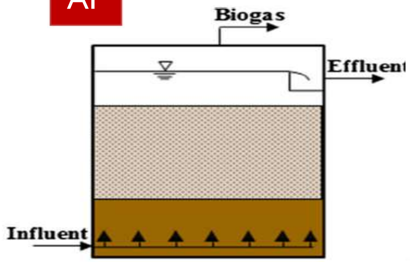
Relative capacity:
1

ACP

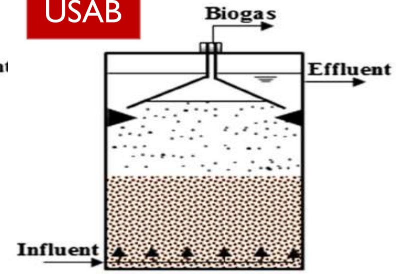


Relative capacity:
5

AF

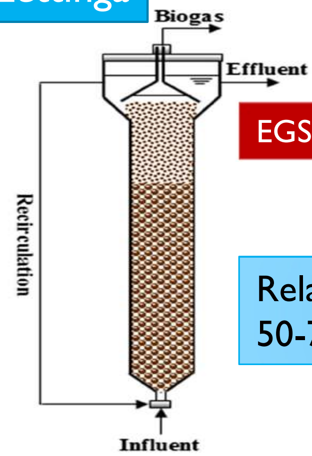


USAB



Relative capacity:
25

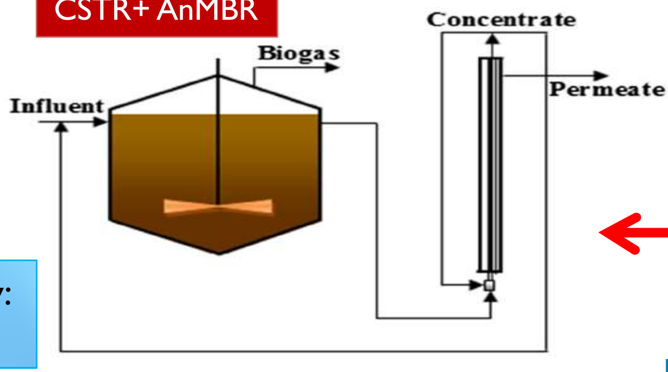
EGSB



Relative capacity:
50-75

High-rate anaerobic systems

CSTR+ AnMBR



Relative capacity:
>75

Gatze Lettinga

Based on van Lier, 2015

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WWTP/WRRF

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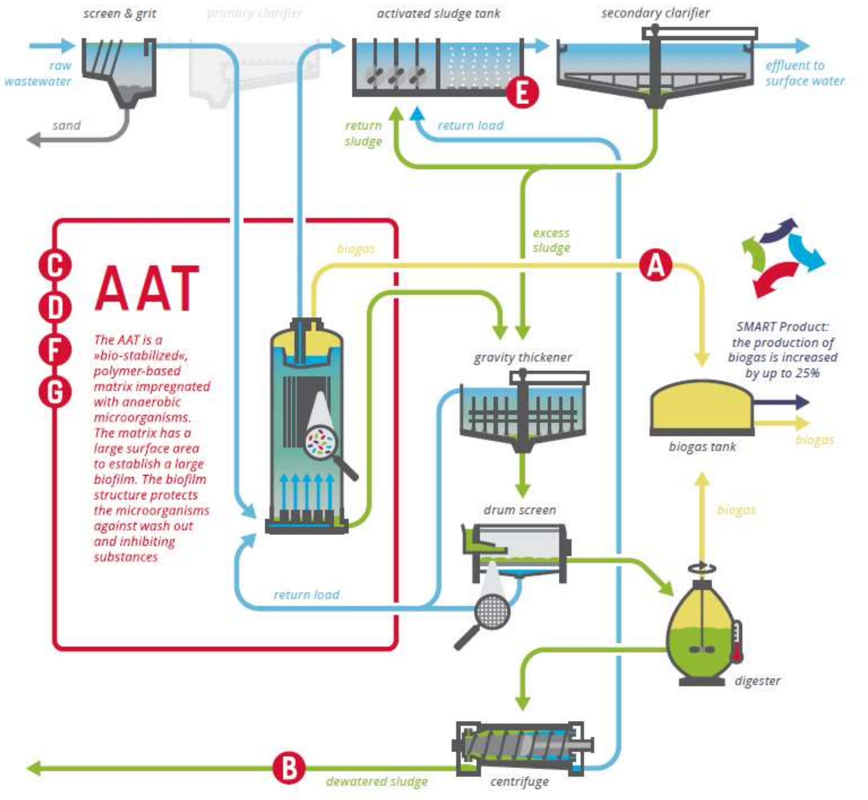
SMART-Plant Approach



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SMARTech 2a – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery*

WWTP – Karmiel, Israel

ETV

Aim

Reduced **loads of COD and TSS** on the biological treatment system → Energy-efficient water reuse; **Biogas** production.

