

Disciplina: Energia da Biomassa

Anaerobic Digestion Process

Docente: Santino Eugénio Di Berardino

Santino.diberardino@lneg.pt



Introduction



- Our development depends on natural resources and energy supply, being necessary to diversify the sources and make them sustainable.
- Our future evolution is linked to this new supply sources.
- Biogas from wastes is a favourable option

Global Objectives

- Sensibilise on organic matter problems and pollution control
 - Present and describe an important process and technology for Organic matter degradation and biogas production
 - Give a global vision of the process potentiality and field of application
 - Describe the positive contribute in energy production, products recovery and warm control
 - Give the basic information and tools to decide and plan a system implementation
- Prerequisite(s)
 - Ecology, microbiology, kinetic, mathematic, physic...

● Basic Concept - Organic matter and ● Biomass

- Both define the biological mass generated by biologic species. The Organic matter, however, includes also synthesized compounds
- Our society is quite exigent in resources and generates large quantity of organic residues.
- Organic matter is **by far the larger source of pollution**
- Nutrients: Nitrogen, Phosphates, sulphur compounds are present in organic proteins molecules .

Organic Waste Problems

- The organic waste from agricultural and Industrial area cause pollution serious environmental problem due to the large quantity and the nutrients carried in the water.
- They must be treated and disposed correctly and safely in the surrounding environment.
- Farm residues are one of the main pollution fonts in Portugal and in others European countries.
- Accumulation of waste originates anaerobic conditions and uncontrolled and undesirable reactions. Bacteria naturally begin the decomposition process of the waste.

Sewage Treatment

- **With the development of modern sanitation, sewage networks were created that kept the dangerous pollutants out of the population.**
- **However the sewer pipes transported pollution to a medium (water course or land) receiving it.**
- **It was necessary to devise a treatment system to improve sewage properties and avoid pollution**

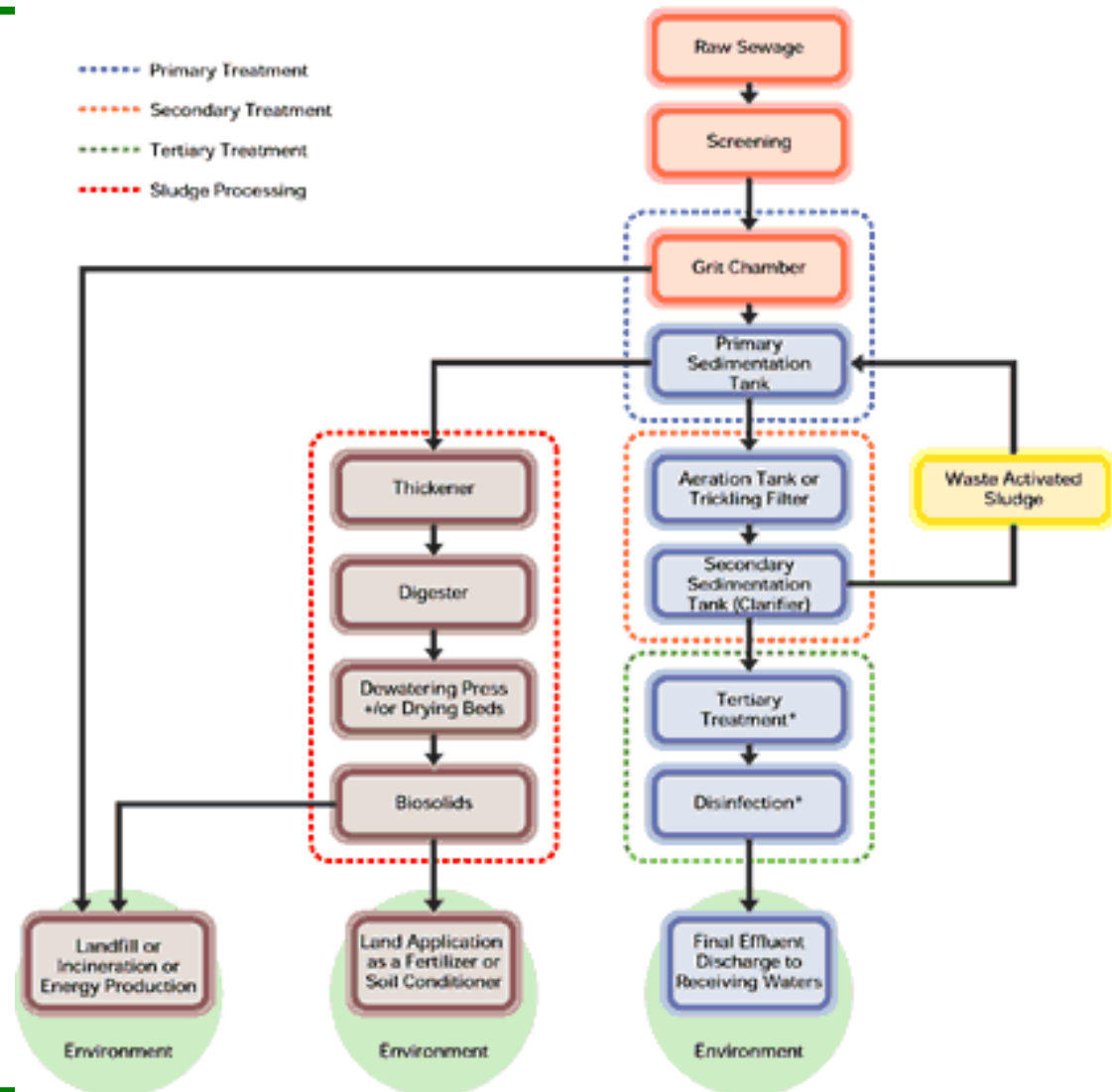
Sewage treatment systems

- **The first sewage treatment systems were anaerobic.**
- **The aerobic processes were subsequently developed.**

Conventional WW treatment system

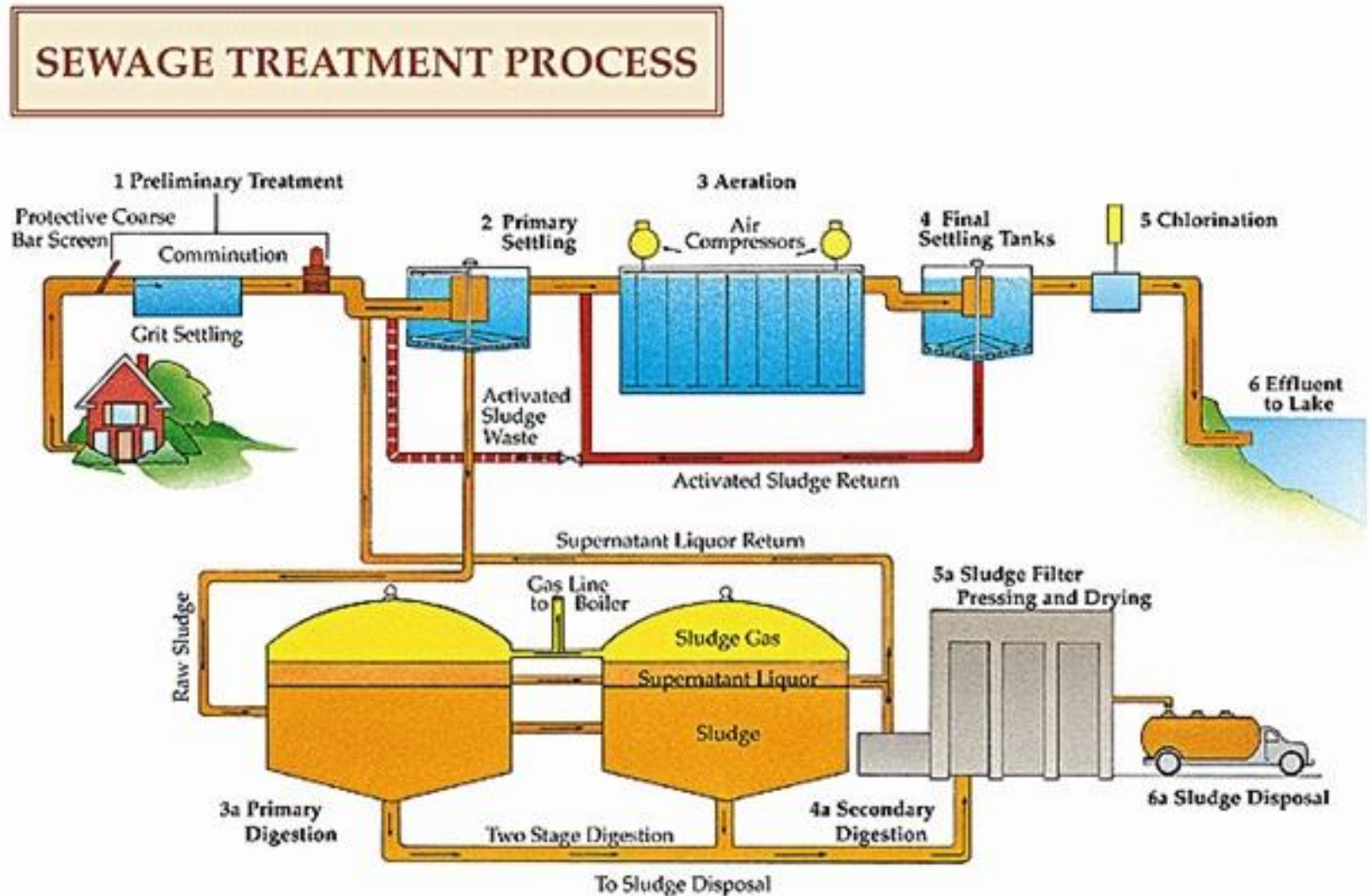
Wastewater Treatment Plant (WWTP) are formed by a sequence of operations and processes as indicated in the scheme:

Today, WWTPs have tertiary treatments to remove nutrients, poorly biodegradable organic matter and disinfection.



*Tertiary Treatment and Disinfection will occur only at some facilities where a very high quality effluent is required.

Typical sewage treatment process



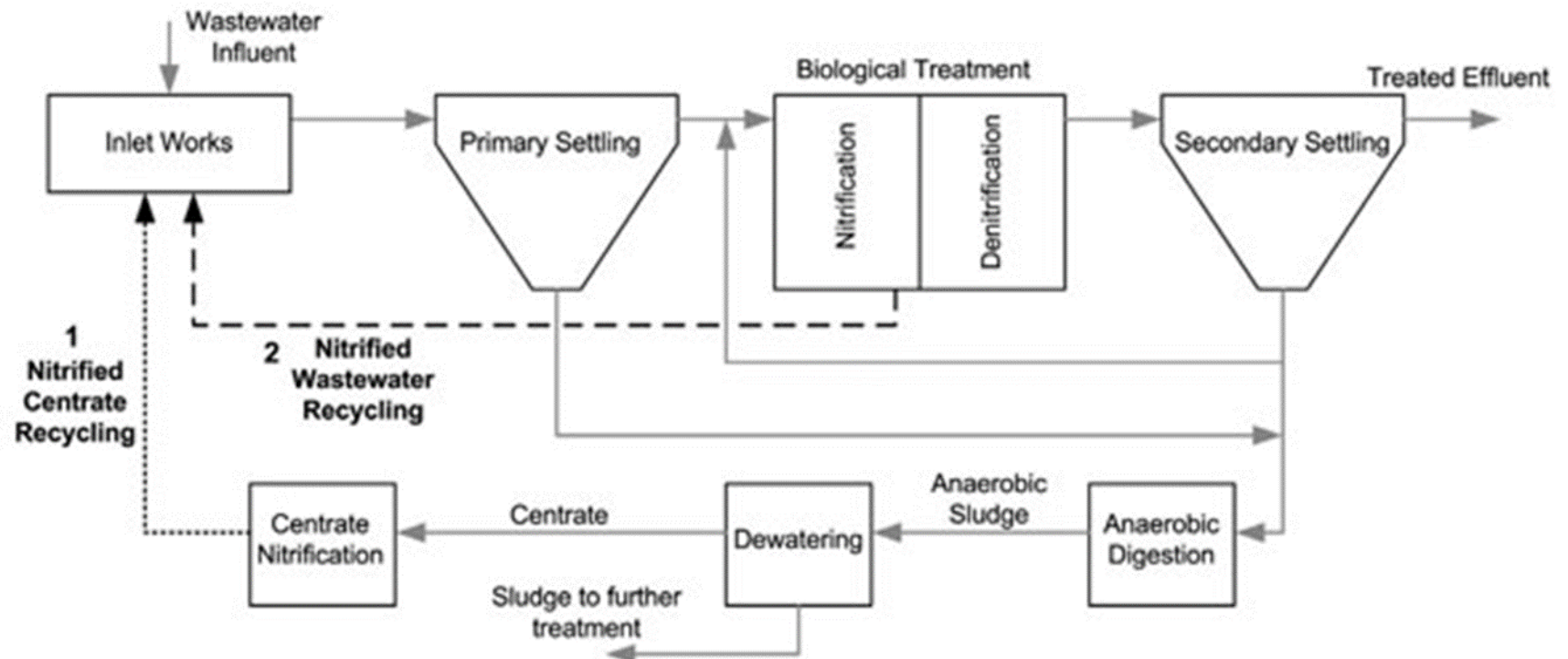
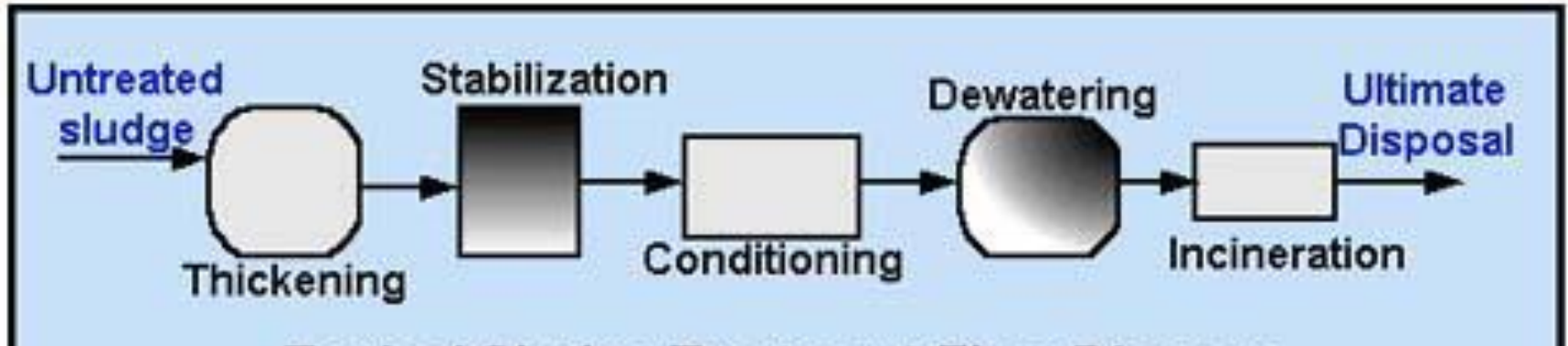
●●● Disposal of treated effluent-options ●●●

