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RESEARCH TO INDUSTRY AND INDUSTRY TO RESEARCH

HOW LAB EQUIPMENT CAN HELP ANAEROBIC DIGESTION (AD) RESEARCH

Most common process challenges within the field of anaerobic digestion

- **The degradation process is too slow and inefficient**: Many raw materials commonly used to produce biogas today take too long to degrade, or do not degrade properly at all. Those raw materials are typically made out of complex structures that are difficult for bacteria to access, and also contain non-degradable substances, like lignin. This structure leads to long retention times inside the bio-digester, resulting in a slow and inefficient process. The most common solution to this problem is to pre-treat the raw materials. And there is a range of pre-treatment techniques to choose from - depending on your needs. The main issue is that pre-treating the feedstock requires high investment costs and high operational costs. With such expenses, you will need to make sure you chose the right pre-treatment option for your specific AD process. Carefully testing and evaluating those options are the key.
- **The presence of nutrients and toxic substances is poorly managed**: The microorganisms involved in the AD process depend on a large number of nutrients to function properly. Those microorganisms are also sensitive to many substances that can be toxic and hinder their activity. In order to put microorganisms in best conditions, it is essential to understand whether the substrate contains enough nutrients - and to make sure it is toxin-free. When nutrition is low, or toxins are present, you can mix different substrates to balance the nutrients and limit the toxic influence. Alternatively, you can add direct nutrient supplements or counteracting agents. However, both of these solutions have downsides. Extensive research needs to be done to identify what is missing in your substrate in the first place, understand what supplements to use, and how to best mix different substrates together.
- **The knowledge of the AD microbiology is limited:** Anaerobic digestion is a very complicated process, involving a large number of microorganisms working together to degrade complex materials in multiple steps. We know very little about the different microorganisms involved, or how they interact with each other. For this reason, most digesters are typically operated as a "black box" – with little awareness of what is actually going on inside. Of course, it is difficult to optimize a process that we do not fully understand. By learning about AD microbiology, we can understand how microbial populations work and optimize the process significantly.
- **The dynamics of the AD process are complex:** Any slight change in conditions can disturb the AD process. In order to avoid any disturbance, digesters are often operated far below their maximum capacity. Again, tackling this problem requires us to truly understand the way the microorganisms operate and work together. But how can we study these interactions? Today, specialized computer models for anaerobic digestion can describe and simulate many of the complex changes and connections between microorganisms during the process, giving us a better idea of what to expect. However, even though much progress has been made, there are still many aspects of the AD process that are unknown to the researchers. A lot of work still remain to fully understand the dynamics of the process and improve the way we operate the plant.

Two laboratorial methodologies that address these challenges today

- **Batch tests – to study substrate characteristics:** Batch tests tell us how much gas can be expected from a material. It also tells us, to some extent, how fast the material will degrade and the metabolic activity of the microorganisms. The most common batch tests include BMP (Biochemical Methane Potential - Figure 1), anaerobic biodegradability, SMA (Specific Methanogenic Activity) and RGP (Residual Gas Potential) assays. BMP assay (Figure 2) is the most convenient way to analyze a substrate for biogas production. The test is quite simple: an inoculum is mixed with the sample substrate to test. This inoculum contains all the microorganisms necessary to degrade the substrate. The mixture is then monitored to see how much gas is produced, and how much time it takes. The test can be used to screen different substrates, or to study the effects of different pre-treatments on a substrate.

FIGURE 1: AMPTS II for biomethane potential (BMP) and specific methanogenic activity (SMA) analysis (Bioprocess Control AB).

Managing editor:
Alberto Pivato
email: alberto.pivato@unipd.it

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FIGURE 2: Gas Endeavour for anaerobic and aerobic biodegradability, residual gas potential (RGP) analysis (Bioprocess Control AB).

- **Continuous tests – to simulate the process and study long-term effects:** Continuous tests simulate a full-scale process by performing experimental tests in a continuous mode. This means that substrate is continuously added to the bio-digester, so you can analyze performance over a long period of time. Gas production is not the only parameter analyzed here. pH, alkalinity, gas composition, VFA and ammonium contents are also measured. Those parameters give you a better understanding of the process and indicate how various changes may affect its performance. The set up for continuous tests is more complex than for batch tests. It also requires more equipment and human effort. This in turn creates cost and limits the number of tests that can be performed simultaneously. Continuous fermentation tests are most suitable to evaluate and optimize the way a process operates and to study the long-term effects of substrates.
  While batch and continuous fermentation tests are key to unlock AD's true capabilities, researchers currently face many challenges in using them. It is very difficult to accurately measure and compare results, and this mainly because of technical limitations (see Table 1).

TABLE 1: Comparison between batch test and continuous test: benefits and downsides.

