feedstock & process optimization of biogas production and data management prospective

沼气工程物料和运行优化技术分享及未来信息化平台展望

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outline

- key elements for biogas plant operation
- fermentation tests in batch and continuous procedures
- increasing functionality and quality demands on system setup
- data management prospective

anaerobic digestion **process**

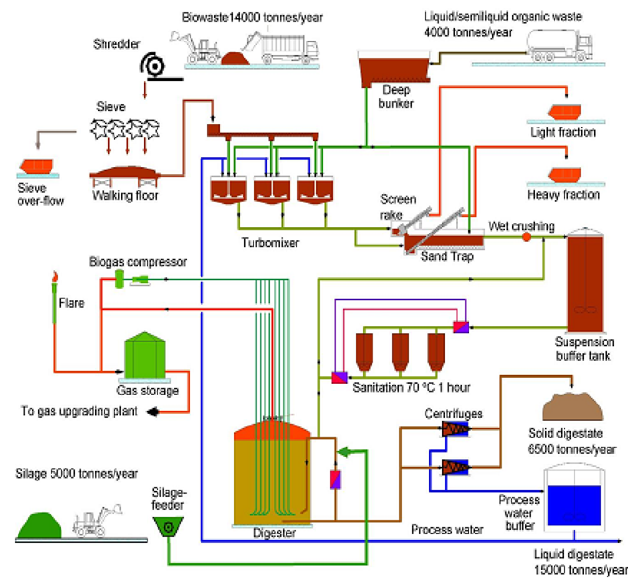
- complexity at **systematic**, **plant-wide** and **biological** levels

- **highly complex** and **dynamic** interaction between feedstock and anaerobic bacteria, where microbiological, biochemical & physico-chemical aspects are closely interrelated
  - multi-step process with different reaction rates
  - more than hundred microorganisms involved
  - difficult to monitor and control in real time (hardly to foresee what will happen)
  - operated far below the max. capacity

- **disturbances** vs. operational stability and efficiency
  - feedstocks are never constant in quality and quantity
  - degradation process is highly dynamic due to:
    - bacteria adaptation/inhibition and enrichment
    - physico-chemical interactions and accumulation
  - equipment and operation failures

key elements for biogas production in **plant-wide** view

- right **feedstock**, pre-treatment and pricing
- right **process configuration** & **instrumentation** to ensure operational stability and flexibility for plant operation
- suitable **process control** and **plant supervision** at both process & plant-wide levels
  - A biogas plant is not only biological fermentation process
  - All process units have to work together in order to ensure the plant is well-functional
- high **market value** of end product to create a sufficient driving force for business development and commercial interest
- biomass and **digestate** transportation and handling
- **professional** technical and management **personnel**



feedstock/substrate is the key

- **a clear trend** - biowaste is **resource** rather than problem
  - biowaste is never constant in quality and quantity - Increasing demand for quality analysis of feedstock in regular time base
  - knowledge on substrates in terms of types, availability, physical & biochemical properties can give a big impact on biogas plant design and process configuration
  - knowledge on substrates has big impact on plant operation, i.e. selection, quality control and prising substrates
  - possibilities of feedstock optimization , such as co-digestion, additives and pre-treatment, bacteria adaption, etc.

methodology for process optimization

- **fermentation tests** in laboratory scale
  - **batch** procedure
  - **continuous** procedure
- commonly used in academic research and development
- very labour-, time- and skill-demanding work
- not commonly used in in industrial operation
- very important step to gain knowledge and experience for plan
  - feasibility study
  - design process configuration
  - plant operation

fermentation test – **batch** procedure

- **Good information on**
  - fundamental evaluation of biomethane/biogas yield and anaerobic biodegradability of feedstock
  - qualitative investigation of anaerobic degradation, i.e. kinetic profile of degradation
  - qualitative evaluation of inhibitory effect
- **No information on**
  - process stability in continuously fed bioreactors
  - biogas yield under practical condition due to possible negative or positive synergistic effects
  - mono-fermentability of feedstock under process condition
  - limits of the organic loading rate per reactor volume

