School of Engineering

Online monitoring of beer fermentation by measurement of evolved carbon dioxide using an infrared sensor

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STU BREW

Introduction

Beer fermentation is one of the world's oldest bioprocesses, yet it still remains relatively difficult to control effectively. Due to this, rudimentary offline sample testing remains the most common means of monitoring fermentation progression in industry(ref). Various methods of online analysis have been studied previously, with the measurement of evolved CO_2 (eCO_2) being deemed the most suitable due to its molar ratio with produced ethanol (ref Daoud) (Eqn. 1).

This project focusses on creating an online monitoring device using an infrared photogate in conjunction with microcontroller hardware to measure eCO_2. The commercially available PLAATO digital airlock is used in parallel to determine the accuracy of the fabricated device.

(1) $$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$$

Glucose Ethanol Carbon Dioxide

Aims:

1. To develop a device capable of providing real-time feedback of fermentation progression through measurement of eCO_2.
2. To confirm relationship between eCO_2 and fermentation progression and to determine suitability of method at commercial scale.

Development of online monitoring sensor

- A Vernier Photogate was controlled using an Arduino Uno microcontroller which determined the time intervals for infrared readings.
- The Arduino relayed the digital output to a Raspberry Pi which posted the data to an online MySQL database through the use of a python programming script.
- The data was plotted to a webpage to provide real time feedback of fermentation progression.

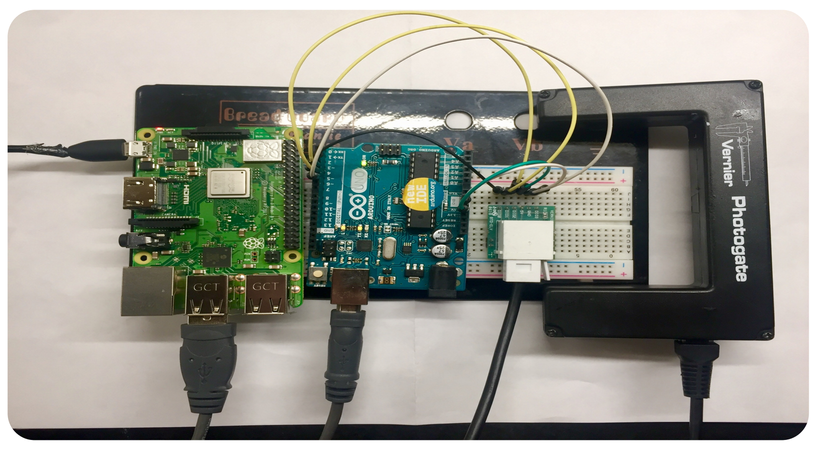

Fig. 1: Photogate and microcontroller hardware wiring

Fig. 2: Logos of hardware and software used to create online sensor

Beer fermentation scales

Fermentations were conducted over a range of scales from10L and 20L laboratory scale up to 625L commercial scale conducted at Newcastle University Stu Brew.

10L and 20L fermentations:

- Two plastic fermentation buckets were charged with identical wort and yeast then stored in a large refrigerator to maintain identical operating conditions.
- The photogate sensor and the PLAATO were attached to each bucket so a direct comparison could be taken.
- TILT hydrometers were used to give live specific gravity readings without the need for taking manual samples.
- Both plastic and steel fermenters were used at 20L scale.

Fig. 3: Two 20L fermentation batches in parallel. Photogate (top), PLAATO (bottom)

625L commercial scale:

- The outfeed air stream was connected to the tap of a water-filled 20L fermentation bucket to allow the eCO_2 to bubble through.
- The photogate sensor was attached to the airlock of the bucket to monitor the outflow of CO_2.
- The PLAATO was not used in parallel for this test to prevent the total eCO_2 stream being split.

Results

- At 10L scale, neither the infrared photogate nor the PLAATO airlock recorded any eCO_2 due to failed seals causing an inability to build sufficient pressure within the buckets and force CO_2 through the airlocks.
- 20L plastic bucket fermentations showed no eCO_2 until fluid was removed from the airlocks at 72 hours. After this point, eCO2 volume was recorded on the PLAATO as triple that of the photogate batch (Fig. 3a, 3b).
- 20L steel conical fermenters ensured airtight seals and promoted more CO2 escaping through the airlocks. Both sensors recorded an earlier onset of eCO2 and higher total volumes (Fig. 3c, 3d).
- Strong linear correlations were shown between the hydrometer and eCO2 readings after the 72 hour point for the bucket fermentations and throughout the steel fermentations (Table 1).

