The following ***"research literature-based assessment"*** is based **Justesen et al. Water-Sweden (2019) 11, 2431.** It will show us a practical application of gas collection over fluids, its environmentally friendly contribution to energy generation, and how the basic knowledge about gas laws can still help scientist come up with simple and useful innovations.

Let's start by defining and understanding the concepts and terms that has been frequently used in this article.

1. Developing techniques for obtaining methane from biological sources has gained a lot of importance in recent years. Considering the sustainability of the resources on earth, why do you think it is an important branch of research?

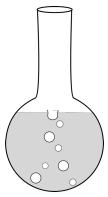
2. With some external research on your own, find what *anaerobic digestion* means, and give an example of an anaerobic digestion process. *(You should find the definition in a book, textbook, or a published primary research article, and cite your resource.*

3. What is the *biochemical methane potential* (BMP)? What kinds of substrates could produce methane via anaerobic digestion?

4. Authors of the article talk about previous techniques to measure biochemical methane potential.

a. How is volumetric measurement of BMP described?

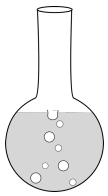
b. For the explanation of the *volumetric measurement*, can you draw a simple diagram to show the set-up to another person? Annotate your drawing to explain *what* is what.
You can add/draw what is necessary to complete the image of methane producing substrate flask below:



c. Which of the simple gas law relationships you learned (in classes or in the relevant chapter/s of your textbook) can be used to mathematically describe the volumetric measurement? Explain your choice.

d. How is manometric measurement of BMP described?

e. For the explanation of the manometric measurement, can you draw a simple diagram to show the set-up to another person? Annotate your drawing to explain what is what.
You can add/draw what is necessary to complete the image of methane producing substrate flask below:



f. Which of the simple gas law relationships you learned (in classes or in the relevant chapter/s of your textbook) can be used to mathematically describe the volumetric measurement? Explain your choice.

5. How does the gas density-based method (GD-BMP) propose to determine the biogas composition and differentiate between methane and carbon dioxide? Just briefly explain their plan in 3-4 sentences.

6. Using the set-up in Figure-1 of the "*Justesen et al. Water-Sweden (2019) 11, 2431*" answer the questions about the GD-BMP method below.

a. What kind of substrates do you think the liquid in the bottle includes in the pre-incubation step (a)? Give a couple examples. *(This may not be in the article, so try to give your own thoughts.)*

b. Why is incubation necessary before starting the measurement steps? *(This may not be in the article, so try to give your own thoughts.)*

c. What do you think is the purpose of the mixing step 1 prior to gas release? *(This may not be in the article, so try to give your own thoughts.)*

d. It seems that the mass of the bottle did not change in step 2, but there must be some chemical changes in the contents of the bottle. What fundamental principle of chemistry does this observation illustrate? *(Hint: This may be covered in the very beginning chapters of the general chemistry textbooks, where the composition of the matter and the total balancing of the reactions are considered.)*

e. In step 3, what do you think is the driving force for the air above the liquid to vent into the syringe under the atmospheric pressure? Explain the process.

f. The loss of which component/s cause the mass drop in step 4?

7. The removed gas sample in step 3 of Figure 1 contains a mixture of gases. When the density (ρ_b) of the biogas sample is calculated, authors correct for the water vapor density (c_{H_2O}).

a. Using the equation (3) in the article, first define and familiarize yourself with each term, then explain <u>why</u> the density of the water vapor is <u>not</u> simply calculated by the [mass/volume] ratio, but rather *requires adjustments* of partial pressure as shown below.

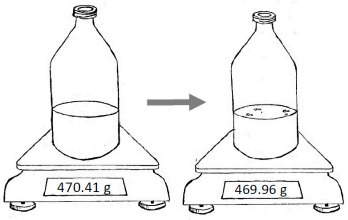
$$c_{\mathrm{H_2O}} = M_{\mathrm{H_2O}} \cdot \frac{p_{\mathrm{H_2O}}}{p_{hs} - p_{\mathrm{H_2O}}} \cdot \frac{1}{v_b}$$

Explanation:

b. First estimate the value in of molar water vapor pressure (P_{H_2O}) at 30°C and report in kPa. Compare it to a reliable reported value from a book or an online database. Cite your resources.