Fermentation test in batch procedures is method for investigation of substrate characterisitics and metabolic activity of bacteria

examples: biochemcial methane potential (BMP), biogas potential test (ISO 11734), anaerobic biodegradation test (ISO 14853; ISO 15985), substrate inhibitory test (ISO 13641), specific methanogenic activity (SMA)

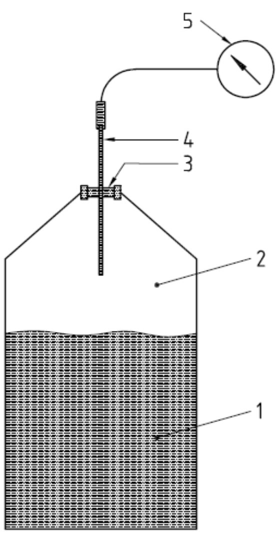
fermentation test – **continuous** procedure

- **Good information on**
  - long-timebase data about the gas yield, gas composition, degradation of substrate and any problem in the degradation process which may occur
  - physico-chemical properties of substrates affect the fermentation process
  - optimized substrate feed, control strategies, start-up operation, stress factors, reactor design/configuration
  - formation and accumulation of metabolic intermediates and their influence on process stability and efficiency
- **No information on**
  - substrate characterisitics and metabolic activity of bacteria
  - substrate inhibition and toxicity

Fermentation test in continuous procedures is method for investigation of process operational conditions to achieve an optimum degradation and gas yield

fermentation test **apparatus**
– batch procedures

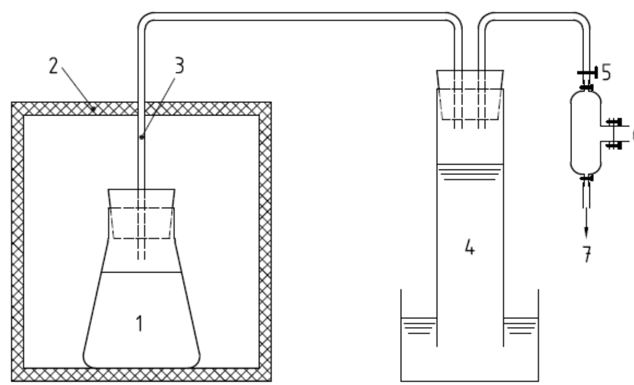
- **Manometric** measurements
  - calcuate the biogas/biomethane volume via measuring pressure increases in closed vessels
  - analyse biogas composition using gas chromatography
- **Volumetric** measurements
  - directly measuring biogas volume from reactor vessels without building up overpressure
  - analyse biogas composition using gas chromatography



1 test suspension (volume V_L)
2 headspace (volume V_H)
3 gastight seal
4 syringe needle
5 manometer

serum bottle

Manometric measuring principle



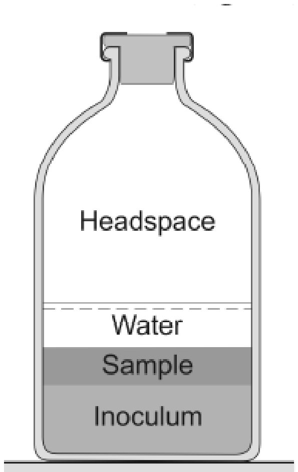
1 digester
2 incubator
3 gas outlet
4 gas collector
5 valve
6 gas sampling
7 gas discharge