- LAUNCH ON THE GROUND
- DISCHARGE IN WATER BODY
- QUICK INFILTRATION
- AGRICULTURAL OR FOREST LANDSCAPE
- SURFACE RUNOFF
- LAUNCH ON THE OCEAN

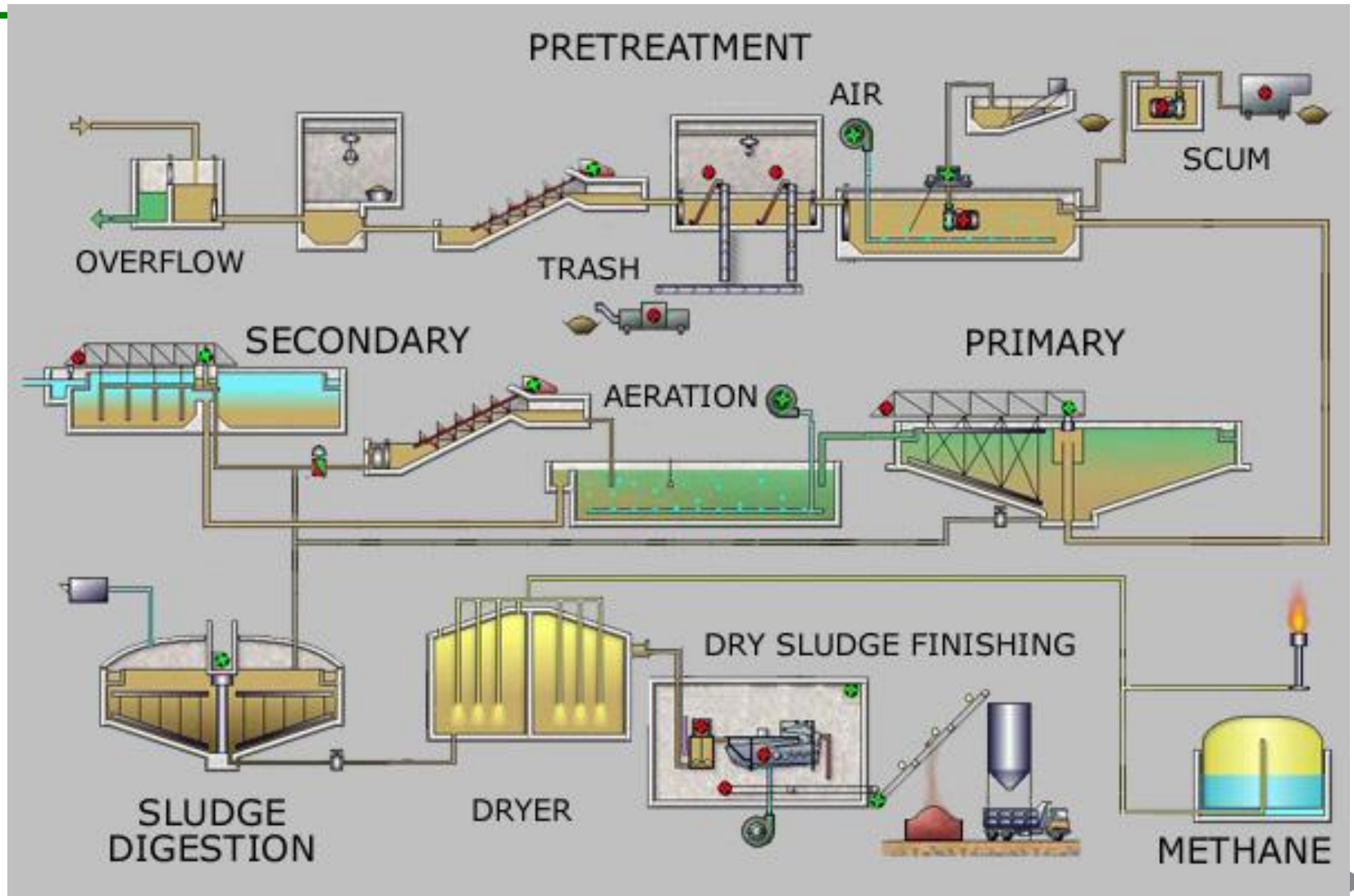
Sludge Treatment

- But sewage treatment does not eliminate pollution.
- Most of the pollutants are concentrated in the sludge, a brown and smelly waste that must be treated.
- Anaerobic digestion was then developed to treat the sludge, or rather to digest or stabilize it.
- Anaerobic digestion removes organic matter and produces biogas.

Conventional sludge treatment scheme



Conventional sludge treatment scheme





Sludge Characteristics



- As lamas primárias correspondem a cerca de 2,5 - 3,5 % do volume de esgoto.
- As lamas secundárias: 1,5 – 2,5 %
- As lamas a tratar e colocar em destino final de ETAR convencional podem variar entre 4 e 7 % do volume do esgoto, consoante o sistema de tratamento e as condições de funcionamento.
- A utilização de reagentes químicos aumenta substancialmente a quantidade de lamas. No caso da remoção de fósforo, por exemplo, contribui com mais 1 %.
- As lamas, apesar de terem um aspecto compacto e escuro possuem uma larga quantidade de água. Teor de sólidos: apenas 3 - 5 % ST.

Characteristics of sludge

Tabela 1: Características das lamas

Tipo de lama	% de sólidos na lama	Resíduo seco (g/hab/dia)	Volume (l.hab/dia)
Lama primária não espessadas	0,2- 2	55	1,1
Lama primária espessada	4 - 10		0,20,5
Lamas da Decantação secundária (Lamas activadas de média carga)	0,5– 1,5	35	0,7-1,1
Lamas da Decantação secundária (Leitos percoladores de alta carga)	0,5-1	20	0-4-0,7
Lamas mistas (Primárias + lamas activadas)	3-5	86	1,8-2,4
Lamas mistas espessadas	5 - 10	86	0,9-1,2

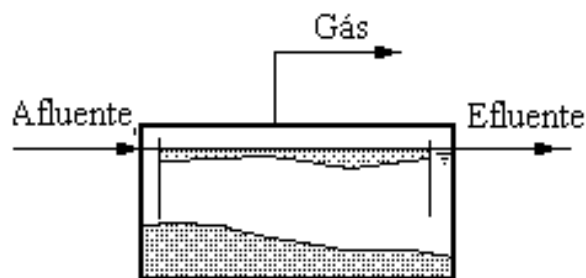


Evolution of AD-Major steps

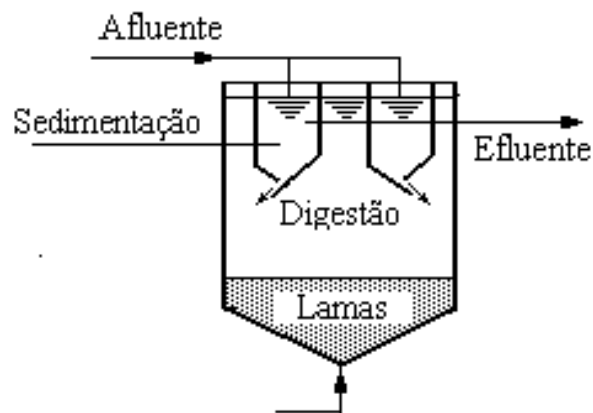


Data	Sistema	Autor
1881	Tanque Séptico	Louis Mouras
1890	Tanque séptico com leito de pedras	Scott-Montcrieff
1895	Fossa séptica	D. Cameron
1897	Fossa séptica com anteparas	Talbot
1904	Tanque combinado	Travis
1905	Tanque combinado	C. Imhoff
1951	Sistema de contacto anaeróbio (lamas activadas anaeróbias)	Scroepfer et al.
1957	Tanque de contacto	Coulter, Soneda e Ettinger
1962	Clarigester	Hemens et al.
1969	Filtro anaeróbio	Young e McCarty
1970	Tanque de fluxo ascendente de leito de lamas (UASB)	Lettinga et al.
1981	Tanque de leito expandido	Switzembaum e Jewell

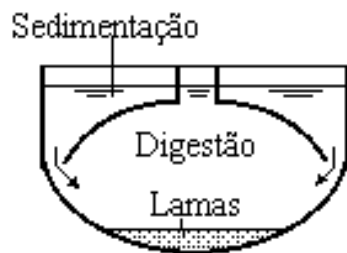
First anaerobic treatment systems



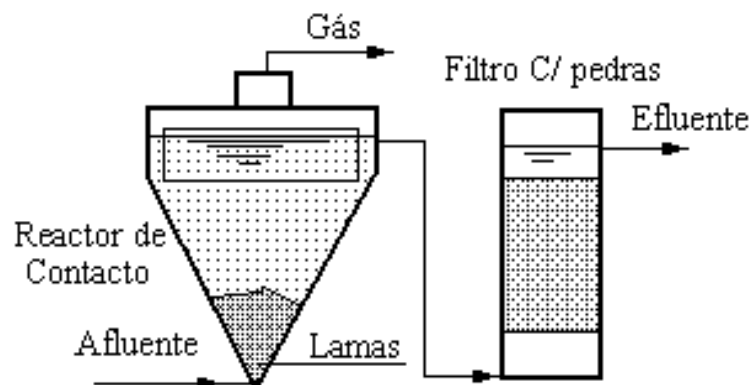
Fossa Séptica
Com anteparas



Tanque Imhoff

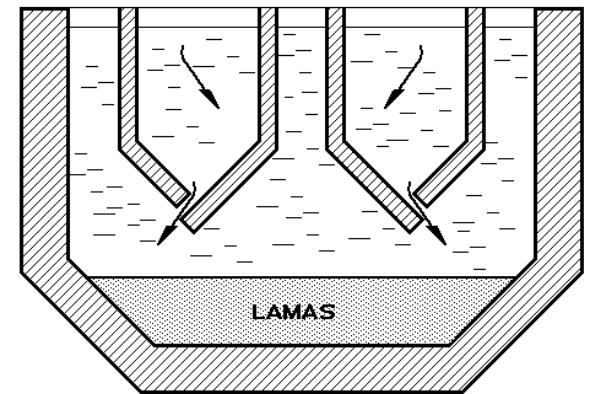
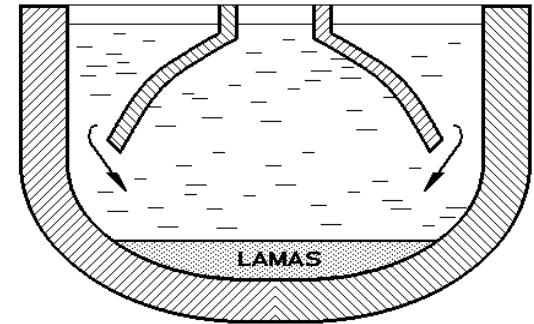
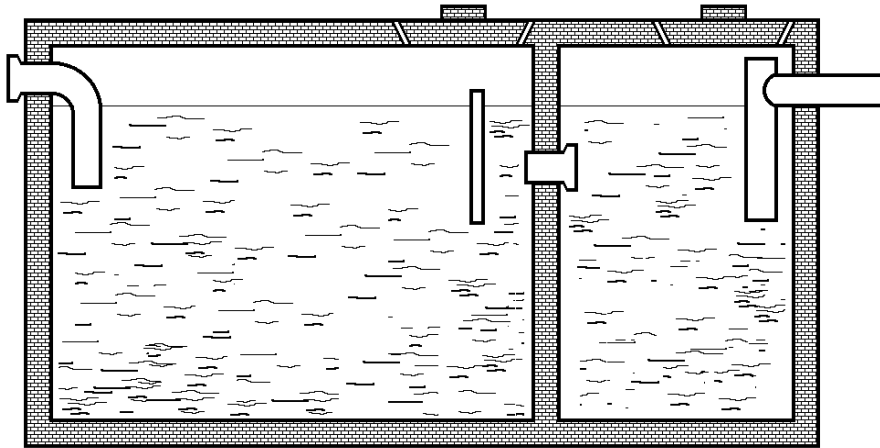