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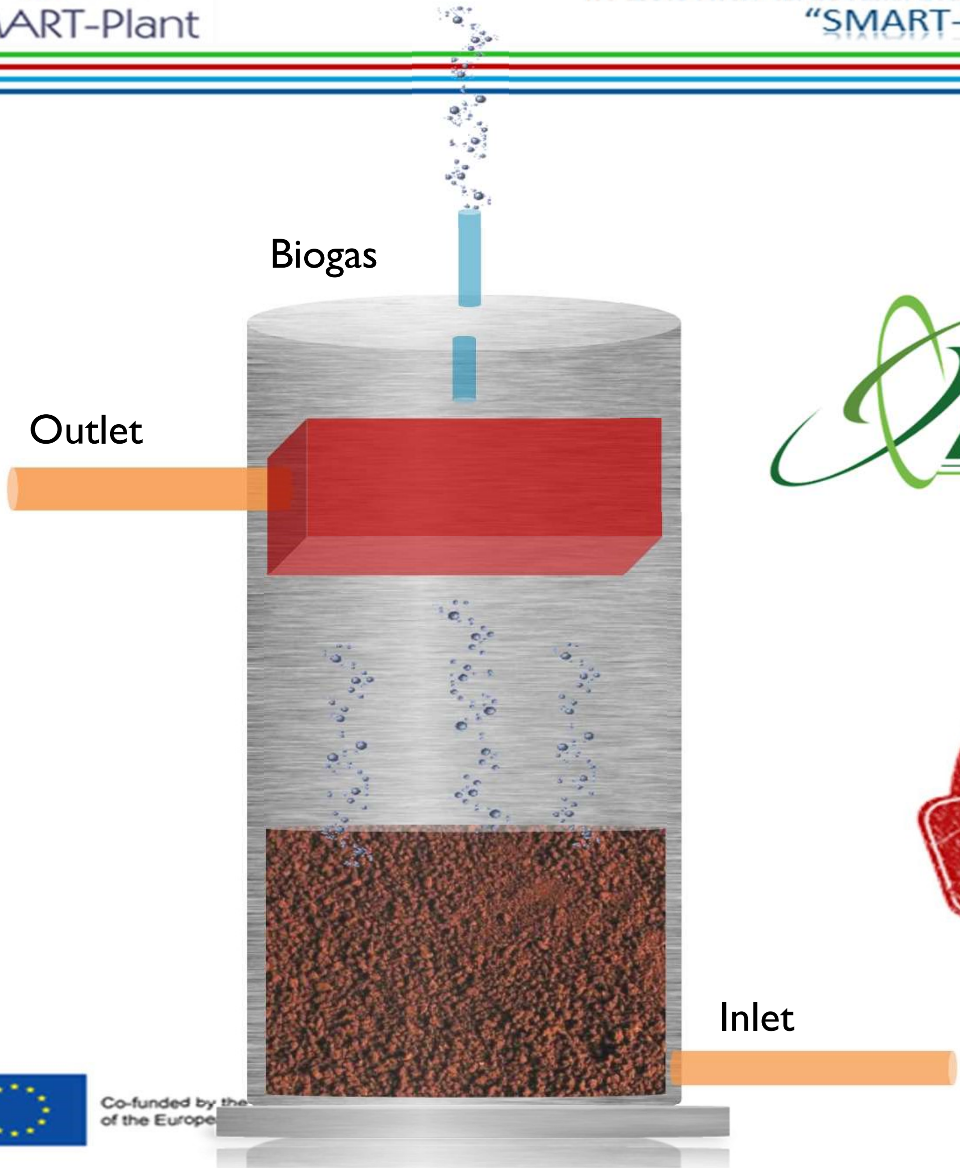
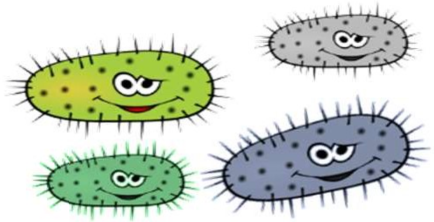
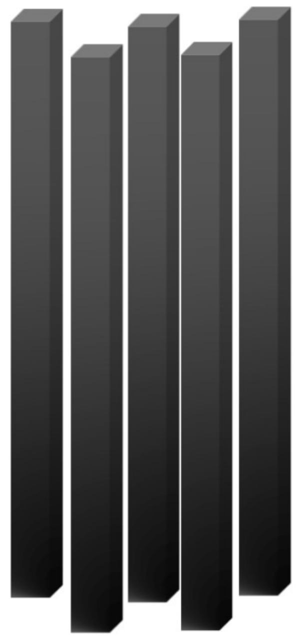
Scale-up of low-carbon footprint material recovery techniques
in existing wastewater treatment plants
"SMART-Plant"



AgRobics





Sabbah et al., 2016, USA Patent # 9452458
Sabbah et al., 2018, Israeli Patent # 221638

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Operational characteristics – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

- ***The matrix*** *has large surface area and high capacity that enables the loading of a higher number of microorganisms compared to incumbent wastewater treatment methods;*

- ***The AAT technology*** *increases process stability, decreases energy consumption, lowers operational costs and enhances the efficiency of the anaerobic process for methane production;*

- ***The bio-stabilizers*** *are prepared in special, patented, modular units and inserted into a proprietary modified high rate up-flow anaerobic system (HRUA);*

- ***This hybrid immobilized-HRUA*** *exhibits better performance characteristics and lower cost, without the need for the typical expensive three–phase separator.*

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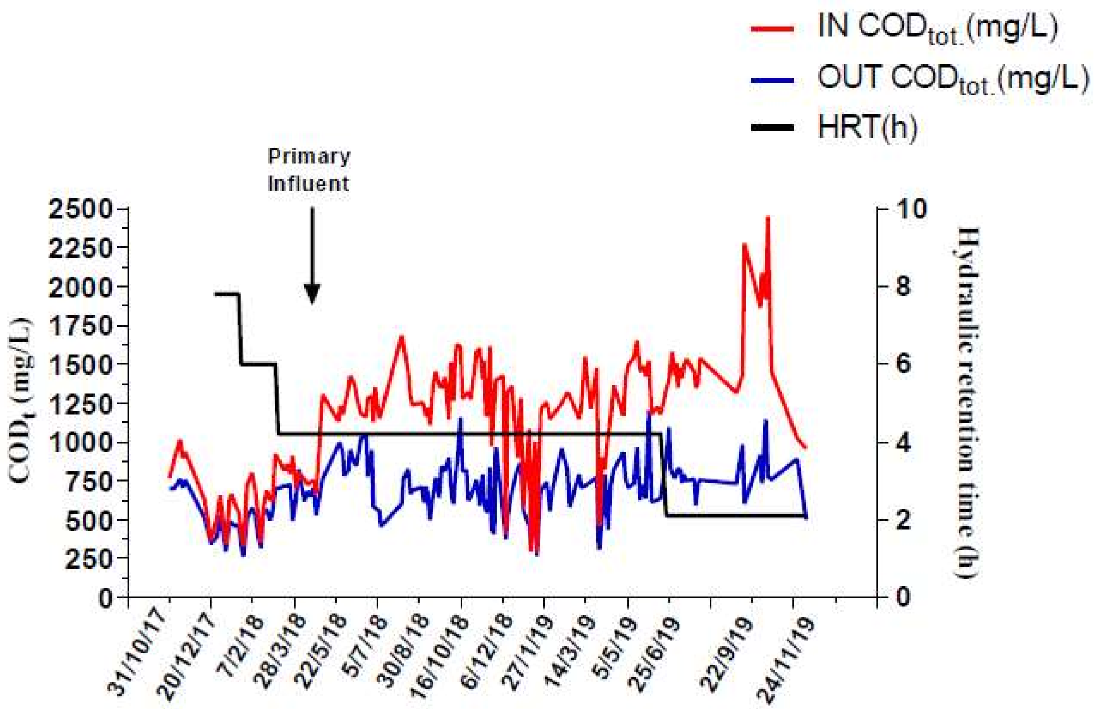
Operation