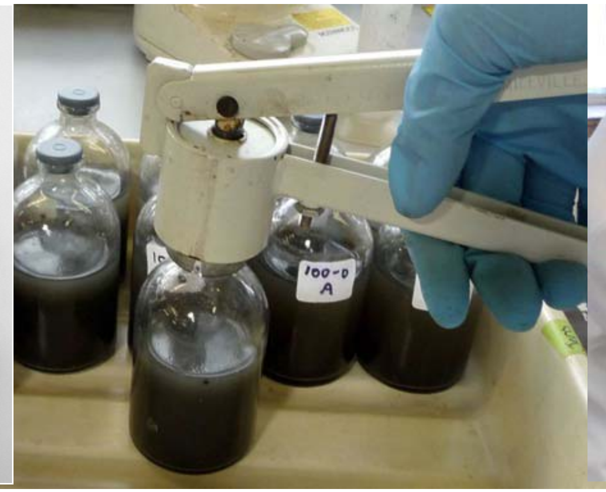
water displacement

Volumetric measuring principle

fermentation test **apparatus** – batch procedures

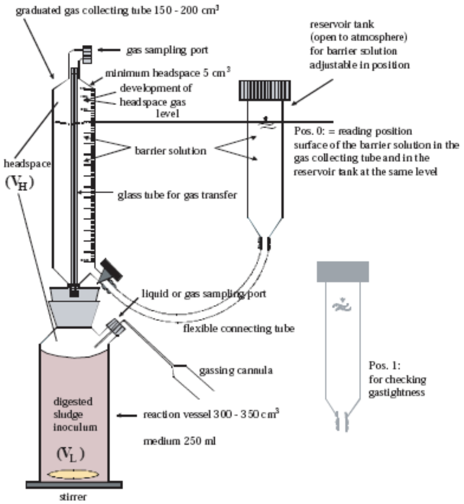
- example of system setup based on **manometric** principle

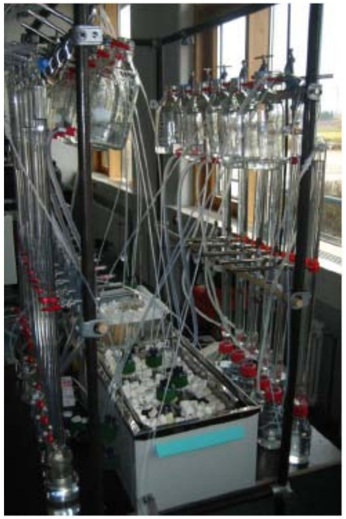




fermentation test **apparatus** – batch procedures

- example of system setup based on **volumetric** principle





technological **challenges** – batch procedures

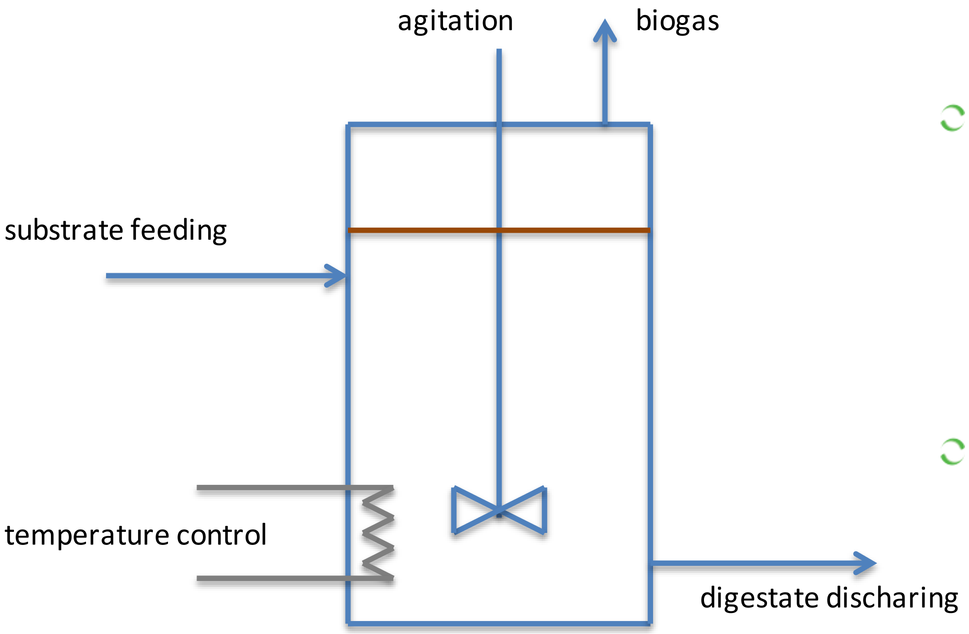
- Lack of **standardization**
  - difficult to compare the results among different batch analysis
- **Time** consuming, **skill** demanding and **labour** intensive procedure
  - too costly for routine analysis in industry
- Risk of experimental **error** due to manual operation
  - demand experience and skill on individuals
- Manual **sampling** and **data registration** in poor quality
  - risk of missing important info on kinetic profile
  - both accumulated volume and kinetic degradation profile are important

increasing functionality and quality **demands** on system setup – batch procedures