Tanque de Travis



Sistema de contacto

Primitive Systems



Septic Tank, Imhoff Tank and Travis Tank

AEROBIC TREATMENTS

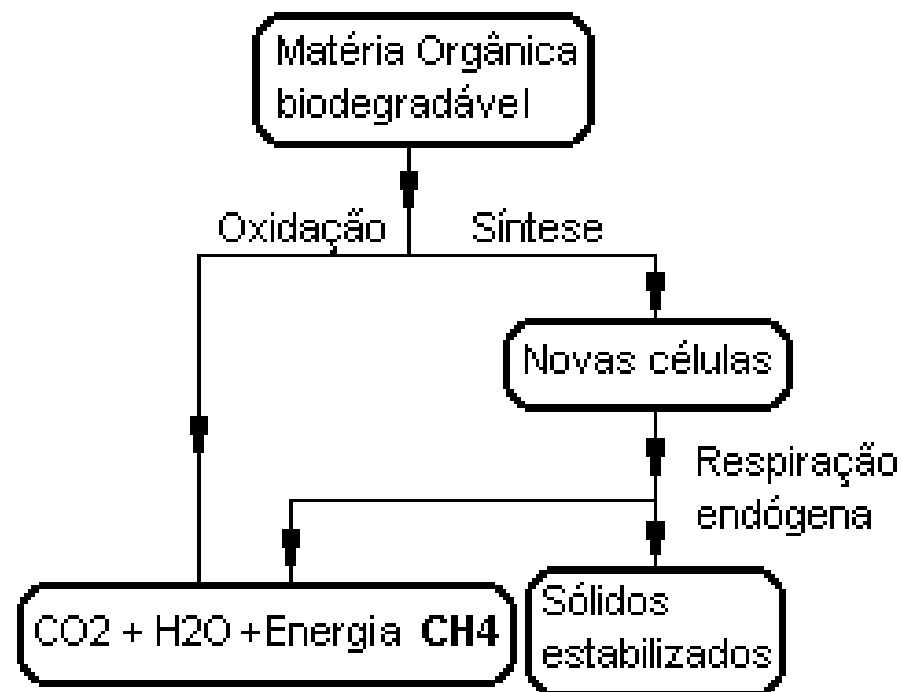
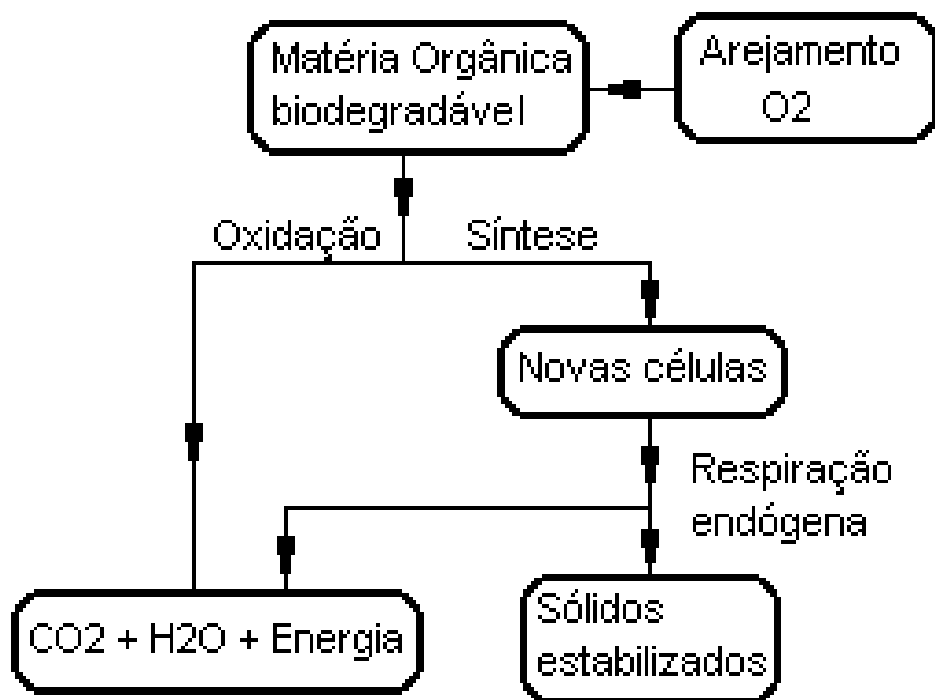
- Transfer of pollution from sewage to sludge
- They give a general improvement to the sewer, remove:
 - 95-99% of M.O.
 - 50% of M.O. In the L.S
 - Nutrients (N, P, S)
 - Heavy metals
 - M.O. Of synthetic origin
 - Others.

Methanogenic fermentation

- a process of biodegradation of organic material, which occurs spontaneously in nature.
- Observed by marshes or puddles, by the release of gaseous bubbles.
- Methane was discovered and identified in 1776 by Alessandro Volta,

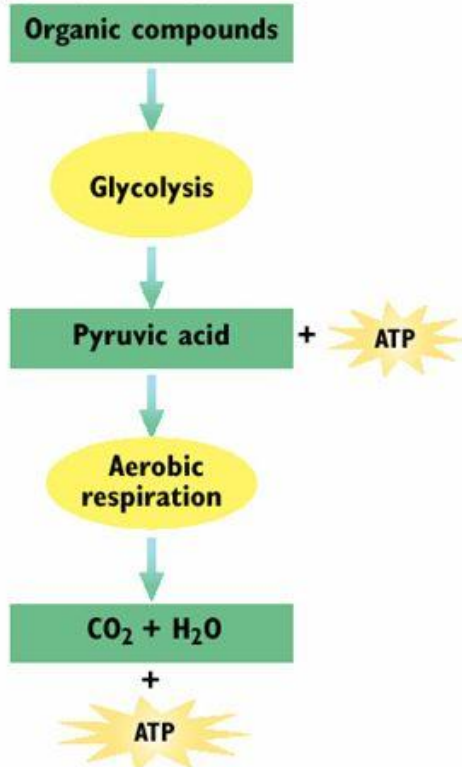


- The biological treatment effects the stabilization of organic matter by the action of various microorganisms. In the presence of oxygen:
organic matter + microorganisms + oxygen + nutrients = synthesis of new cells + H₂O + CO₂ + energy
- In terms of sanitary sewers:
sewage + sludge + air = excess sludge + final products
- In anaerobic methanogenic processes:
organic matter + microorganisms + nutrients = synthesis of new cells + H₂O + CO₂ + energy + CH₄

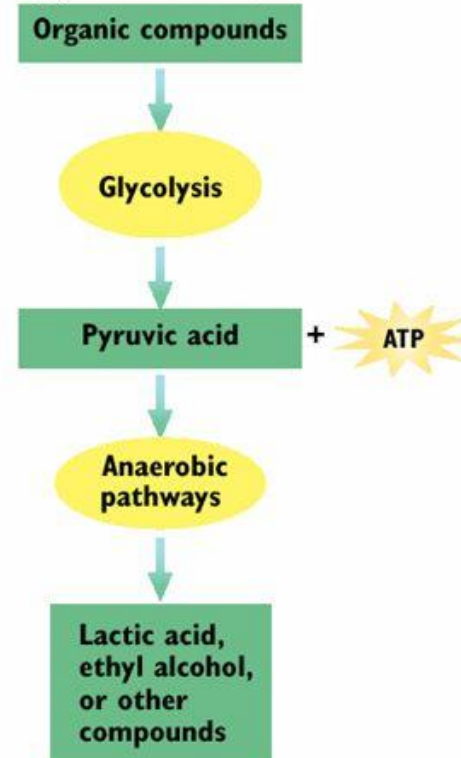


Aerobic vs. Anaerobic

(a) CELLULAR RESPIRATION



(b) FERMENTATION



ação
ana

Aerobic vs anaerobic

AEROBIC VS. ANAEROBIC

AEROBIC RESPIRATION

** Required oxygen*

**Complete oxidation of respiratory material.
Produced maximum 38 ATP molecules per glucose

**Consists of glycolysis, Krebs Cycle and oxidative phosphorylation*

**Respiratory materials is completely oxidised*

**Water is formed*

ANAEROBIC RESPIRATION

**Does not require energy*

**Incomplete oxidation of respiratory material.
Produce only 2 ATP molecules per glucose

**Consists of glycolysis and incomplete breakdown of pyruvate*

**Respiratory materials is not completely oxidised*

**Normally water is not formed*

las
espiração
ndógena

los

Farm Wastes: Pollution load or source of primary matter ?

- Farm wastes have an interesting chemical composition. They are nutrient-rich, for soil fertilization

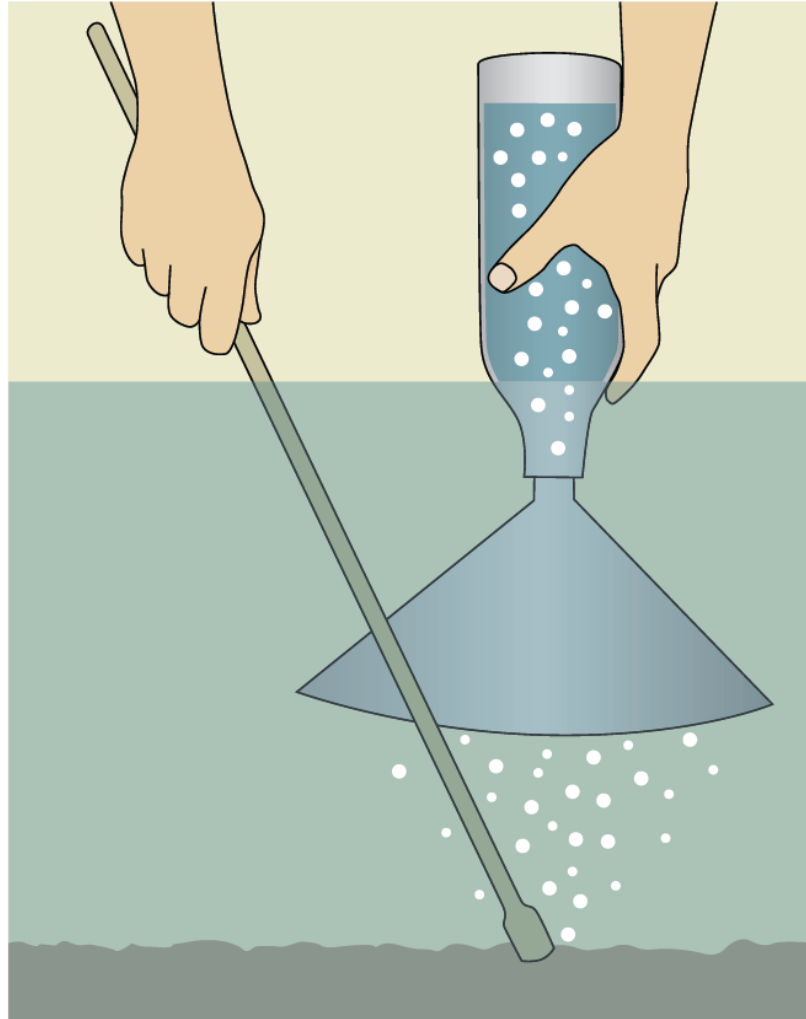
Chemical composition of farm residues
(Kg/100 Kg of animal weight)

<i>Animal</i>	<i>CBO₅</i>	<i>CQO</i>	<i>CBO/CQO</i>	<i>Ntot</i>	<i>C/N</i>	<i>Nam</i>	<i>P</i> (<i>P₂O₅</i>)	<i>K</i> (<i>K₂O</i>)
Chicken	3,46	9,8	0,35	0,74	-	0,26	0,60	0,30
Swine	3,1	6,4	0,48	0,51	20	0,24	0,42	0,40
Milk cow	1,15	9,8	0,11	0,23	30	0,23	0,01	0,02
Cows	1,61	9,42	0,17	0,32	25	0,11	0,18	0,23

Waste treatment or valorisation ?

- **Conventional treatment approach**: The pollutants are transferred in a concentrated phase, which is dumped, obtaining a more dilute phase, which is dispersed. The treatment and disposal of organic residues is quite expensive both in capital and energy costs.
- **Modern treatment approach**: The wastes are treated in a way to allow the recovery and reuse of components. Anaerobic digestion, improves residue quality and produces energy. Important energy savings are obtained by the substitution of aerobic process and the **fertilising properties of the effluent can be reused in agricultural crops.**

Biogas Bubbles



● From Morgensen

Biogas use - important data

- 1776: Discovery of the gas Methane (Alessandro Volta).
- 1859: First Biogas Application biogás, leprosarium (Bombay)
- 1895: First European application Street lighting Exeter (England).
- 1895-1940: Small specific applications
- 1940-1945: Use in heating, lighting and municipal trucks (Second World War).
- 1945-1972: Abundance of conventional energy. No use in developed countries. Use in China and India) in small communities
- 1973 – 2004 - After the first Energetic crises methane from anaerobic digestion is more and more used.