- 240 m^3/d waste water flow
- 55-60% COD removal
- 50% TSS removal
- HRT= 2-4 hours

Recovery Efficiency

- 5-10 m^3 biogas/day
- 72% CH_4



Methane Yield: 0.12-0.15 m^3 CH_4/kg oDM

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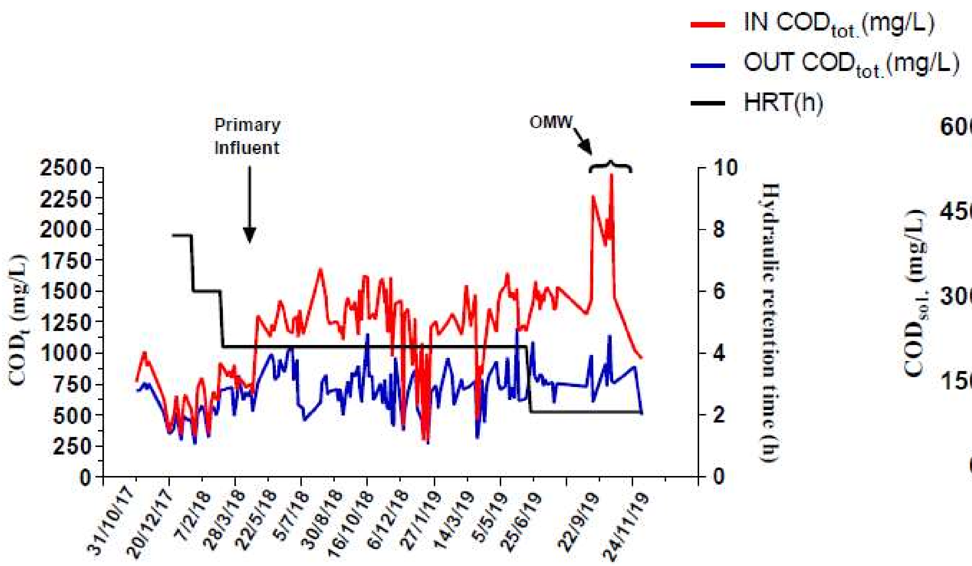
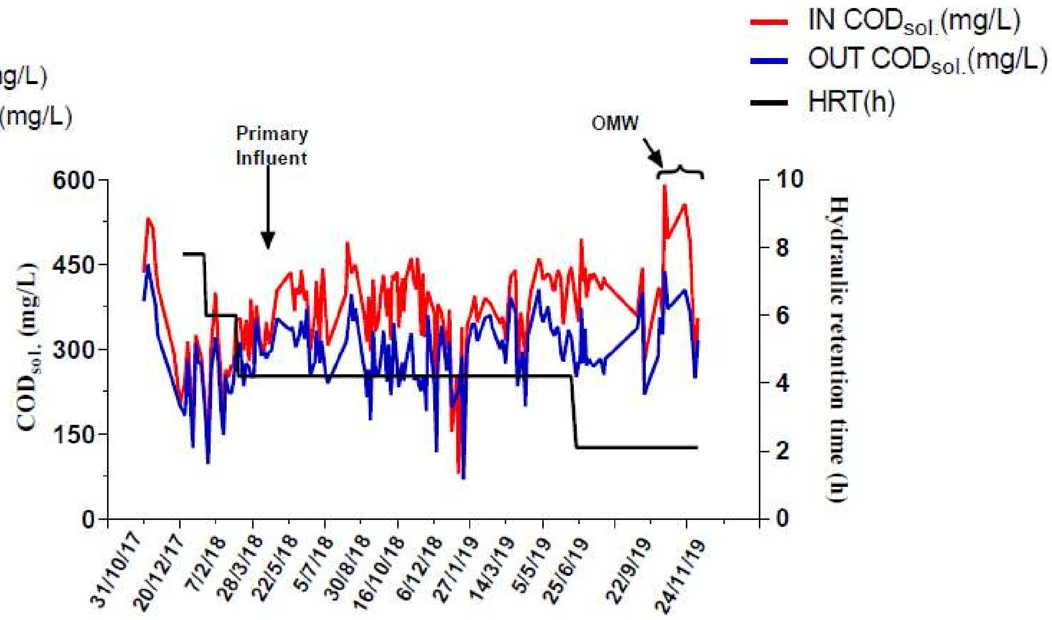
Shaving the peaks





