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## Solid anaerobic digestion of pig manure with dry and fresh food waste

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Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης





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# The project



Developing Solid State Anaerobic Bioreactors Aiming in Optimum Utilization of Mediterranean Agro-wastes for Energy Production



European Commission



National/Regional Research and Innovation Strategies for Smart Specialisation (RIS3), Region of Crete





# The project



The DRYGAS (KPHP1 – 0028938) project consortium consists of: two SME and one University department. ENVIROPLAN S.A. is the leader partner.



The project's duration is 35 months.





Laboratory of Natural Resources Development & Agricultural Engineering Start date 23/04/2020

End date 23/09/2023



# The project

**DRYGAS** aims to :

- ✓ the development / optimization of dry anaerobic digestion as a technology of energy utilization of the Mediterranean Agro-waste.
- the development of a dry anaerobic bioreactor (Solid State Anaerobic Bioreactor), able to produce the max possible volume & optimal biogas composition.
- ✓ the development of 2 basic types of dry anaerobic reactors (batch mode), with the maximum possible degree of automated operation

The project consists of the following Work Packages:

•WP1 Determination of Optimal Operational Parameters of Dry Anaerobic Digestion

•WP2 Development of Technical Structures for Dry Anaerobic Bio-reactors

•WP3 Development of Operational Control Software (Dry Anaerobic Digestion Operating System -DABOPS)

•WP4 Operation and Optimization of Pilot Bio-reactors

•WP5 Environmental & Economic Assessment - Results of Exploitation Actions

The expected results from the DRYGAS implementation is an optimum management especially for the residues produced in the Mediterranean basin, and a technological step, which will allow the transfer of knowledge from the laboratory to the field, allowing the commercial development of dry anaerobic digestion.

#### **DEVELOPMENT / OPTIMIZATION:**

#### First step Aim is to determine:

- the **optimum inoculum** to substrate ratio
- **operational conditions** (temperature, moisture, Hydraulic Retention Time)

that will allow the **maximization of the efficiency of the system**, and therefore lead to the development / **optimization of dry anaerobic digestion** as a technology of energy utilization of the Mediterranean Agrowaste.

#### Second step Aim is to determine:

To **identify all the parameters** in order to develop a dry anaerobic bioreactor (Solid State Anaerobic Bioreactor), which will be able to **manage in an automated and optimal way**, all the Mediterranean Agrowaste and produce:

- Maximum possible volume
- Optimal biogas composition.

#### **Development of Dry Anaerobic Bioreactors**

Design, synthesis, testing and improvement of different electromechanical structures. Key technical questions:

- How to safely remove biogas,
- How to heat bioreactors,
- The material and design of structures inside them, and
- The operation of sensors and data transfer.



## Introduction

Solid-state anaerobic digestion

Suitable technology for treating organic wastes with high total solids content (>15%) and compared with conventional wet AD will enhance digestion and reduce liquid digestate generation



Batch dry anaerobic digestion is a wellestablished technology

- 1. Inoculum to substrate ratio
  - 2. Feedstock composition
- 3. Size of feedstock materials

Need further investigation avoid process instability

## Aim & Innovation



Examine the effect of different waste mixtures with >15 % solids (Mediterranean Agro-wastes) available in Crete for extracting energy with solid state anaerobic bioreactors

Key element: residue mixing will be achieving the desired moisture 70-85%, not the desired Volatile Solids (VS)

The approach and results could facilitate the development of biogas production in other Mediterranean regions with similar sources of organic residues

### **Raw Materials – Mediterranean**

Food Waste (FW)



65% Cooked meal 5% Bread 20% Vegetable & salads





#### **FOOD WASTE**

Food waste (FW) in their initial form (wet) used as a feedstock in our experiment, was collected from the students' restaurant at the Hellenic Mediterranean University, Heraklion.

- Homogenized using a mechanical mixer (approximately 4.0 mm).
- Solar drying process was used in order to dehydrate fresh food waste and produce dried material (FWD).

#### **PIG MANURE**

From a local pig farm in Crete.

#### **INOCULUM**

Inoculum was obtained from an anaerobic digester located at Wastewater Treatment Plant in Heraklion, Greece (population about 200,000).

#### FEED MIXTURE

Consisted of pig manure, food waste (wet or dry) and anaerobic sludge.