Inorganic elements in wastes

- Concentration of inorganic elements (g/l)
- The energetic potential of organic matter contained in these residues is important,

Animal	Ca	Hg	Zn	Cu	Fe	Mn	Na	K	P	S	N
Chicken	-	-	-	-	-	-	-	-	-	-	-
Swine	4,9	0,79	0,06	0,015	0,27	-	-	-	-	1,43	-
Milk cow	2,53	1,0	-	-	0,036	-	-	4,53	0,9	0,453	5,07
Cows	2,56	1,7	0,045	0,006	4,09	0,51	1,05	4,62	-	-	-



Anaerobic Digestion Process



- Biological process in which some categories of bacteria attack the structure of the complex organic materials contained in the sewage to produce simple compounds: methane, carbon dioxide, water, etc., extracting at the same time the energy and the compounds necessary for the own growth.
- It is described as consisting of **three main stages** involving different strains of microorganisms:
 - hydrolysis of organic molecules into sugars and fermentation in volatile acids, alcohols, hydrogen and CO₂, by means of heterotrophic microorganisms; oxidation of higher molecular weight acids and of alcohols for the formation of acetic acid and hydrogen;
 - methanogenesis, performed by strict anaerobic bacteria, which convert acetic acid and hydrogen into methane, keeping the concentrations of these compounds low.

Anaerobic Methanogenic Fermentation

- The anaerobic decomposition (or anaerobic digestion process) occurs naturally in wetlands, Lake Bottoms, and deep in soils, where no oxygen is available.
- Oxygen is toxic to methanogenic bacteria and cannot be present.
- During anaerobic organic matter degradation, Biogas is produced, which contains about 60% methane, 40% carbon dioxide, and trace amounts of nitrogen, hydrogen, and hydrogen sulphide.
- Methane was discovered and identified in 1776 by Alessandro Volta.

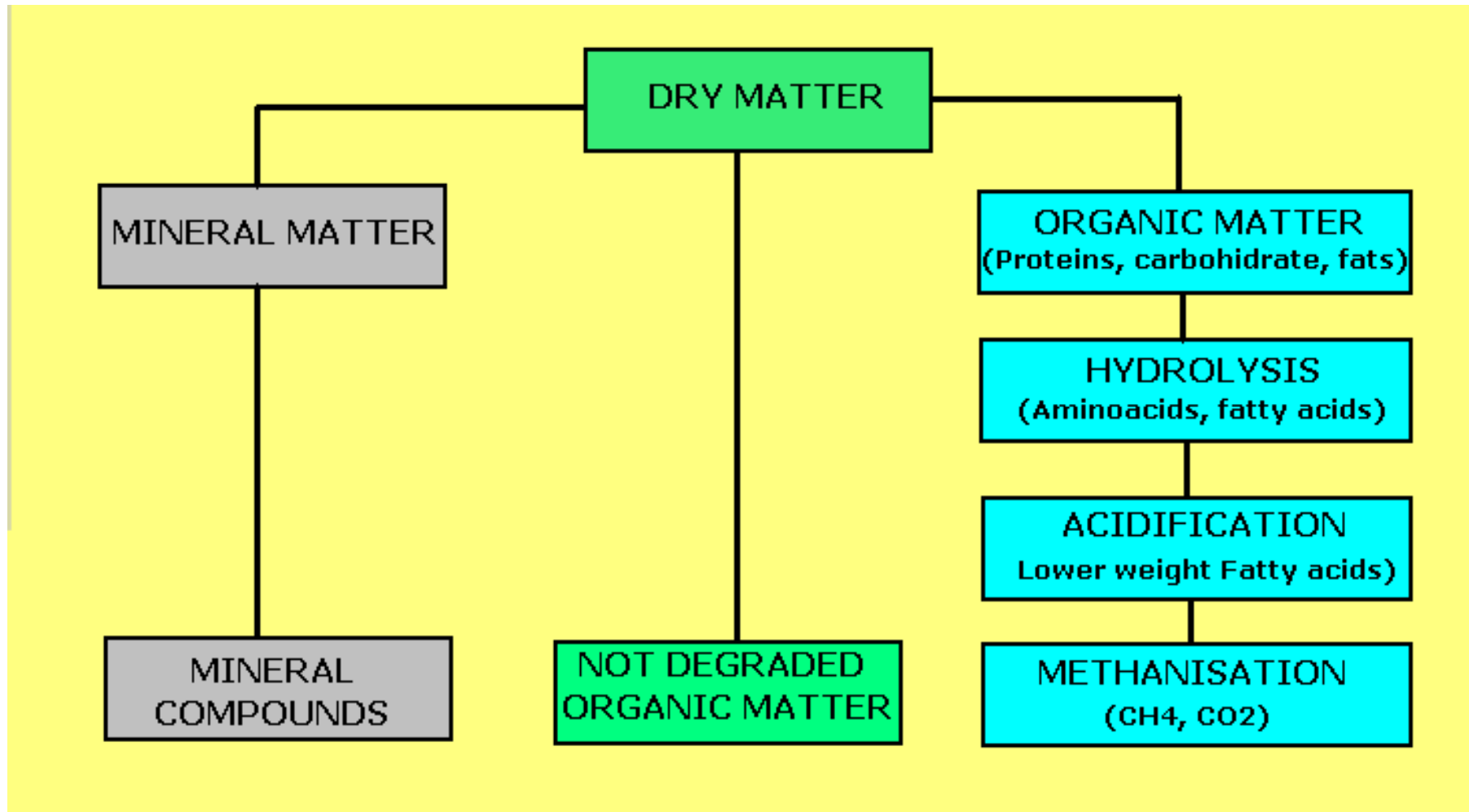


Stages of Anaerobic Digestion

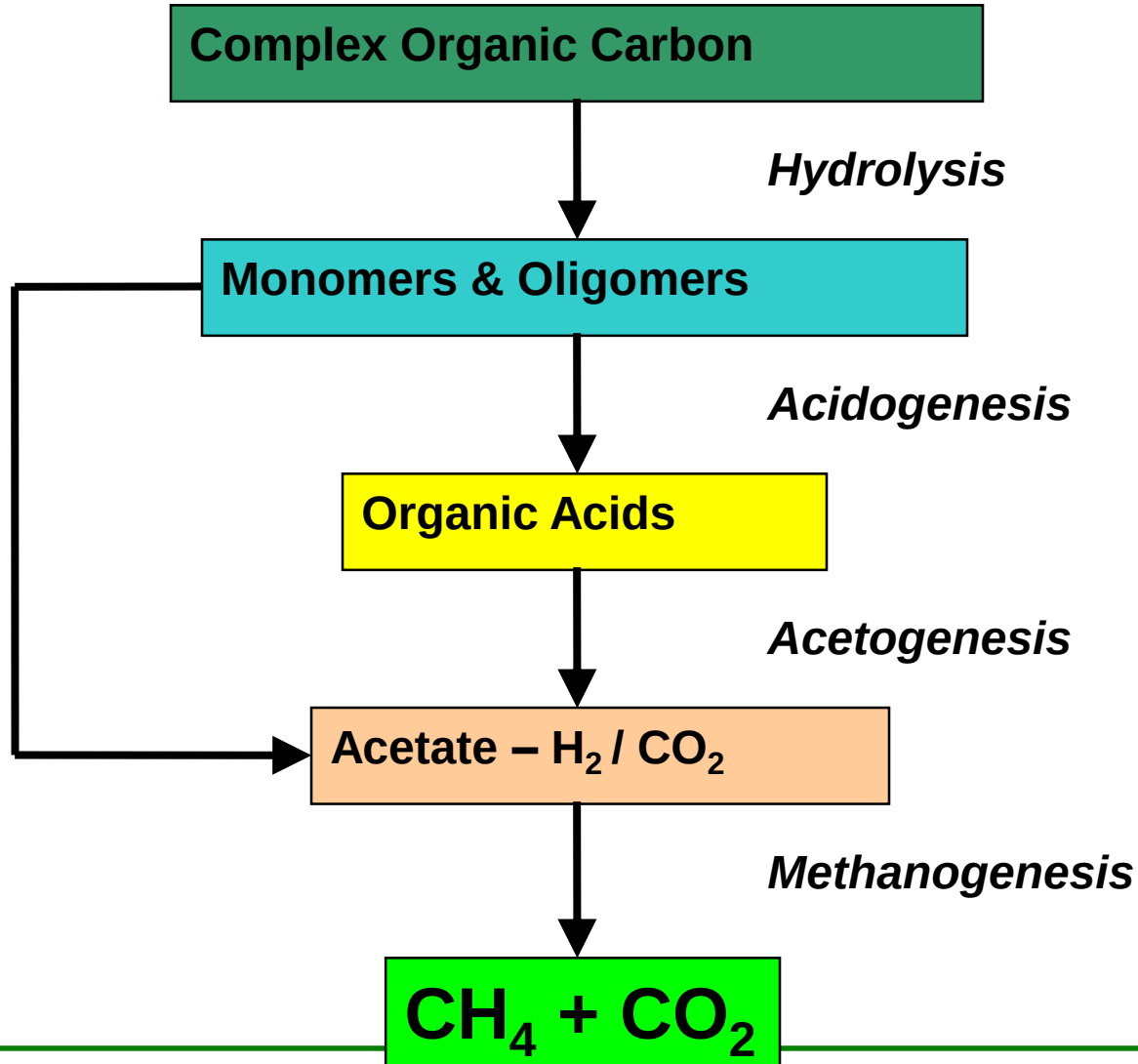


- Anaerobic Digestion is a biochemical process carried out in a number of steps by several types of bacteria, which grows using the organic waste.
- In a simplified way, can be described as a three-stage process as follows:
- Hydrolysis of suspended and particulate solids are broken into soluble particles by extra-cellular enzymatic attack.
- Acidification: Acid-forming bacteria break complex organic wastes down into volatile fatty acids.
- Methane Production: Methane-forming bacteria (methanogens) use acids formed in previous acidification stage, hydrogen and carbon dioxide to generate methane.

Schematic representation of Anaerobic Digestion



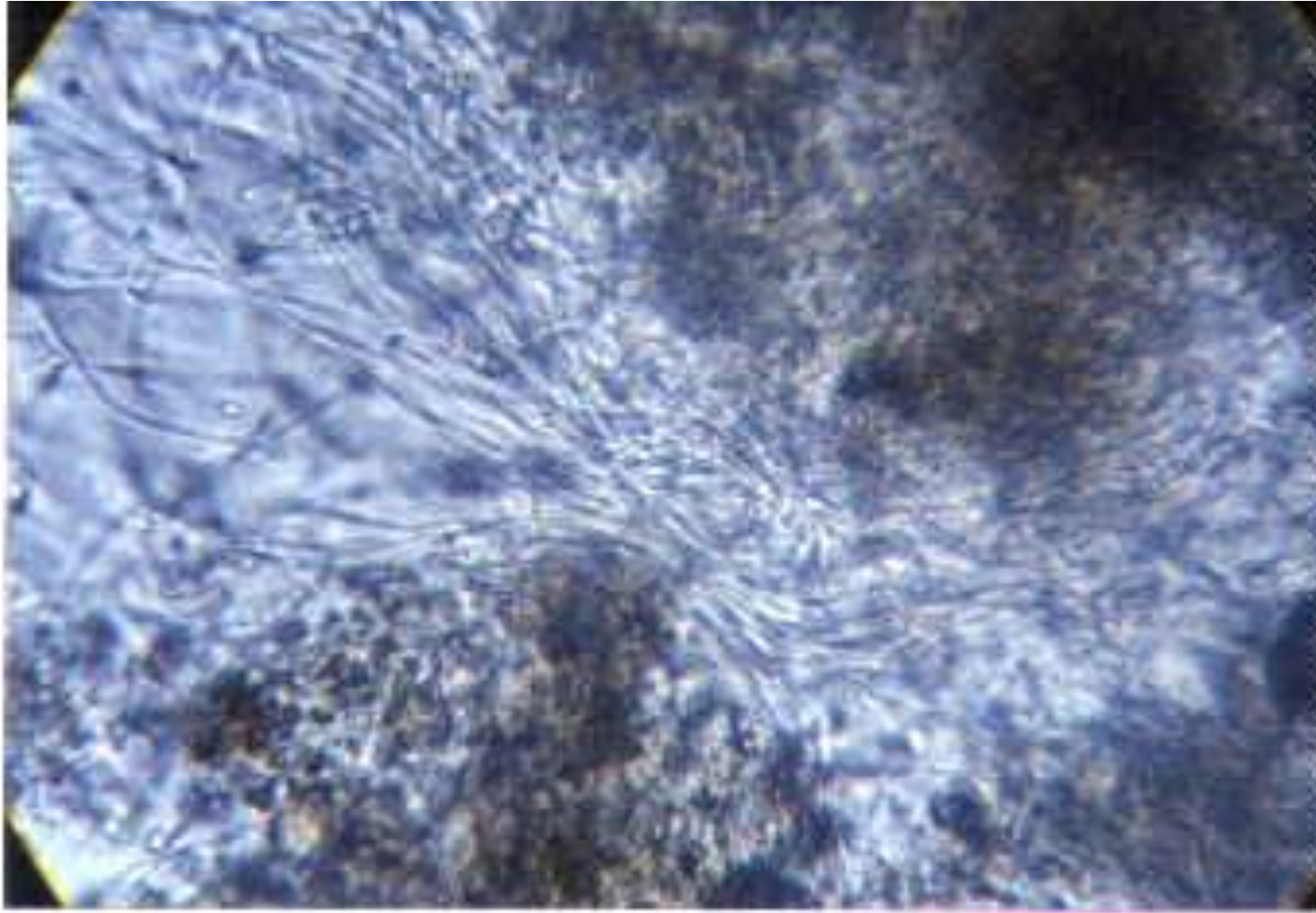
Anaerobic Digestion stages



Anaerobic digestion: Symbiose and syntrophy

- The microorganisms involved in anaerobic methanogenic degradation lives in Symbiosis and Sintrophy:
- Hydrolytic and acidogenic bacteria prepare the food necessary to Methanogenic bacteria: Acetate, CO₂ and Hydrogen.
- Methanogenic bacteria removes organic acids, controls the pH and provides energy for the process.