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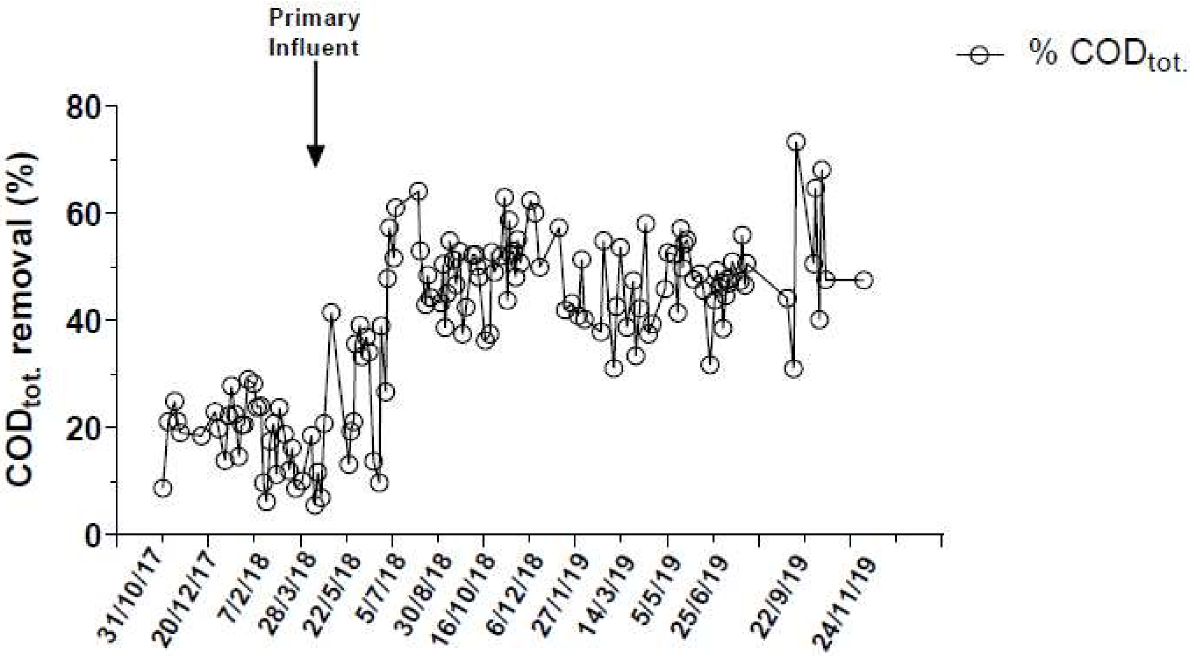
Primary
Influent
% CODtot.
CODtot. removal (%)
80
60
40
20
0
31/10/17
20/12/17
7/2/18
28/3/18
22/5/18
5/7/18
30/8/18
16/10/18
6/12/18
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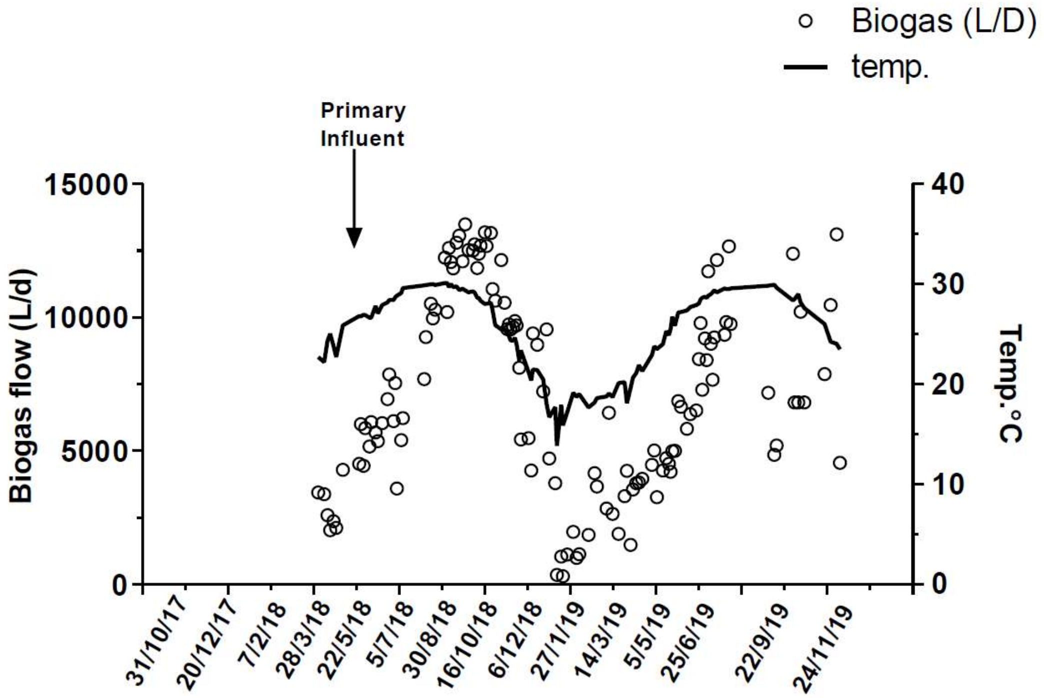
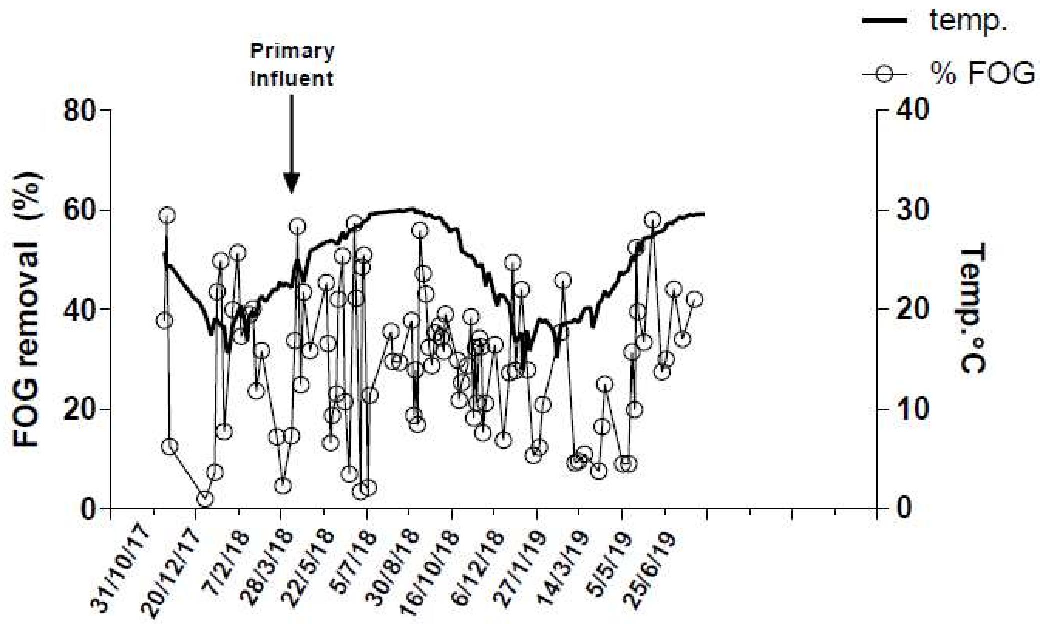
22/9/19
24/11/19