8. A case study: Calculate the density (ρ_b) of the biogas sample in a hypothetical set-up similar to Figure 1 in the article with the following parameters:

- Pressure in the headspace (volume over the liquid) is assumed 101kPa.
- Molar volume for water vapor is assumed to be 22.3L.
- Mass difference is shown as gravimetric measurement on the left.
- Volume in the headspace is approximately 300mL.
- All other parameters such as molar masses can be found in the article.



(Figure was adapted and modified from *Justesen et al. Water-Sweden (2019) 11, 2431* to provide an easy visual for this question.)

9. Compare your result from question 8 to relevant part of the table 2 shown below. According to your theoretical calculation, which substrate (cellulose, ethanol, or the animal feed (FI1)) might have been used for the experimental set-up used in Figure-1? Explain your answer.

Substrate	Gas density (GD_t) mL/g	
	Mean	SD
Cellulose	386	56.2
Ethanol	664	81.5
FI1	375	33.1

(Data table was adapted from *Justesen et al. Water-Sweden (2019) 11, 2431* to simplify the calculations for this question.)

10. The overall density (ρ_b) of the biogas sample belongs to two main gases present in the sample, but it is crucial to make the distinction of how much of each exists.

a. Do authors of the study have to remove carbon dioxide from the gas mixture to assess methane production?

b. Using the proper equations (including equations 4 & 5 from the paper - also shown below) first explain how this study theoretically proposes to calculate the relative ratios of methane and carbon dioxide in the biogas mixture. Be sure to make sense of the terms first.

$$M_b = \rho_b \cdot v_b$$

$$x_{CH_4} = \frac{M_{CO_2} - M_b}{M_{CO_2} - M_{CH_4}}$$

Explanation:

11. Using the same parameters as in Q8, and your answer for the biogas density (ρ_b), calculate the mole fraction of methane (χ_{CH_4}).

12. In order to prove that the gas density-based method (GD-BMP) is a practical and a reliable technique compared to other high-tech methods, authors cross-checked their results with a gas chromatography instrument, as shown in Figure-3 of Justesen et al. Water-Sweden (2019) 11, 2431.

Gas chromatography (GC) technique can accurately separate and identify the components of a gas mixture. In this case it shows exactly what fraction of the biogas sample is methane. In the graph shown in Figure-3, if the fraction of the methane obtained from the new gas density-based method (GD-BMP)GC matches the result from a GC instrument, they should meet in the mid-solid line. A close match confirms the reliability of this method.

According to this graph and after your close analysis of multiple measurements made for each digest, which substrate digest gave the most accurate results with the new method?

(Plotting symbols for the figure are as follows: triangles for ethanol, crossed squares for cellulose, solid squares for the animal feed FI1, plus signs for animal feed FI2.)

Explain your answer:

Note to the students:

Please note that we did not go into extensive details of trouble shooting that was done by the authors in these experiments. Scientists often come across unexpected obstacles along their experiments, and as you can see form this paper, there are a lot of hindsight corrections to their initial plan. Nevertheless, persistence and creative solutions lead to successful innovations.

As Thomas Edison once said: "*I have not failed! I have found a thousand ways that won't work*".

This exam and the literature should be a hopeful look to future about how we are dealing with our waste. As a chemistry student, the knowledge you are gaining now is the foundation for the ideas you will be forming throughout your career. If you choose a discipline other than chemistry, then you will be an informed citizen who reads and understands the current progress in science.

This article is a proof of principle for making the methane detection easier. But of course, using methane as the energy source requires purification steps after detection. For those of you who are interested, here is an article for another practical chemical approach to purify and collect the methane gas.

"Three-Dimensional Printable Sodium Carbonate Composite Sorbents for Efficient Biogas Upgrading"

By Murialdo et al. Environmental Science & Technology 2020 54 (11), 6900-6907
DOI: 10.1021/acs.est.0c01755
https://pubs.acs.org/doi/10.1021/acs.est.0c01755?fig=abs1&ref=pdf