Methanothrix picture

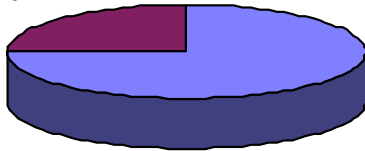




What means Digestion ?

Resíduo Orgânico

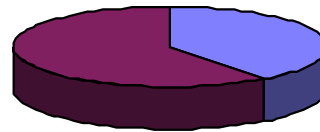
Matéria
Mineral
25%



Matéria
orgânica
75%

Resíduo Digerido

Matéria
orgânica
40%



Matéria
Mineral
60%

Resíduo Mineralizado

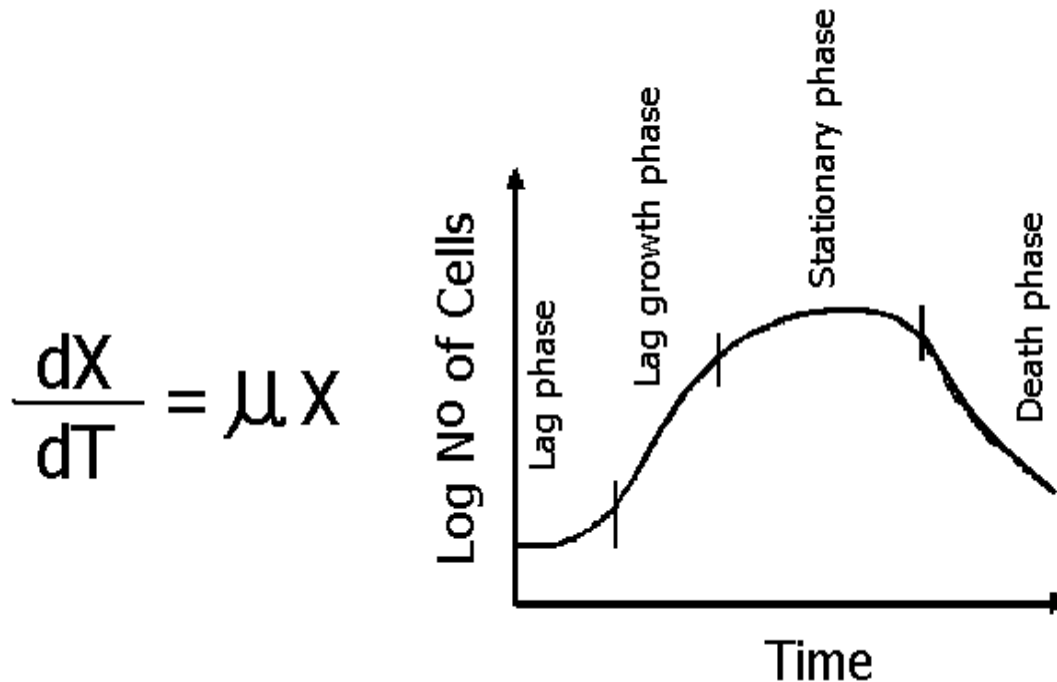
Matéria
orgânica
0%



Matéria
Mineral
100%

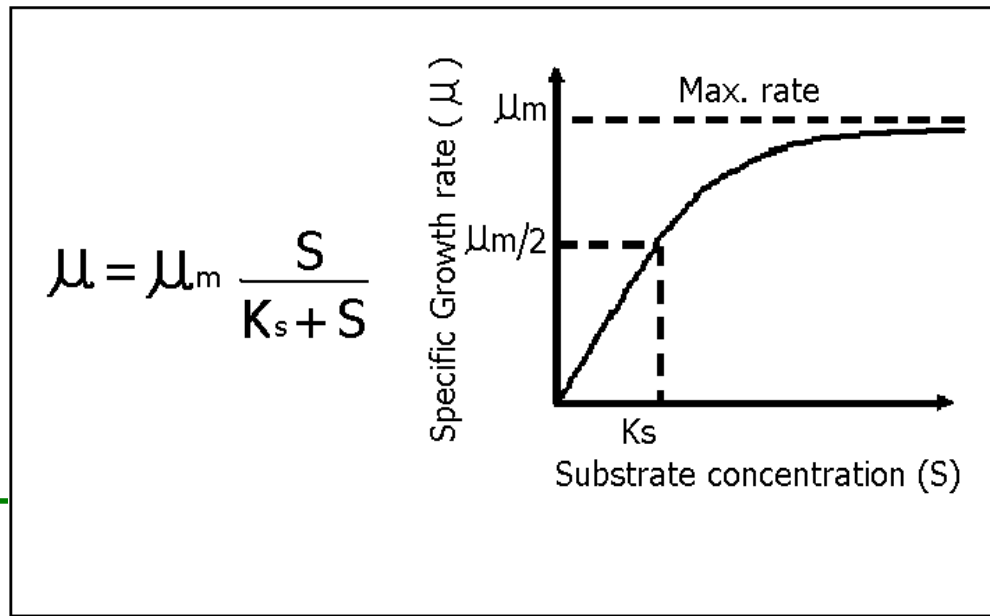
Biological growth of bacterial community

- Exponential growth: The Number of Microorganisms living in a digester increases according to the following shape.



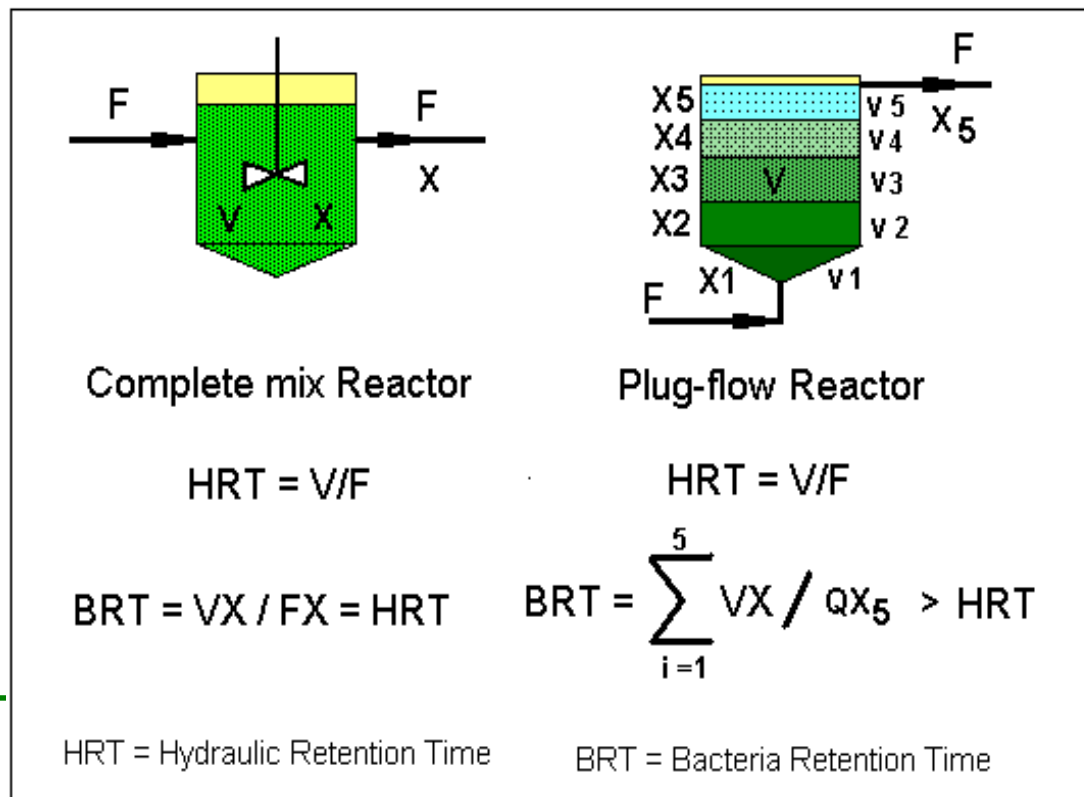
Biological growth - kinetic

- When substrate is limiting, the growth of microorganisms follows Monod Kinetic Model.
- Many other models are available today (Haldane, Andrews, Hashimoto etc.). The choice depends on the specific case.



Hydraulic and Bacteria Retention Time

- According to the mixing regime HRT and BRT are different
- Plug flow systems allows higher BRT than HRT





Organic load



- Important Combined parameter for System design
- Defines the quantity of organic matter that the reactor is able to degrade each day for unit of volume
- Is expressed as Kg COD/m³.day⁻¹, para os efluentes industriais or as Kg SV/m³.dia⁻¹, For sludge or agricultural wastes.

$$\text{Organic Load (OL)} = \frac{C F}{V} = \frac{C}{T}$$

C = Organic matter concentration as COD or VS (g/l)

F = Flow rate (m³/day)

HRT = Hydraulic Retention Time

V = Reactor Volume (m³)



Anaerobic digestion: sensibility



- Anaerobic Digestion requires the balanced growth of all involved communities.
- The bacteria are very sensitive to changes in their environment.
- Their growth, the rate of decomposition and gas production are influenced by many parameters
- The Energy available for the process is small. A significant quantity of energy leaves the process as methane.

Temperature

Temperature influences metabolism of all the involved microorganisms. It affects anaerobic digestion as follows:

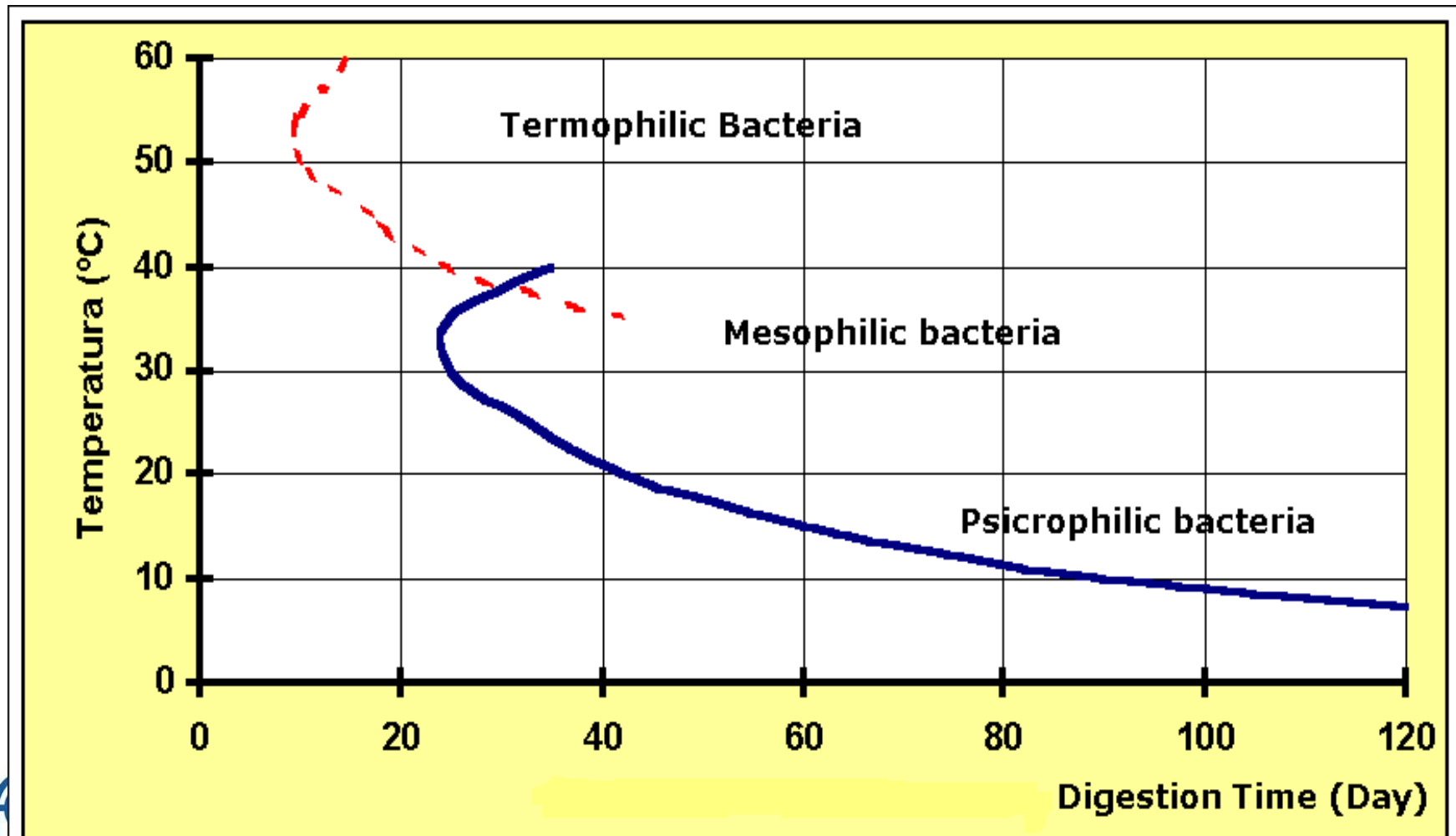
- Bacteria Growth Kinetic
- Biogas production
- Substrate degradation,
- Start-up time
- Stability of the process
- Desinfection
- Hydraulic Retention Time

Temperatures Range

Anaerobic digestion occurs in a wide temperature ranges: from 4 to 70 °C.