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Material and Methods – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

SMART-Plant

Operational data from over 1-year of experimental data (October 2017 – January 2019)

- **Two scenarios were evaluated during the operation period:**

  1. **Scenario 1:** raw sewage flowed first to the primary clarifier (PC) before flowing into the AAT (Q = 48–120 $m^3.d^{-1}$) – startup phase – ***HRT: 0.4 – 0.2 d (9.6-4.8 h)***;
  2. **Scenario 2:** raw sewage flowed directly into the AAT (Q = 120 $m^3.d^{-1}$) – steady-state phase – ***HRT: 0.2d (4.8 h)*** ;

- **The following parameters were analysed : total COD, soluble COD, particulate COD, TSS, and gasflow;**

- **Modelling was done with data from the second scenario.**

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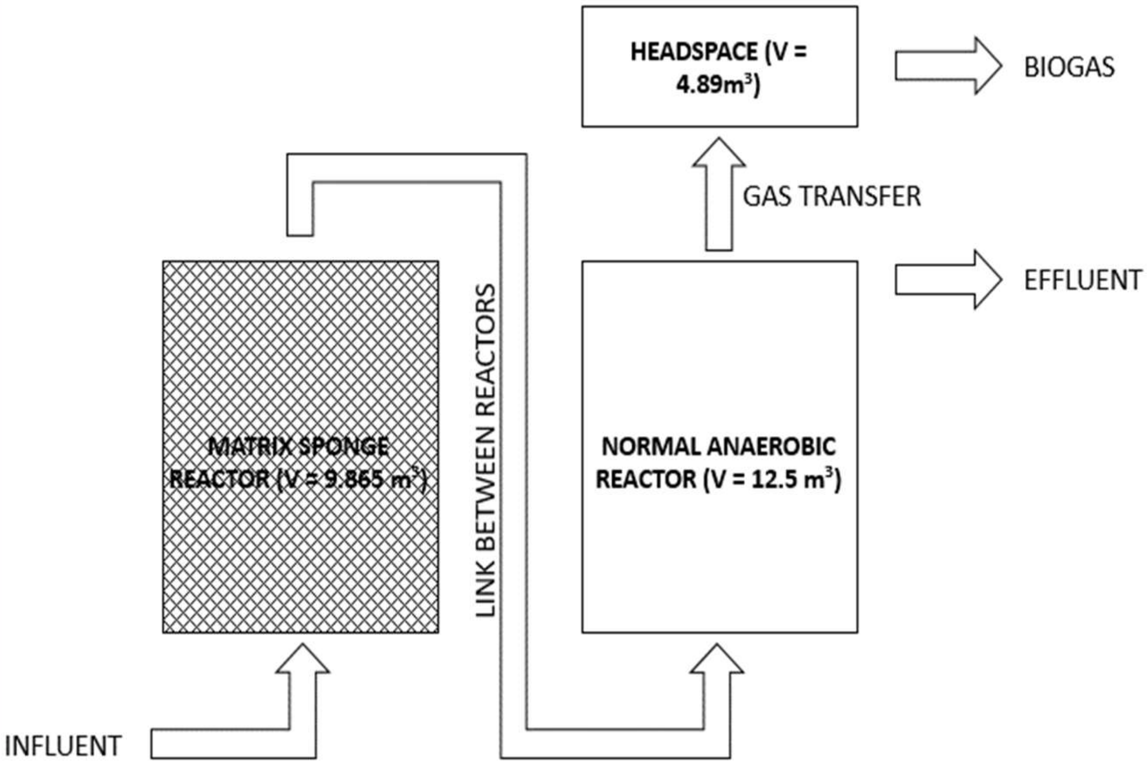
Modelling approach – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel



Considerations:

- **Anaerobic Digestion Model 1 (ADM1);**
- **Two separate completely-mixed reactors in series → plug-flow regime;**
- **Simulation software AQUASIM 2.1v;**
- **Sludge Retention Time (SRT):**
  - **Matrix reactor = ∞ (biomass remains in the reactor);**
  - **Second reactor = 20 d (similar to normal UASB);**
- **Higher concentration of biomass in the matrix reactor;**
- **Fixed percentages used for the influent characterisation into state-variables.**