- **high precision** & **accuracy** in continuous monitoring of biomethane/biogas production for extracting process kinetic information
- minimised manual operation to **reduce random errors**
- **standardization** of data interpretation and presentation
- **high accessibility** for monitoring and data visualization
- **reduced time**, **labour** and **skill** demand for both industrial and academic applications

fermentation test apparatus – continuous procedures

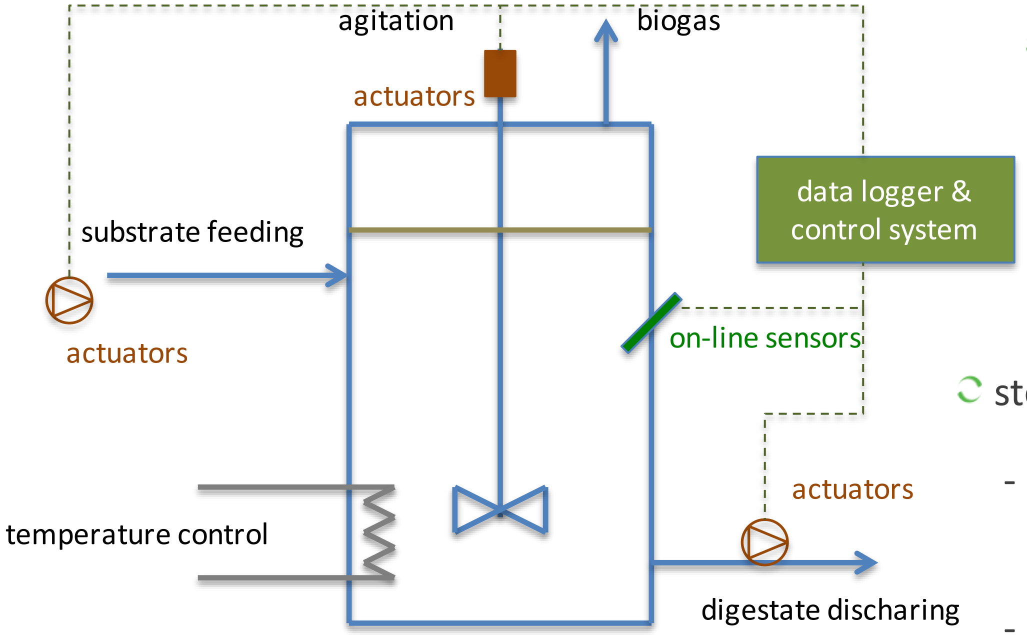
- **Simple** continuous fermentation test unit



- **fundamental** elements
  - Bioreactor with various configurations
  - Agitation or mixing
  - Temperature control
- key **variables** to be controlled & analysed
  - Feeding
  - Discharging
  - Biogas production
- how to **operate**?
  - Manual feeding and discharging
  - Manual sampling and data registration

fermentation test apparatus – continuous procedures

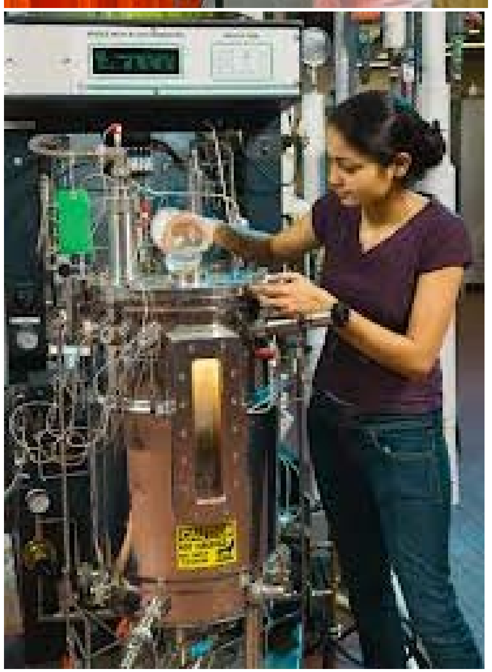
- **Advanced** continuous fermentation test unit
  - step 1: improvement on process **monitoring**
    - on-line sensors (*gas flow, composition, pH, temperature, etc.*)
    - real-time data logging
  - step 2: improvement on **automation**
    - actuators (*feeding & discharging pump, valves, agitator, etc.*)
    - process automation
  - step 3: possibilities for **process control**
    - automated operation according to pre-defined and control sequence
    - process control strategies for optimization