- **Psicrophilic digestion**: temperature range from 4 °C to 25 °C
- **Mesophilic digestion**: temperature range from 20 °C to 37°C
- **Thermophilic digestion**: temperature range from 40 °C to 60 °C,

Temperature and digestion time



Temperature utilization

- The temperature determines bacteria doubling time and hence the HRT and the size of the digester.
- Heating make the digestion system more complex. Requires: heating system, stirring, and gas collection and storage, etc.
- Psicrophilic reactors: used in simplified systems (septic tanks, small digesters, ponds) and modern systems (UASB and anaerobic filters).
- Mesophilic reactors: Sludge, Agricultural wastes, industrial wastes
- Termophilic systems: Thermophilic bacteria provide more organic matter degradation, more biogas production and higher kinetic. High temperature also provides higher reduction of pathogens. Very used in large scale collective systems.

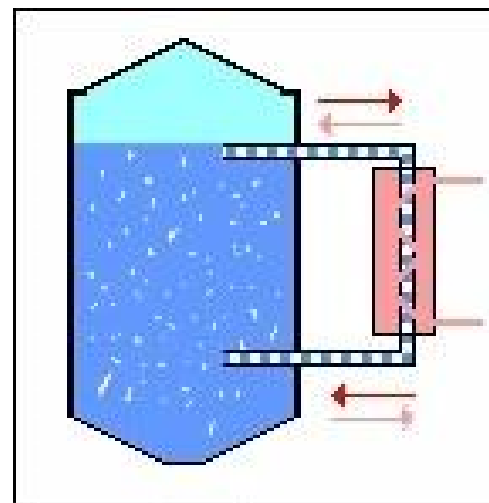
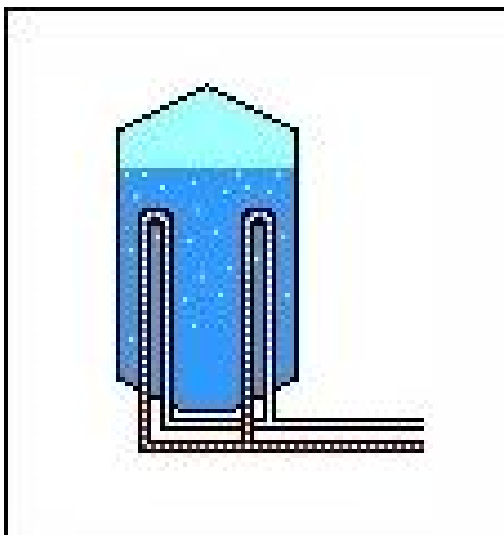
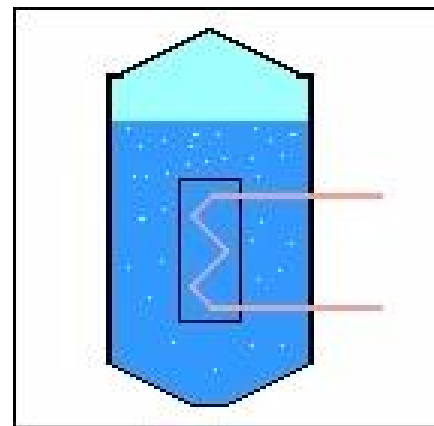
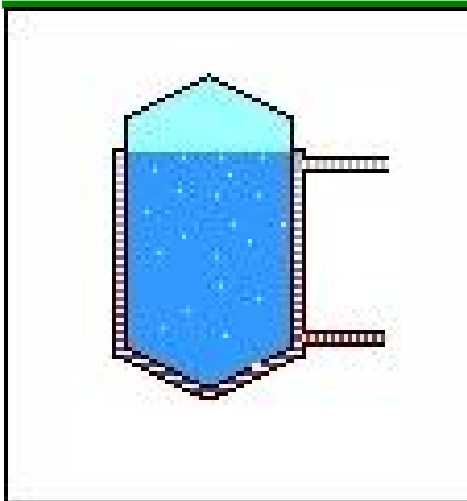
- 1 – Heat Exchanger Inside to the Digester
- 2 – Heat Exchanger external to the Digester
- 3 – Steam injection

Specific characteristics depend on the manufacturer

Heat Exchange coefficient. Internal system

Fluid Type	Transfer rate Kcal/h/m ² /°C
Sobrenadant	10 – 15
Sludge	6
Thick Sludge	2 – 3