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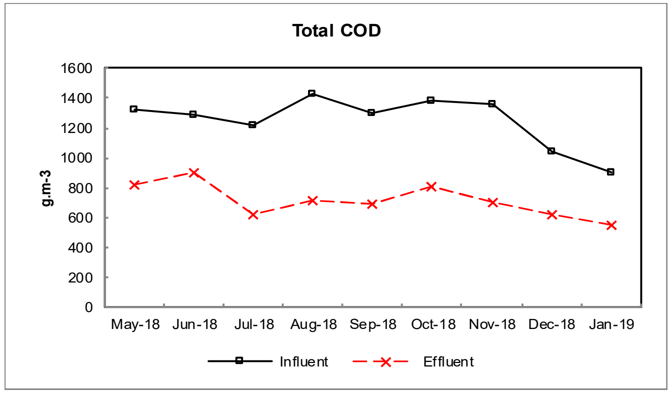
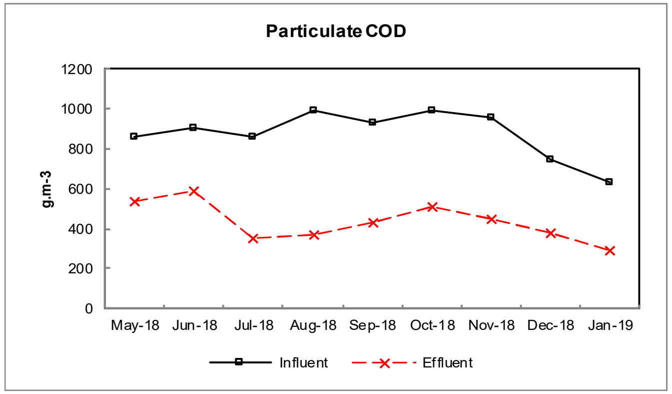
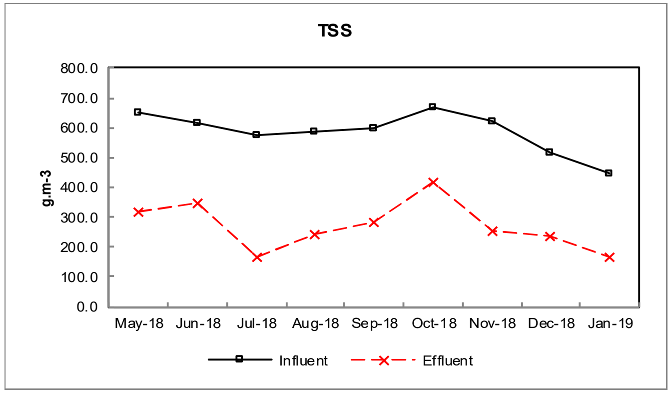
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