## **Raw Materials**

Composition of Food Waste (FW), Pig Manure (PM) and Anaerobic sludge (AS)						
Parameters	AS	FW	PM			
pН	7.7 ± 0.1	4.1 ± 0.1	7.3 ± 0.1			
TS (g/kg)	46.1 ± 1.0	233.2 ± 4.8	199.5 ± 1.5			
VS (g/kg)	$20.5 \pm 0.4$	221.6 ± 3.1	159.1 ± 1.1			
Moisture (%)	89 ± 0.4	79 ± 0.4	81.2 ± 3.2			

## **Experimental procedure**

- ✓ 4 type of feedstock:
- ✤ D1: 100% anaerobic sludge (AS) (as blind)
- ✤ D2: 60% AS, 40% PM
- **♦ D3:** 40% AS, 50% PM, 10% FW
- ✤ D4: 40% AS, 50% PM, 10g FWD
- $\bigstar \text{ Mesophilic AD, } 37^{\circ} (\pm 2^{\circ}) C,$
- ✓ Influent & effluent samples analyzed TS, VS, pH and methane content in biogas

<b>Operational parameters - Digester characteristics</b>						
D.	Digester working					
Digester no	volume (L)	Time (days)	Feedstock			
1	4	65	AS (100%)			
2	4	65	60% AS, 40% PM			
3	4	65	40% AS, 50% PM, 10% FW			
4	4	45	40% AS, 50% PM, 10g FWD			

Food Waste wet and dry (FW, FWD) Pig Manure (PM) Anaerobic sludge (AS)

### Lab scale solid anaerobic digester



- bed bottom for better agitation

### **Feedstock Results**

Characteristics of experimental materials as feedstock						
Parameters	D2	D3	D4			
pН	7.1 ± 0.1	7.3 ± 0.1	$7.3 \pm 0.1$			
VS (g/kg)	78.5±6.9	107.9 <b>±</b> 2.6	144.2 <b>±</b> 1.3			
Moisture (%)	82.3 ± 0.5	83.9 ± 1.2	83.3 ± 1.1			

D2: 60% AS, 40% PM D3: 40% AS, 50% PM, 10% FW D4: 40% AS, 50% PM, 10g FWD



## **Results – Total Biogas production**



FW & FWD addition – VS increase but decrease biogas production in solid state reactors



D2: 60% AS, 40% PM D3: 40% AS, 50% PM, 10% FW D4: 40% AS, 50% PM, 10g FWD

#### **RESULTS**

After co-digestion of D2: 60% AS, 40% PM, the total biogas production was 111.2 L while when FW wet (D3) and FW dry (D4) were added to the feed, the total biogas production was 45.4 L and 52 L respectively.
I.e. the total biogas production was decreased approximately 2 times, although VS is higher.

**Probably depends of VS concentration of the mixture**, i.e. whet VS are very hight, the increase after a specific threshold is acting suspendigly.

• The **Inoculum - Anaerobic Sludge is very important for the begging** of Solid state anaerobic process. The Inoculum - Anaerobic Sludge, that was used, was liquid anaerobic sludge.

The anaerobic process begun after 10 days for D2 and 20 days for D3 and D4.

Note: In other experiments with solid state sludge the process starts from the first day and the biogas production is almost twice.



# **Results – Biogas production**

Biogas and Biomethane production, biogas composition						
Parameter		D2	D3	D4		
Total Biogas Production (L)		111.2	45.4	52		
Total Biogas Production (ml/gr VS)		350	100	90		
Biogas comp. (%)	CH <sub>4</sub>	52.4±8.6 <b>max 63.9</b>	65.2±7.1 <b>max 72.8</b>	63.6±8.9 <b>max 72.6</b>		
Total Biomethane production (L)		58.3	29.6	33.1		

### **Results – VS**



D2: 60% AS, 40% PM D3: 40% AS, 50% PM, 10% FW D4: 40% AS, 50% PM, 10g FWD  $D2 \rightarrow 39.4\%$  $D3 \rightarrow 24.6\%$  $D4 \rightarrow 21.6\%$ 

VS removal of PM in the feed was higher in comparison with wet and dry FW addition

The extra VS concentration in solid state anaerobic digestion decrease VS removal



# Conclusions

- Solid state anaerobic digestion is a suitable technology for treating organic wastes with high total solids but it is important the VS concentration
- This new direction would generate insights into the upper limits to which volumetric feed rates can be supported
- □ The highest Methane composition was obtained by co-digestion of FW and PM

Inoculum - Anaerobic Sludge is very important for the begging of SS-AD
Inoculum with Digestate of the bioreactors is much more efficient

└ Co-digestion and pretreatment are promising for improved methane yields and stability during SS-AD







https://www.drygas.gr/

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