Heating solutions



Digester with internal heat exchanger

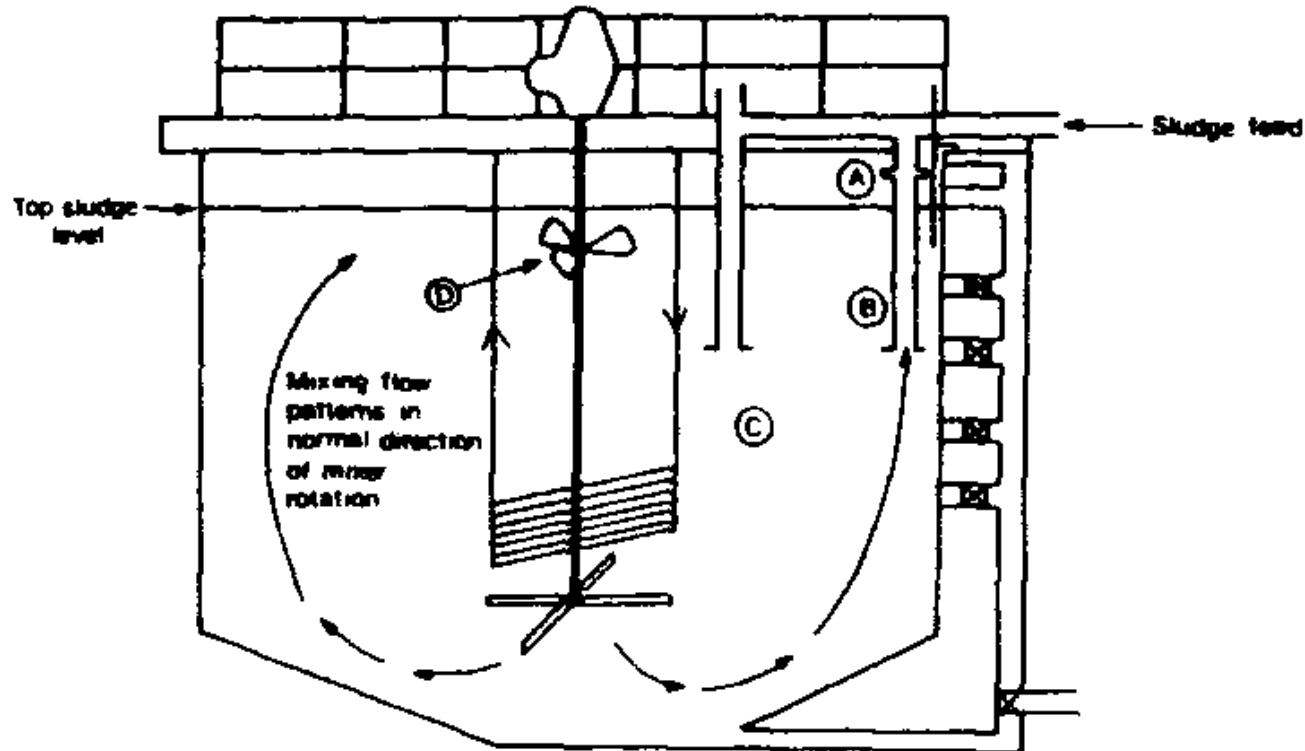


Fig.6. Feeding and mixing arrangements within the Shirebrook digester

Heating flowsheet

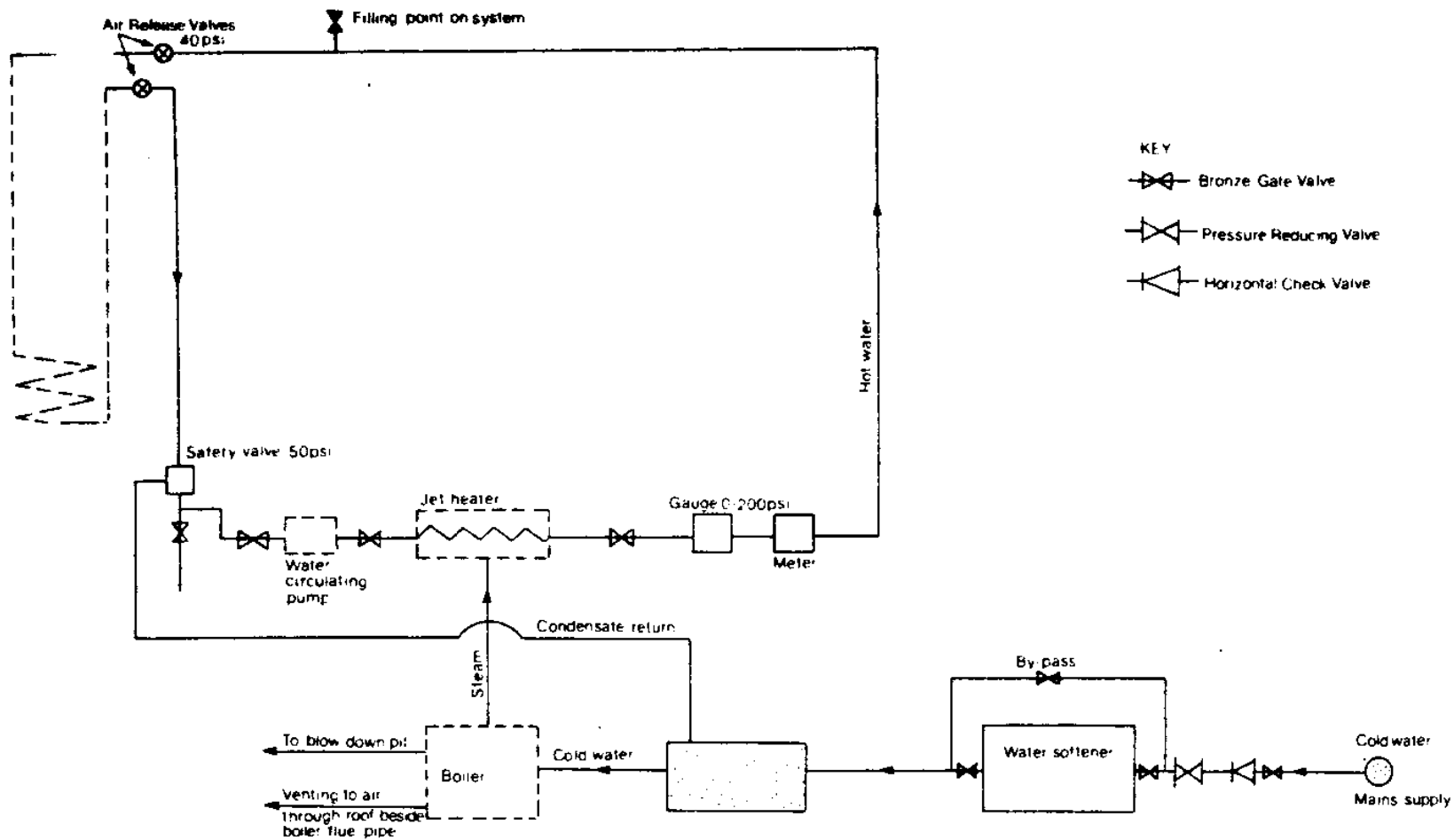
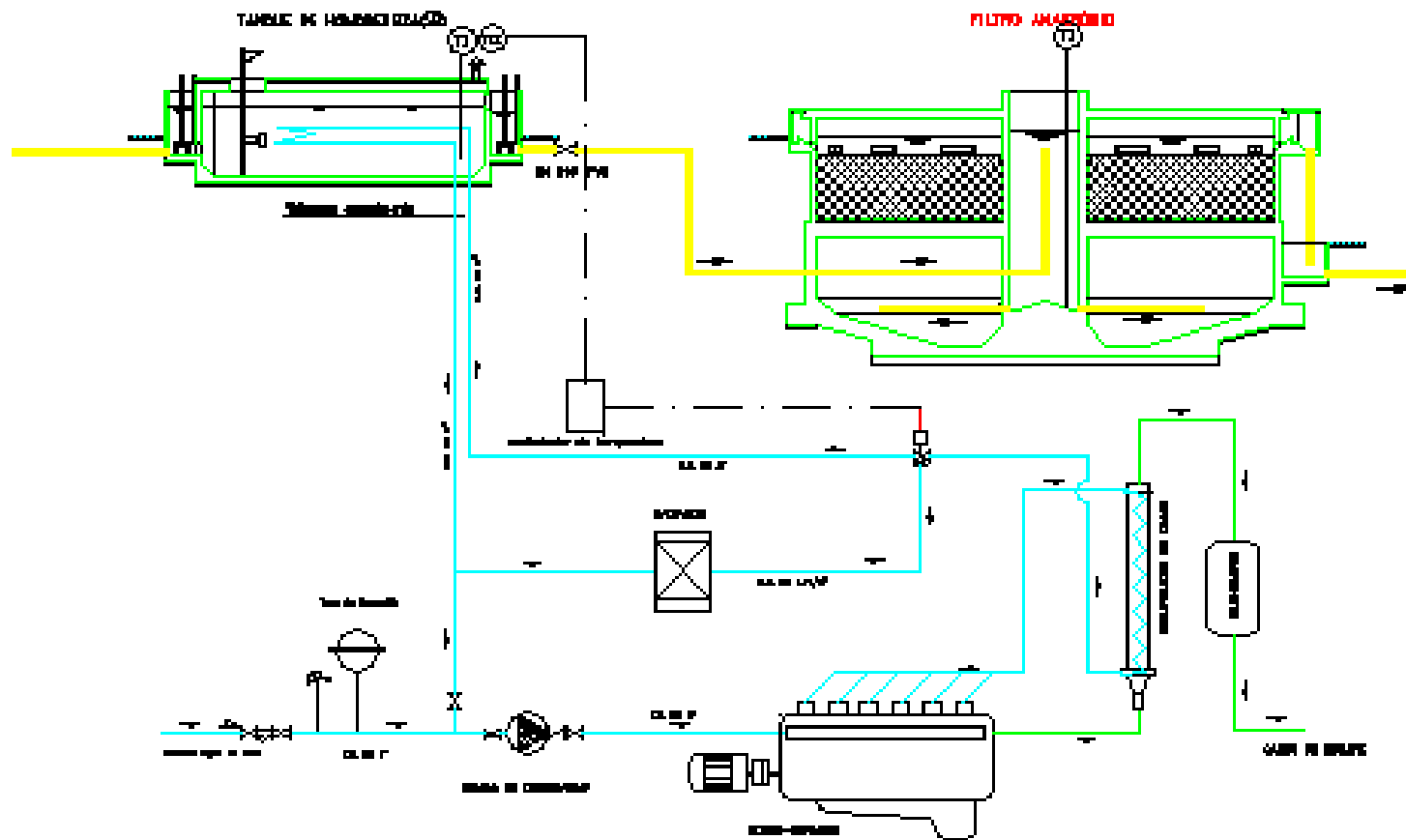
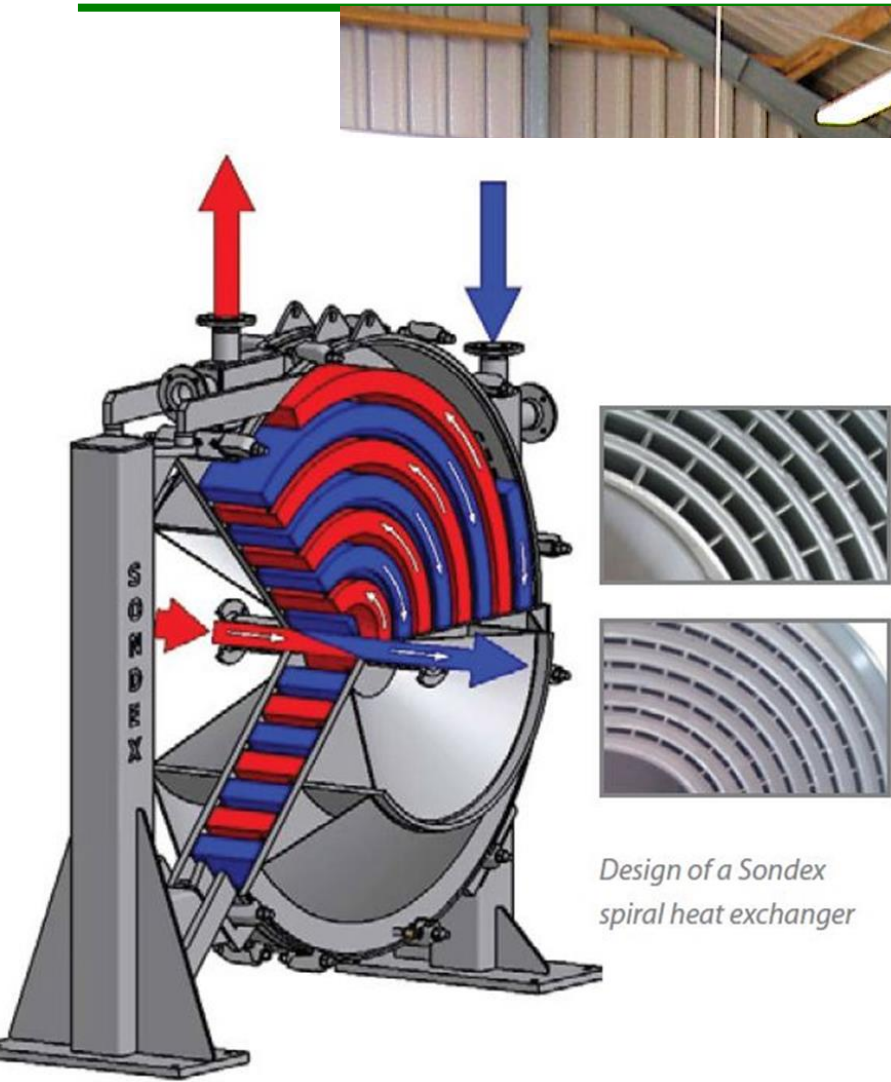


Fig.5. Water heating circuit — Shirebrook digester

External Heating system



Spiral Heat Exchanger



Design of a Sondex spiral heat exchanger



●●● Pormenor da montagem



Small Heat exchanger



●●● Permutador de placas



Permutador com tubos horizontais



Counter current double pipe exchanger with isolation



10/1/2002

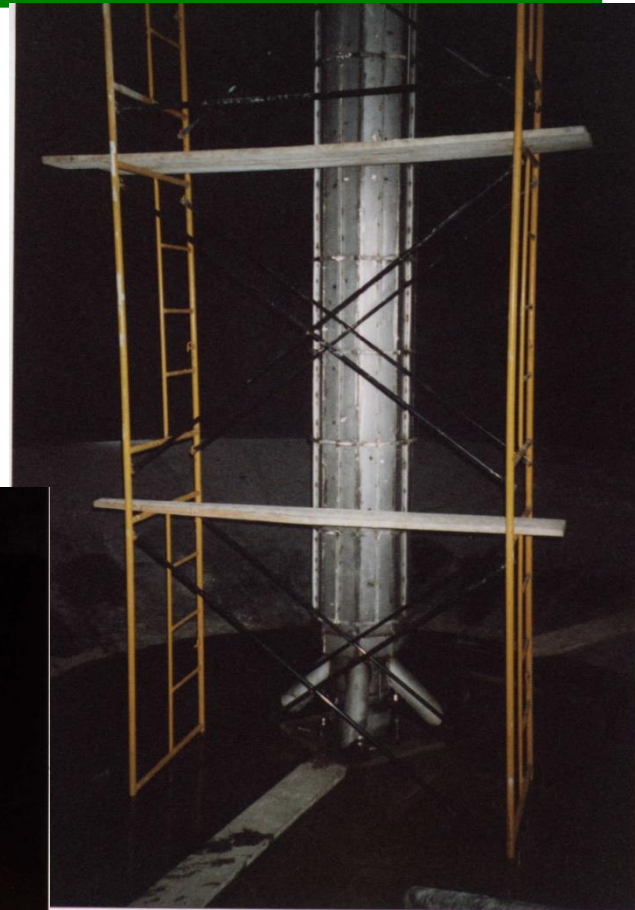
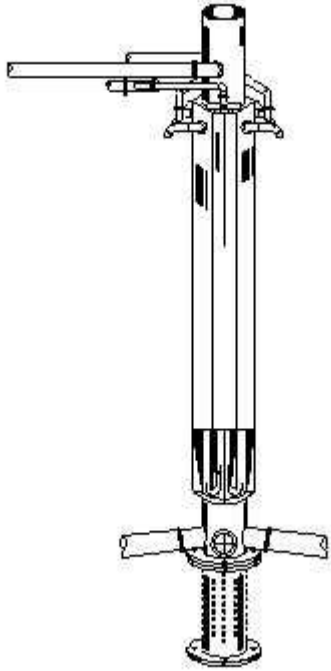
Counter current double pipe exchanger without isolation



TASK 27

14/3/2002

Internal combined Heat exchanger (INETI)





Mixing Systems



- 1 – Mechanical Stirrers fixed or submersibles.
 - 2 – Gas recirculation and injection systems.
 - 3 – Digesting liquid recirculation.
- Specific characteristics depend on the manufacturer

Parameters affecting Anaerobic Digestion

- pH
- REDOX potential
- Organic matter biodegradability
- Nutrients (Nitrogen, Phosphorus, Sulphur)
- Micronutrients:
 - Metals as Iron, Cobalt, Nickel, Molybdenum, Magnesium,
 - Sulphide, sulphate, and
 - Mg^{2+} , Ca^{2+} and Ba^{2+} .



INIBITORS



- Many compounds can be stimulatory or inhibitory, depending on its concentration:
 - Acetate, Ammonium, sulphide, metals and mono and bivalent cations.



Influence of pH

- Bacteria are very sensible to pH value of surrounding media
- Optimal pH values

Microorganism	pH
Hydrolitic Bacteria	7,2 - 7,4
Acidogenic Bacteria	$\pm$ 6
Acetogenic Bacteria	7,0 - 7,2
Methanogenic bacteria	6,5 - 7,2



Application of Anaerobic Digestion



- **agricultural and industrial wastes:**
 - **Pig, Poultry, Beef and dairy cattle manure**
 - **Pulp and paper**
 - **Sugar refineries, Olive oil mill waste**
 - **Potato processing waste**
 - **Wineries, food and drink effluents**
 - **Slaughterhouse effluents**
 - **Solid wastes**
 - **Agricultural Wastes**
 - **Energetic Crops**
 - **Mixtures of wastes (Co-digestion)**

Anaerobic Digestion technology

- Many consolidated and efficient anaerobic technologies, are today available.
- some of them are sophisticated and technologically complex.
- The reactor can be classified according to the feeding regime, Type of mixing and bacterial support.



Characteristic



Feeding regime

Continuous and batch Flow

Type of mixing

Plug flow and complete mix

Bacterial support

Attached Biomass (fixed film)
and Dispersed biomass

Recent Anaerobic Digestion Technology

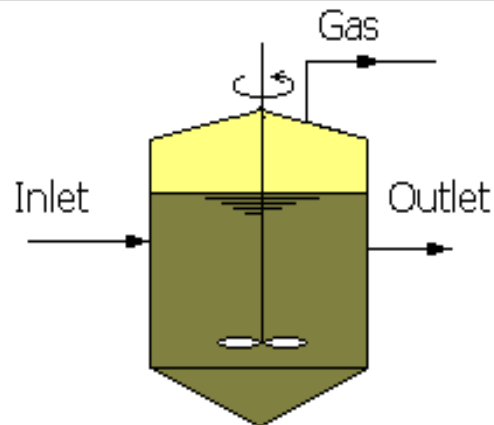
High rate reactors concept

- Promote maximum active biomass concentration in the reactor by mean of: sedimentation, recirculation, biofloculation, imobilization in fixed or moving bed, in order to get: ($BRT > HRT$).
- Promote mass tranfer by mean of good and efficient mixing
- Enhance biomass activity by adaptation or by addition of stimulatory compounds

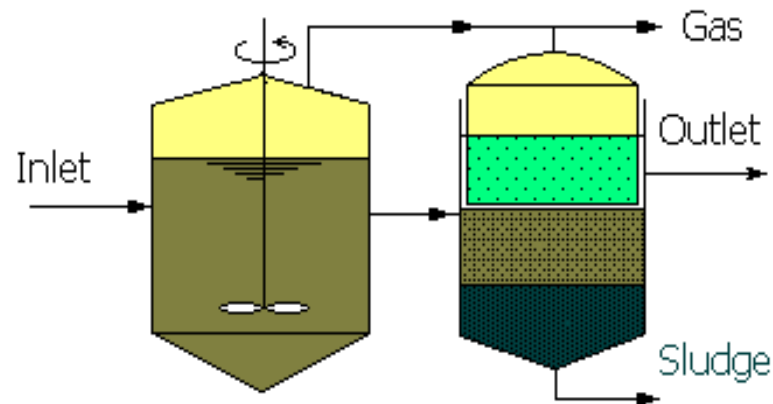
AD- Applied Technologies

Applicable Technology depends on suspended solids content and waste biodegradability:

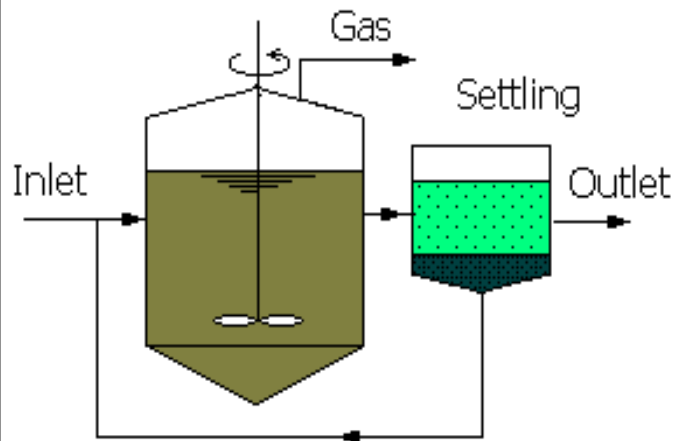
- Wastes with high suspended solids content: Dispersed biomass reactors.
- Soluble wastes: fixed film reactors.
- Solid wastes: Dry-anaerobic Digestion.
- Wastes with high biodegradable compounds: Two-stage process: acidification-methanisation.
- Wastes with not biodegradable compounds: Two-stage process: Hydrolysis-methanogenic.