fermentation test **apparatus** – continuous procedures

- examples of system setup

technological **challenges** – continuous procedures



- Large system **variations** due to the large differences in feedstock, reactor & process configuration
- Test apparatus is hardly to be standardized and always require certain level of **customization**
- Very **time** consuming and **labour** intensive routine work to follow up the continuous fermentation test over **long-time** period – too costly to be widely implemented in industry
- Risk of experimental **error** due to manual operation – demand experience and skill on individuals
- Manual **sampling, analysis** and **data registration** in poor quality

    - labour intensive work for a large amount of data over time

    - poor data quality

increasing functionality and quality **demands** on system setup – continuous procedures

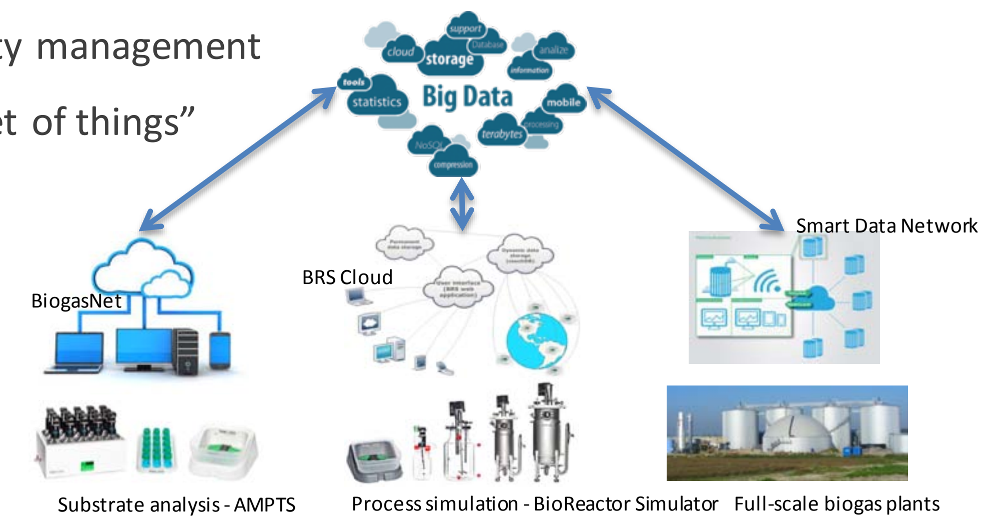
- **High precision** & **accuracy** in continuous **monitoring** of key process parameters
- **Standardization** of registered parameters, data interpretation and presentation
- Long-term **stability** and large **capacity** for data logging and handling
- **User friendly** system for both easy experiment setup and follow-up
- Minimised manual handling and analysis to **reduce random errors**
- **High accessibility** for monitoring and data visualization
- **Reduced time**, **labour** and **skill** demand for both industrial and academic applications

Priority order:
monitoring → automation → process control

data management prospective
- road map in biogas sector

Demands on data and information management for plant operation

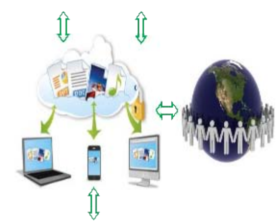
- stable and efficient (profitable) plant operation requires extensive knowledge on both feedstock and process dynamic
- extensive knowledge relies on more off-line & on-line analysis and automation for process diagnosis and supervision
- utilization of smart instruments allows data rich in both quality and quantity with less manpower, time and skill
- gather and manage key process data in efficient matter meet increasing demands on optimization of process operation and authority management
- match perfectly with the concept of “internet of things”