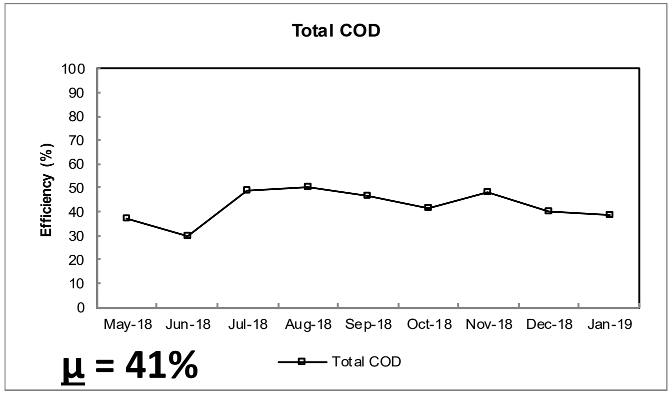
Concentration

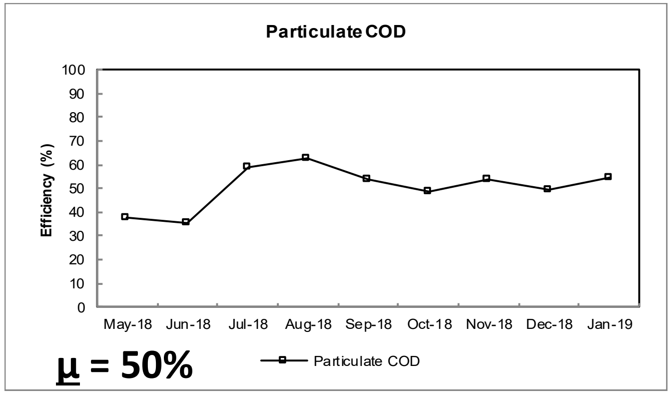


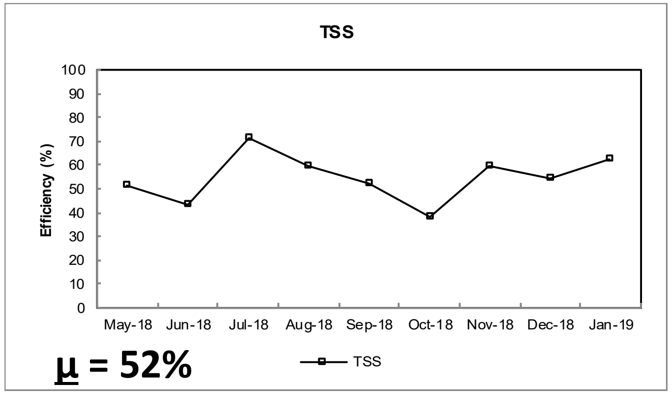




Removal efficieny







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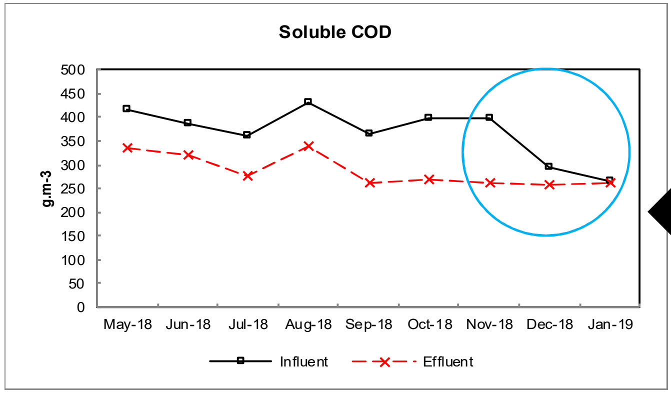
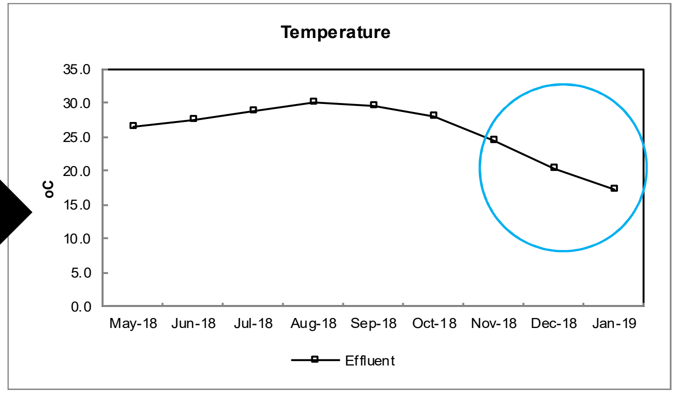
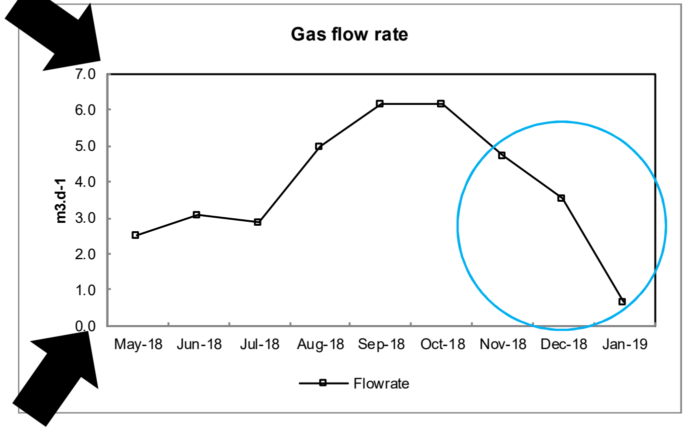
2nd Scenario (steady-state operation without PC) – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Concentration

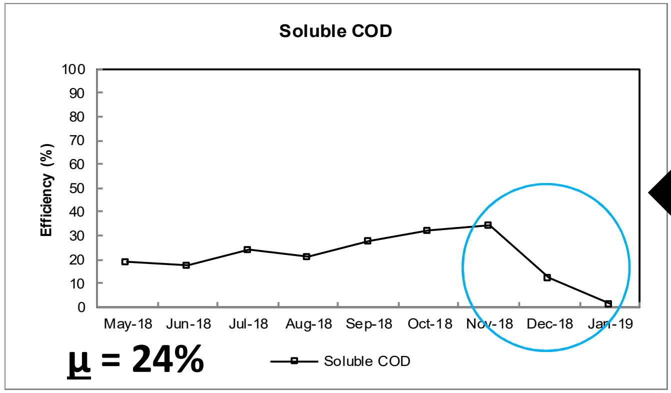


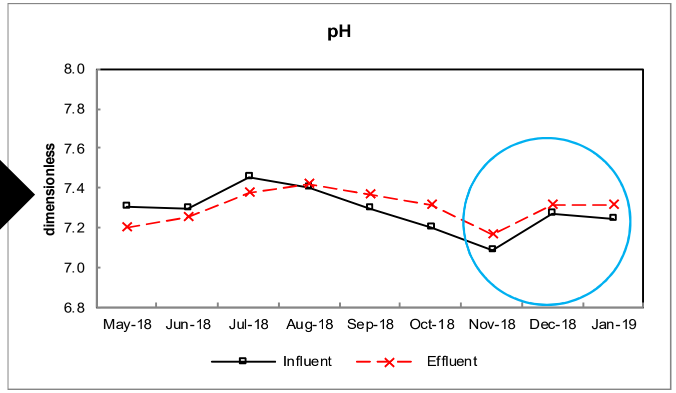


High production during hot months



Removal efficieny





High rainfall + lower temperature → diluted influent → less biogas production (influence on soluble COD) → pH stable

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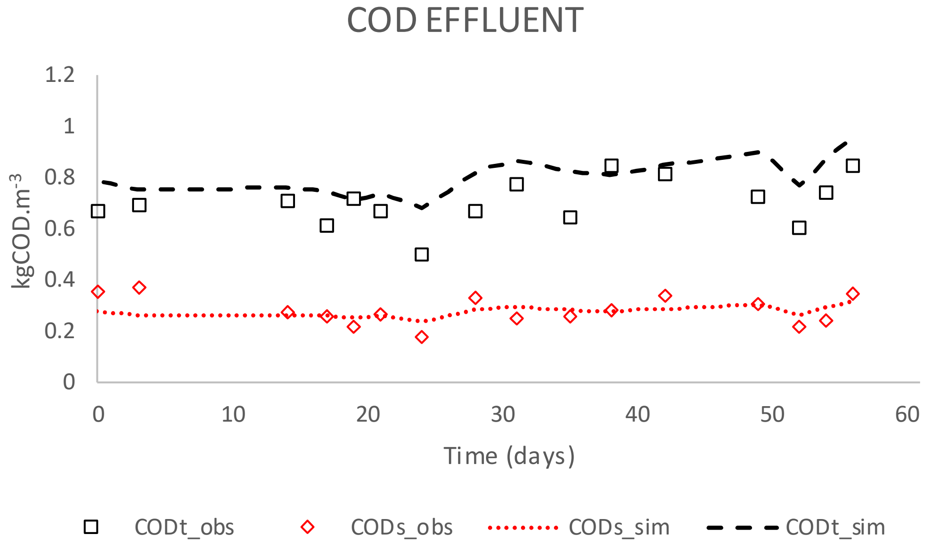
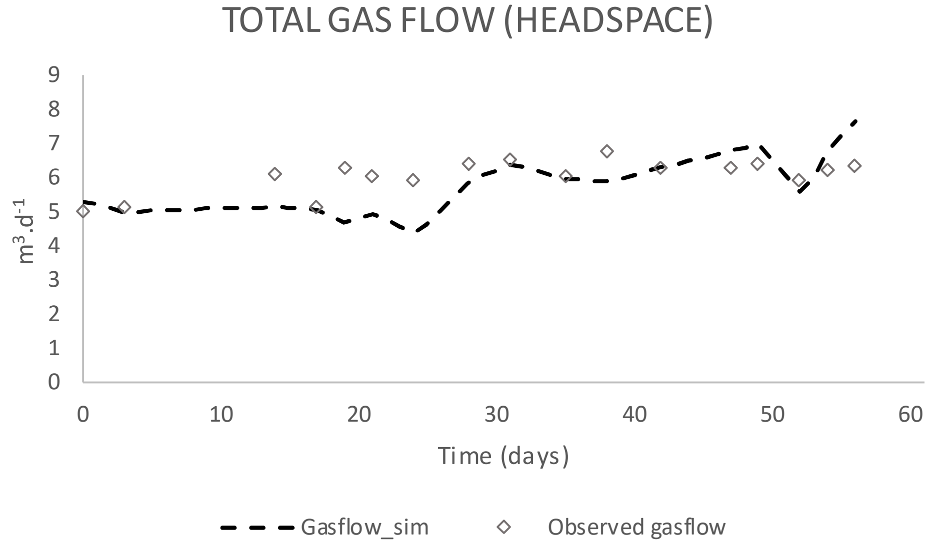
Model Calibration – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