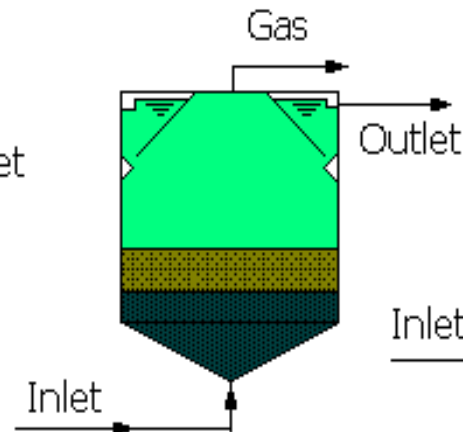
Complete mix reactor



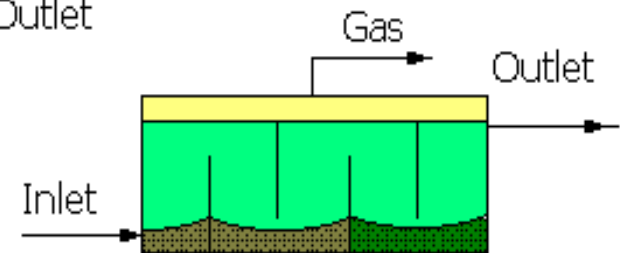
High rate two stage system



Anaerobic Contact System

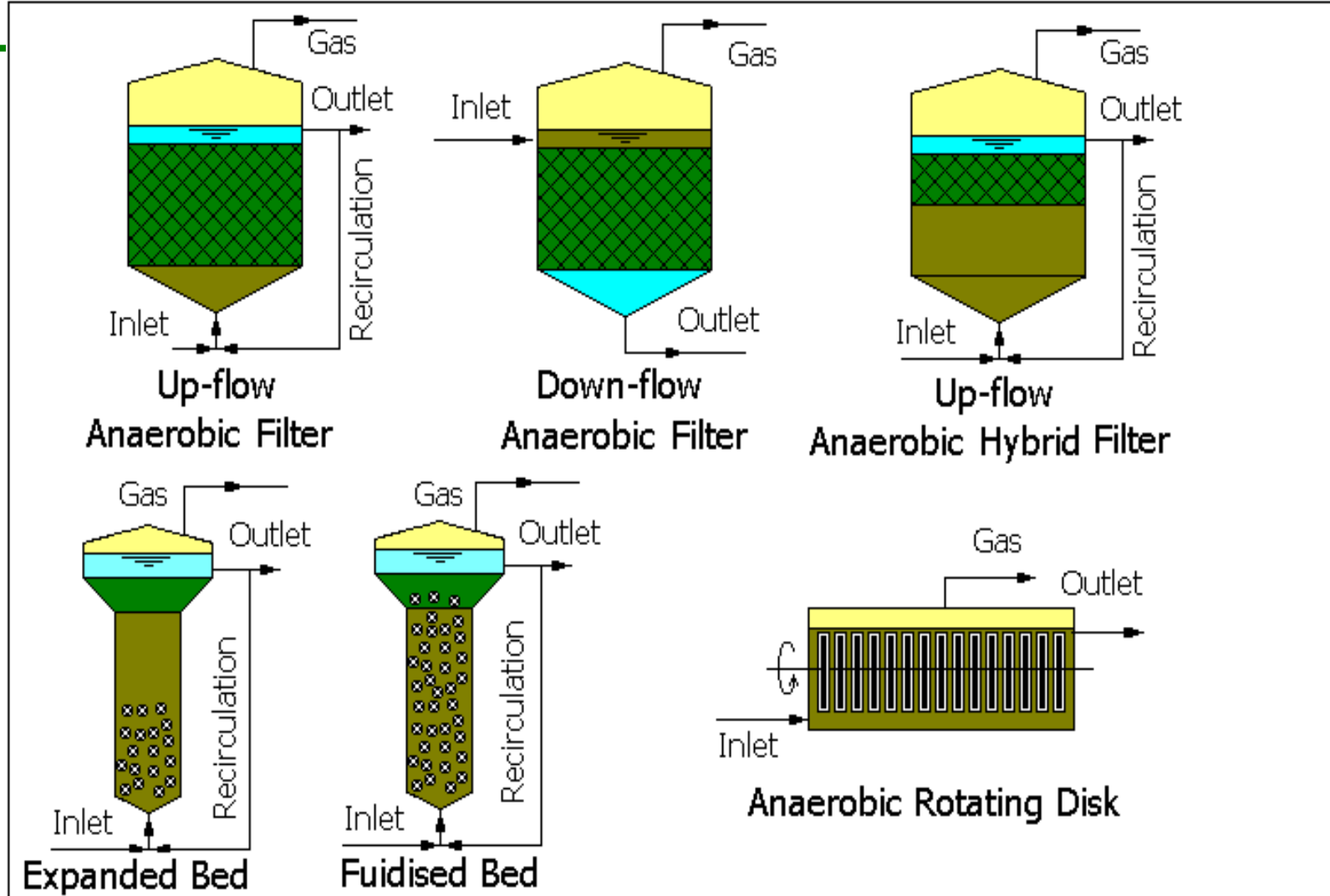


UASB



Baffled Reactor

Dispersed biomass reactors



Attached Biomass Reactors



Organic loads of anaerobic digesters



- An. Pond or Cold digester 0.1 to 2 kg COD/m³/d
- Two stage system 1 to 5.5 kg COD/m³/d
- Anaerobic contact 1 to 5.5 kg COD/m³/d
- Anaerobic filter 5 to 15 kg COD/m³/d
- UASB 5 to 25 kg COD/m³/d
- Fluidized bed 10 to 40 kg COD/m³/d

Anaerobic Digestion advantages

- Improves residue quality and produces energy as biogas
- Degrades large quantities of organic matter in short time.
- Is a low energy demanding treatment process.
- Biogas can be used to produce valuable electric and/or thermal energy.
- Generates a small quantity of stabilised residue, compared to aerobic process.
- The effluent has fertilising properties and is reused in agricultural crops.

Anaerobic Digestion drawbacks

- Anaerobic Digestion removes essentially only organic matter
- Is not able to meet the standard for discharge in water course
- Long start-up period or need of adequate inoculation.
- Incapacity to sustain organic matter over-loadings.

Agronymic National Farm Digester

Fonte –Boa Portugal



Animal waste Anaerobic Digesters



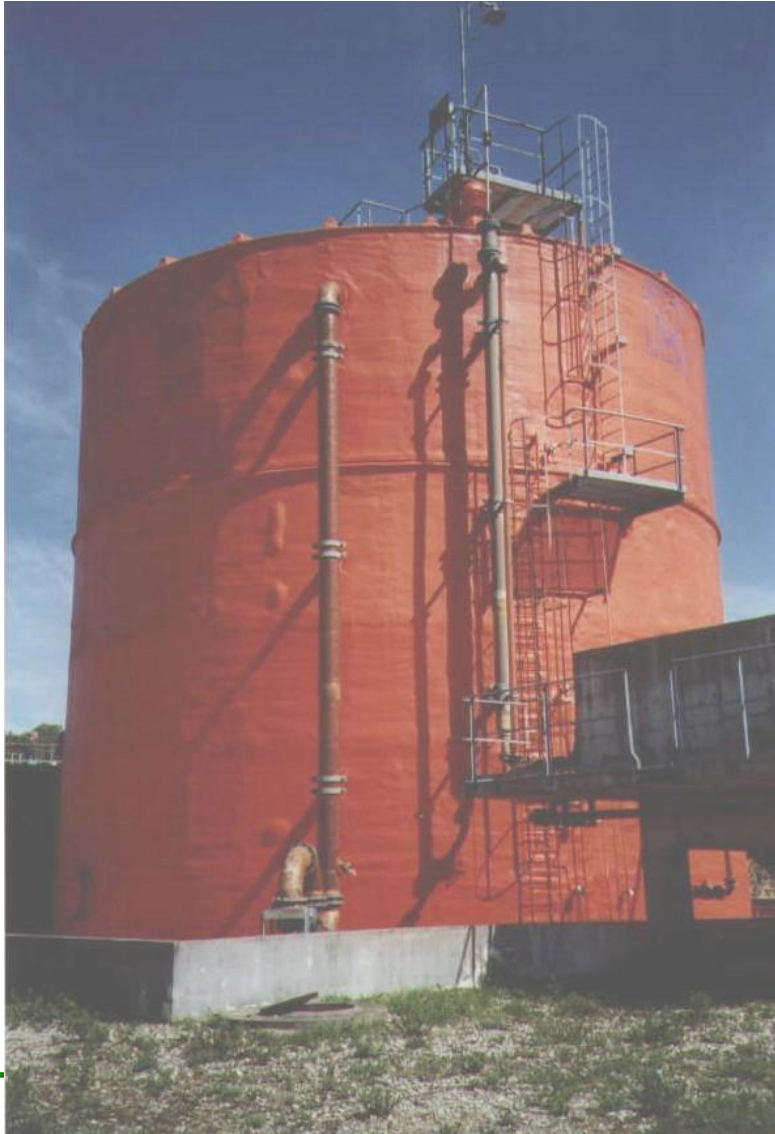
Municipal sludge Digesters



Municipal sludge Digesters



Anaerobic Digestion - INDUSTRY

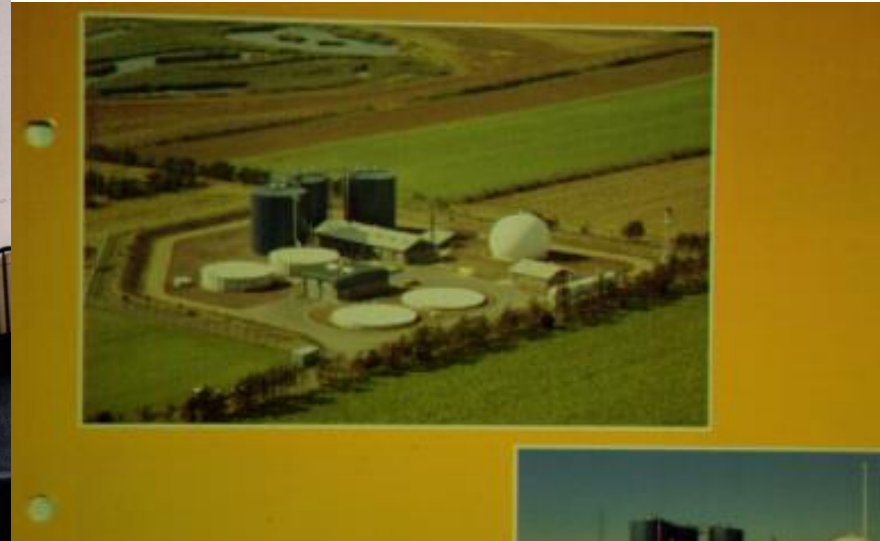


Anaerobic Digestion - INDUSTRY



vegno Lanciano – 25 Gennaio 2008

Collective Anaerobic Digesters



Solid Waste Digester



● Agronomic National Farm Fonte –Boa

● – Plastic Bag Gasometers



● Agronomic National Farm Fonte-Boa

● – Motor generator



● Milk Industry - Anaerobic Hybrid Fiter and ● motor-generator



Food Factory - Anaerobic Hybrid Filter



Gas water –trap and gas meter



Conventional steel gasometer with helicoidal roof



Membrane gasometer



Biogas from Landfill