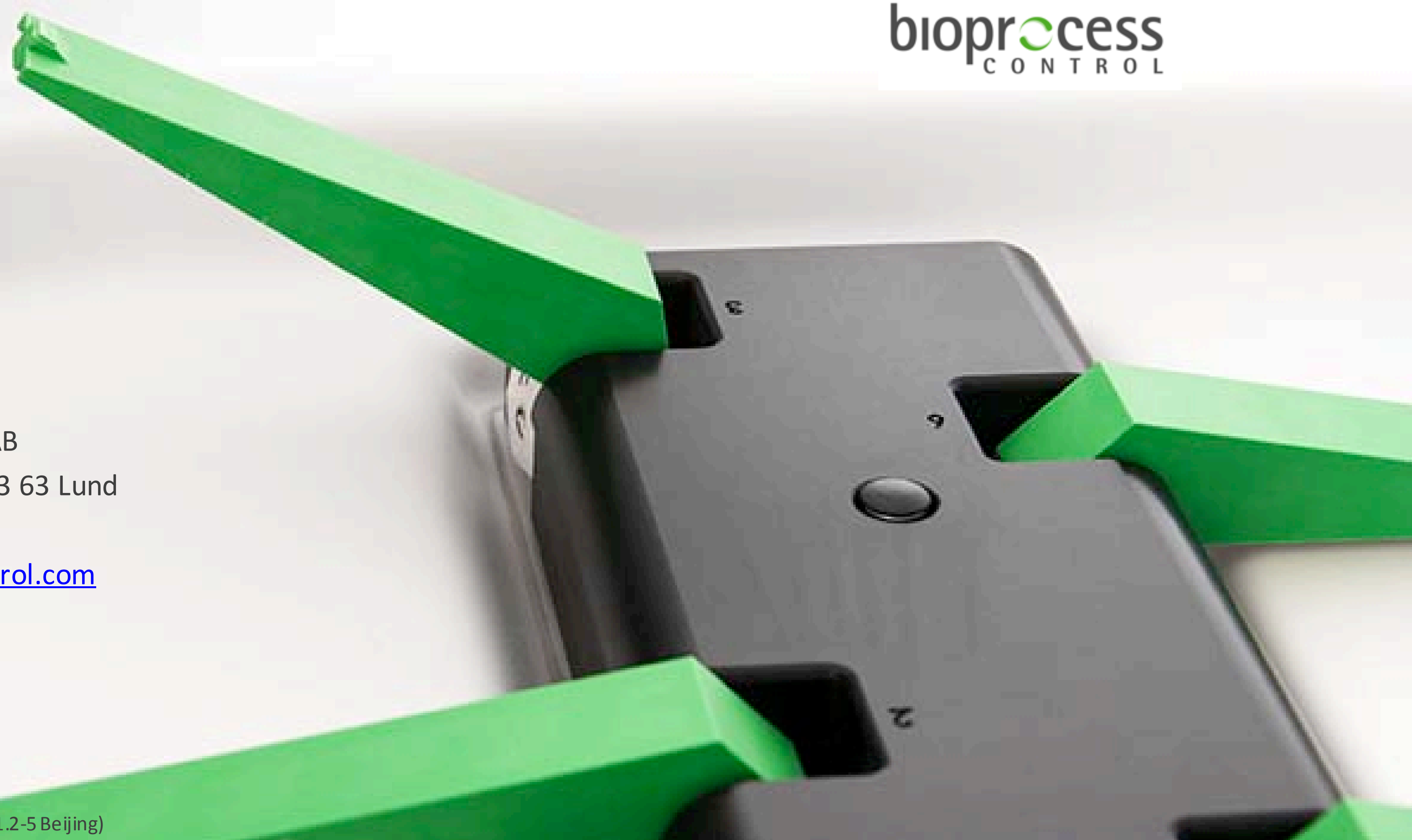
data management prospective
- challenges

a long and non-smooth journey

- immature industry (business model, professional talent, supplier chain, etc)
- insufficient incentive and modification in very recent years
  - low energy price
  - Instable and short-term policy support
- conservative industry and personal barrier
- certainly there is risk
  - technology and business confidential to third party
  - network security
- less resistance to be implemented within signal organization
- varies according to countries and market develop



Thank you for listening !



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