Data from 10/8/18 to 11/10/18





Variable	NRMSD
COD_t	0.178
COD_s	0.176
Gas flow	0.133

Good fit to the experimental data → relatively low NRMSD

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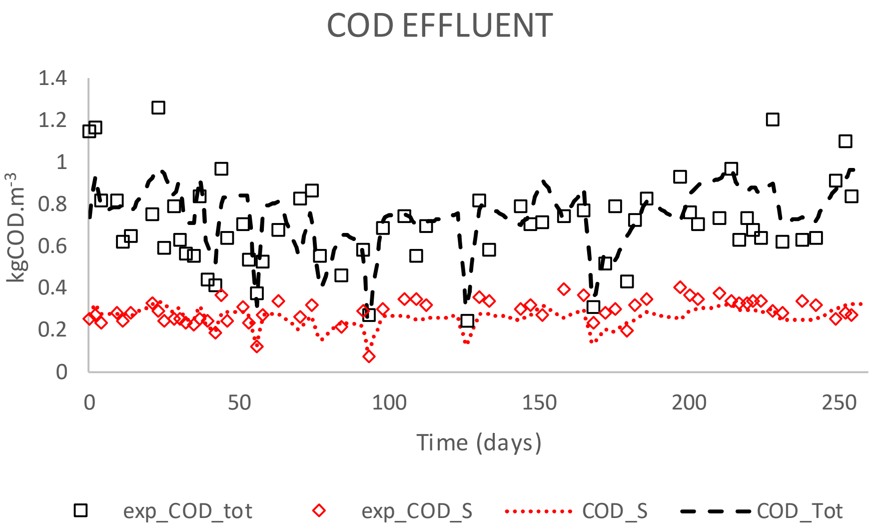
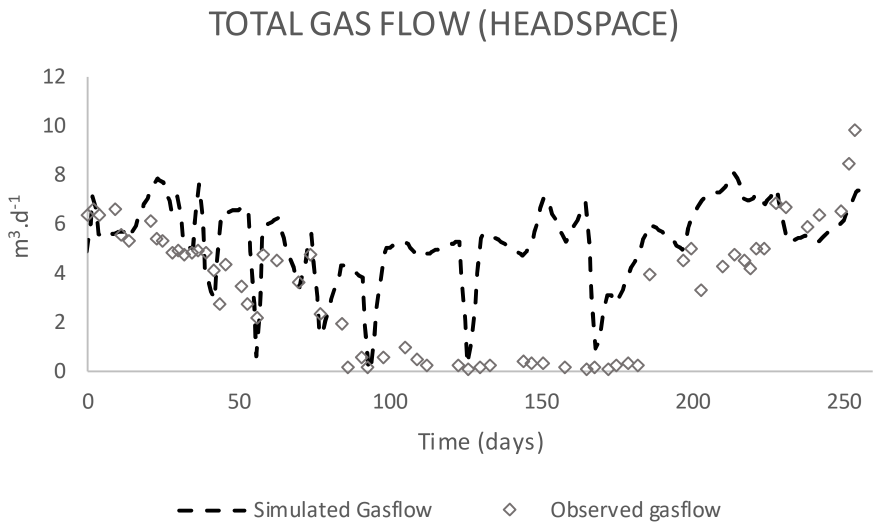
Model Validation – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery*

WWTP – Karmiel, Israel   Data from 14/10/18 to 31/1/19





Model validated with a separate set of data → considering seasonal variation → towards the end data set the model predicted well the amount of CODt and CODs → gasflow was also affected but predicted low flows at the end

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Conclusions – *Mainstream polyurethane-based anaerobic biofilter with biogas recovery* WWTP – Karmiel, Israel

After 390 days of continuous operation of the AAT which included the startup phase and consequently the steady-state phase, the following conclusions can be made:

- ✓ The biomass within the reactor adapated well to the real domestic sewage;
- ✓ After removing the PC, the biomass adapted well to the higher organic load received and continued to increase removal efficiency and biogas production;
- ✓ No bad odours were encountered in the vicinity;
- ✓ Very good removal effciecieny was observed given the low HRT of the reactor and organic load
- ✓ The modelling approach with the ADM1 adapted well to the characteristics of the reactor, therefore usable for future purposes;
- ✓ The purpose of the model is to contribute to designing similar processes in other applications and to allow for also process optimisation. This could be done by varying the flow rates, and lower or higher influent concentrations. It also allows to predict eventual biogas recovery and therefore foresee the amount of a renewable energy that is recovered, as well as the impact on downstream units.

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