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Volume and rate measurement of slowly generated gas bubbles

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Highlights

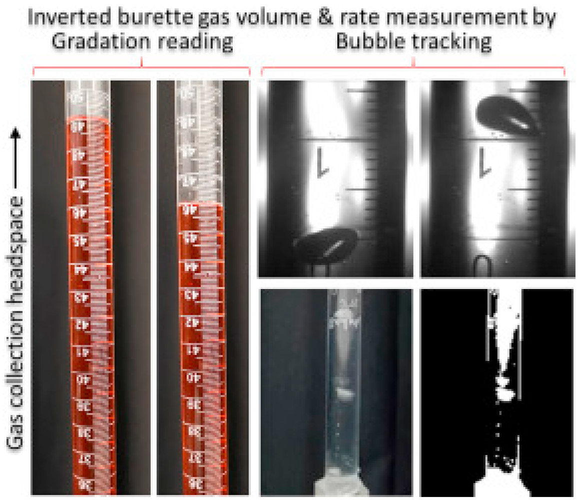
- The inverted burette arrangement here improves on the classical inverted jar in volume and rate gas measurement.
- Good measurement correspondence, linearity and repeatability of volume was confirmed with absolute syringe pump.

- Bubbles formed have constant volumes and regular periods between their creation to aid flowrate measurement.
- Optical analytical and simulations reveal problems with flowrate determination using bubble size measurement.
- A virtual gate approach that involves the binarization of images allows use of standard cameras.

Abstract

The use of an inverted burette arrangement that allowed volume and time-course tracking of bubble movement via camera imaging is shown here to improve on the classical inverted jar (or beaker) method for measuring gases generated in small volumes and at slow rates (below 1 mL/s). In tests involving discrete gas volume measurements delivered at 0.57 mL/s, comparison with pre-set air volume delivered by a syringe pump showed high correspondence, linearity, and repeatability. Tests with continuous gas flows at 0.2, 0.32 and 0.57 mL/s revealed average bubble count versus volume trends that displayed high linearity to indicate that the bubble volumes (at any flowrate) were constant. The average bubble count versus time also showed linear trends and repeatability indicating that the time intervals between the appearance of any two bubbles (at a particular flowrate) were uniform. The analytical and simulated results helped to explain why bubble size determination by high speed camera recording for measuring gas volume and flowrate is fraught with inherent problems. An analysis using light ray tracing showed that flowrate determination using such an approach would necessitate complicated image correction when two cameras are used for simultaneous recording due to distortion effects resulting from refraction. A virtual gate approach involving the binarization of images recorded with a standard camera is shown to be more feasible in establishing the flowrate using bubble counting or finding the time interval between bubbles.

Graphical abstract



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Introduction

Compositional characterization and volume measurement of gases released in liquids are important in areas such as agriculture [1], environmental monitoring [2], food production [3], fuel generation [4], and materials processing [5,6]. If these gas samples are aerosolized, the biological entities contained within them can be identified using techniques such as DNA profiling [7].

In addition to compositional elucidation, two other parameters that are important in gas sample analysis are their average rates and total volumes of production over specific periods. Flowrate sensors measure the former parameter and deduce the latter from it. The devices and architectures that are applied to achieve this can be costly and complex depending on the mensuration principle that is used [[8], [9], [10]]. A more direct measurement method involves delivering the gas to an airtight syringe, wherein the extent of plunger movement over time allows both parameters to be determined [11,12].

A variety of natural [13] and devised [14] processes generate small volumes of gases at rates slower than 1 mL/s. In such cases, measurements made using typical flowrate sensors and airtight syringes are fraught with high degrees of uncertainty. For this reason, the method of collecting bubbles over an inverted jar, first described by Priestley [15] in the 18th century, still remains widely in use [2,5,6,[16], [17], [18]]. This is because gas bubbles that rise to the upper liquid surface only need to overcome limited resistance at the gas-liquid interface where they merge and accumulate within the head space of the jar. However, it is necessary to ensure that these bubbles do not impinge on and attach themselves to any highly hydrophobic surfaces as they move upwards within the liquid as this will affect volume and rate measurements [19,20].

The accuracy of gas volume and production rate measurements using the inverted jar method is affected by difficulties in determining the height of the gas column within the jar. In addition, the head space is inaccessible which renders it unamenable for easy collection of the gas accumulated there for compositional analysis. In this work, we show the use of an inverted burette arrangement that obviates existing difficulties of the current inverted jar measurement method. This setup allows easy determination of gas volume via direct reading of gas column height from the burette gradations, determination of gas production rate by image-based analysis of bubbles moving up the burette and easy retrieval of the collected gas from the accessible burette head space for compositional analysis. In this work, the physical realization of this approach will be assessed according to amenability for effective measurements. For the image-based determination of bubble flowrate, the feasibility of using bubble sizing will be assessed against the method of bubble counting or finding the time between successive bubbles.

Section snippets

Setup

The use of a jar with a large cross sectional area (e.g. 40 mm diameter for a standard 50 mL beaker) for gas sample collection will not yield sensitive measurements of volume based on the height of the column. However, the use of a narrow cylinder with a small cross-section will not allow an easy passage of the gas sample through the liquid column to the collection headspace. In the setup developed (see Fig. 1), a standard 50-mL capacity burette (Haines, LW150701) with 13 mm inner diameter is…

Results and discussion

The process of precise filling (and refilling) of the inverted burette with water in preparation for gas delivery was found to be significantly easier compared to the current approach of inverting a gas jar over a trough of water. Clearly, the water level in the reservoir should always be kept lower than the lowest liquid level in the burette to allow easy liquid drainage during collection of air in the burette headspace. It is also possible to contain all the elements of the setup (shown in …

Conclusions

The approach of using an inverted burette with camera imaging is studied here to facilitate the measurement of the volume and rate (<1 mL/s) of slowly generated gas bubbles. When the gas volume delivered is discrete with a flowrate of 0.57 mL/s (lower than the 1 mL/s used to define slow), the water level in the inverted burette can be easily distinguished to facilitate volume determination. The pre-set air volume delivered by the syringe pump and the collected volume of gas measured from the…

CRediT authorship contribution statement

Hassan Ali Abid: Formal analysis, Investigation, Methodology, Validation, Software, Visualization, Writing - original draft, Writing - review & editing. **Jian Wern Ong:** Formal analysis, Investigation, Methodology, Validation, Software, Visualization, Writing - original draft, Writing - review & editing. **Eric Shen Lin:** Formal analysis, Investigation, Methodology, Validation, Writing - original draft, Writing - review & editing. **Oi Wah Liew:** Formal analysis, Methodology, Writing - original draft,…

Declaration of competing interest

The authors declare no conflicts of interests.…

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