	Benefits	Downsides
Batch test	• Relatively simple and cheap to perform • Many tests can be performed simultaneously • Easy to compare different types of substrates or evaluate the effect of different pre-treatments, co-digestions, additives etc.	• No information on long-term effects • Limited information on process dynamics
Continuous test	• Possible to evaluate the long-term effects of substrates • Investigate and optimize operational parameters	• More expensive and labor intensive to perform • Can only compare a limited number of tests

Current limitations with batch and continuous fermentation tests

- **The lack of standardization:** Batch and continuous fermentation tests suffer from a lack of standardization, at the test procedure level, measurement requirement, as well as the way results being presented. There are many different protocols out there, and it's pretty common for researchers to adjust the existing protocols to their own specific needs. In that context, how can you benchmark your tests against the others? As a good example, the volume of a gas depends on its temperature and pressure. When studying gas volume, it is vital to consider and accurately report both of these parameters. Still, researchers today might simply assume a pressure or temperature measurement. Alternatively, they might just take a spot measurement. The problem with this approach is that over the course of time, the temperature and pressure may vary significantly resulting in an inaccurate gas volume measurement.
- **Self-developed and varying lab set-ups:** Today, still a large number of batch and continuous tests are performed with lab set-ups that have been built and designed from scratch by scientists, or laboratory technicians. Typically, these self-developed lab set-ups are not user friendly, and leave room to uncertainty in recorded results, due to lack of standardization and because too little time was invested validating the system. Once again, it makes it difficult to compare test results within the researcher community.
- **Manual and varying techniques for gas sampling and analysis:** Just like with the equipment, solutions for analytical measurements vary greatly. This is particularly true for measuring gas, which can be difficult due to the frequent low flow rates and gas composition variation. At lab scale, gas flow rates can be less than 100 ml/day, and a lack of conventional flow meters in this range drives researchers to develop their own solutions to determine the gas volumes. This then leads to large variations in results and data quality. Another issue is that most of these methods are manually operated – which leaves room for human error which can be the biggest source of random errors. In addition to this, measurements can only be taken when an operator is present. This leads to limited datasets in low quality and quantity. There is also a high chance that important kinetic information about the degradation process is lost because measurements are not taken often enough at variable time intervals.
- **The skill factor:** Traditionally, many of the tasks involved in batch and continuous fermentation tests involve manual operations. This means that the lab worker needs to show sufficient level of skills and experience and if not enough attention is put into the operation, results can be unreliable and hard to use for benchmarks.
- **The procedures are time consuming and labour intensive:** The high number of manual activities leads to tests that are time-consuming and labour-intensive for the lab worker. This in turn increases the cost of the test procedure, thereby limiting the number of tests that can be performed.
- The limiting factors we just covered here lead to one main conclusion: inaccurate results are difficult to compare. This is actually quite an issue: It's not uncommon to see large variations and contradicting results when

looking through the scientific literature. Tests often have to be repeated to ensure more reliable results. In order to advance our research further, the key is to reduce the time and effort spent on batch and continuous tests; reduce the room for error, and produce more reliable, accurate results.

Keys to improving the batch and continuous fermentation tests

- **Selecting professionally designed and standardized equipment:** We have reviewed how conventional labs are setup above. In order to improve their performance, researchers need more standardisation, and dedicated equipment packages that can be used by all laboratories. By using professional and standardised solutions for heating, mixing and feeding, it will become much easier to repeat or build on previously reported experiments. It will also be easier to educate skilled lab workers, because simple instructions videos and manuals can be used.
- **Welcoming automation:** With the goals to reduce human error and free up lab workers' time, more automatic functions must be introduced. Automatic and continuous gas measurements can simplify the testing procedure and produce higher quality data, making it more reliable. Continuous measurements of temperature and pressure should be introduced – as well as automatic corrections of these parameters. Not only will this reduce the time and effort required from the lab worker, but it will also guarantee that the data is presented in a consistent and accurate manner. With less time dedicated to manually managing tests, it becomes possible to perform more parallel tests and thereby drive the study much further and more efficient utilization of manpower and skill for scientific research.
- **Sharing data and engaging with online communities:** The development of online databases and practitioner communities greatly advances the field of AD research. These tools are already extremely helpful for data management and communicating latest research. They are particularly useful for continuous processes with large datasets. By improving the accessibility of your test results, data from different experimental batches cannot only be used within your research team but also be shared easily with desired partners. Today this is a highly achievable: With cloud-based solutions becoming increasingly popular, it is easier than ever to store, study and share complex datasets.

Conclusions

By implementing the recommendations mentioned hereabove it is expected that the advancements in the research related to AD will progress much faster. Researchers will have access to data of both higher quantity and quality and key findings can more easily spread via online communities, resulting in higher impact. This will lead to faster solving of the current technological challenges, namely slow and inefficient degradation processes, and nutrient limited and toxic substrates. It will also increase the understanding of the microbiology and process dynamics. Overall right lab equipment tools ensure the highest demands for data quality in modern research. The test can be simple and fully automated, allowing for better time management and the optimisation of limited manpower resources.

Jing Liu[1,2,*], Sten Strömberg [2] and Mihaela Nistor [2]
[1] *Division of Biotechnology, Center for Chemistry and Chemical Engineering,Kemicentrum, Lund University, Naturvetarvägen 14, Sweden*
[2] *Bioprocess Control AB, Scheelevägen 22, 223 63 Lund, Sweden*
* email: jing.liu@biotek.le.se