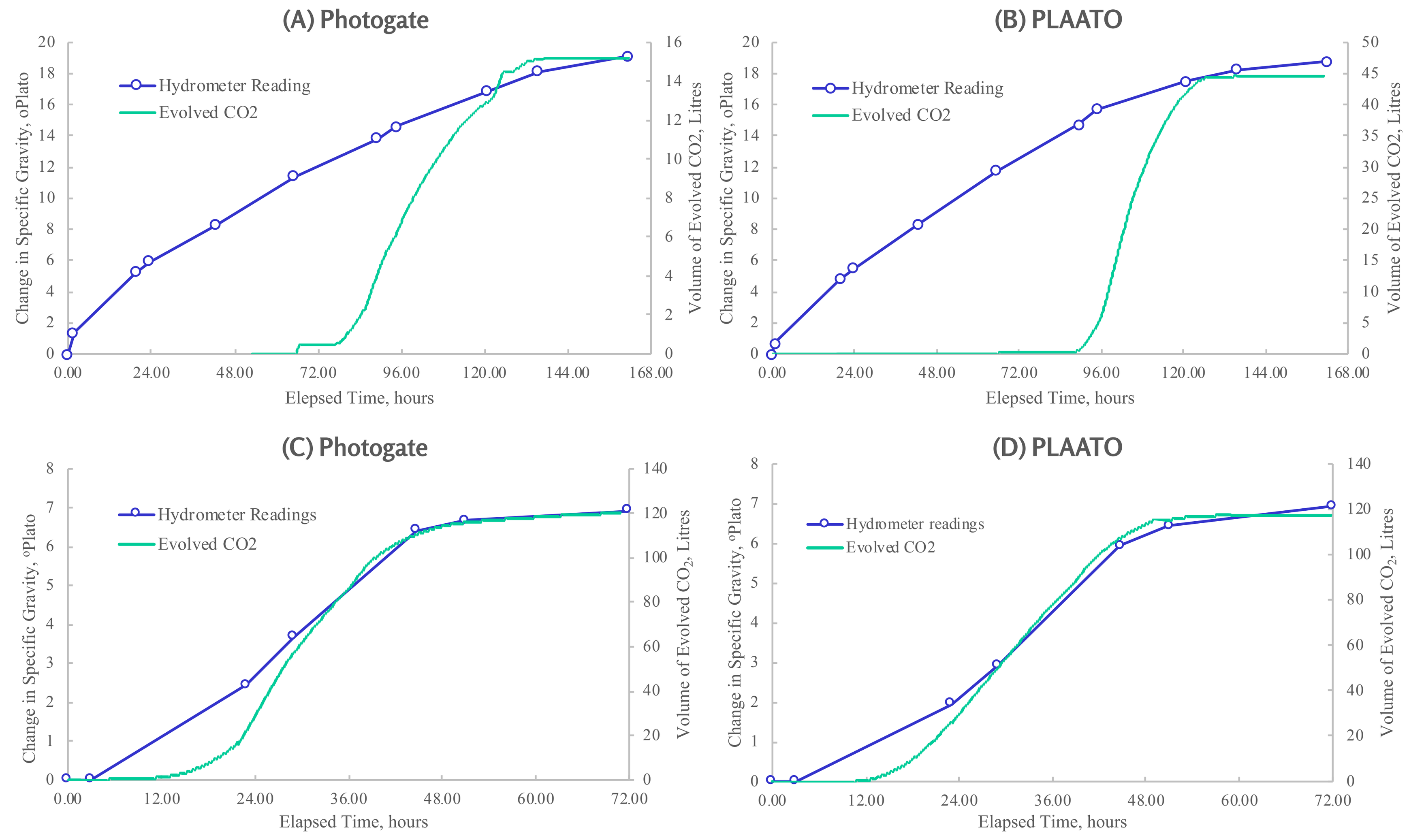

Fig. 4: Evolved CO_2 and hydrometer readings for 20L Steel fermenter batches. Photogate (A), PLAATO (B)

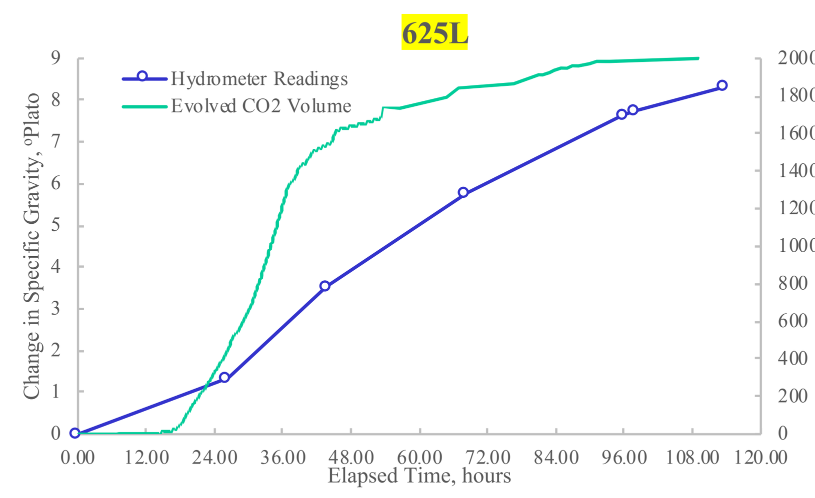

Fig. 5: Evolved CO_2 and hydrometer readings for 625L brewery fermentation

- Commercial scale showed a strong linear correlation but the strength of the eCO2 flow often forced the fluid out of the airlock which gave false positive results.
- The PLAATO showed consistently higher accuracy values but both sensors recorded low eCO2 volumes when compared to theoretical yields (Table 1).

Batch scale	Fermenter type	Sensor	Correlation Coefficient		Theoretical eCO2 (L)	Recorded eCO2 (L)	Accuracy of sensor (%)
20L	Plastic bucket	Photogate	0.857†	0.975*	731	15	2.1%
		PLAATO	0.721†	0.963*	733	44	6.1%
20L	Steel conical	Photogate	0.984		273	45	16.3%
		PLAATO	0.997		284	117	41.4%
625L	Steel cone and cylinder	Photogate	0.960		10183	2000	19.6%

Table 1: Correlation coefficients and sensor accuracy percentage over varying batch scale and fermenter type
† = Coefficient for full data range, * = Coefficient for data after 72 hour mark

Conclusions

- Strong linear correlation between eCO2 and change in specific gravity confirmed suitability of eCO2 in fermentation progression analysis as proposed in literature (ref).
- PLAATO showed improved accuracy over the photogate sensor when used in parallel – likely due to more uniform bubble flow.
- Accuracy of both sensors was particularly low for each batch type - more uniform stream of CO2 bubble stream needed to allow for more accurate determination of volume of CO2 in each bubble pulse.
- At commercial scale, airlock required that can withstand vigorous flow of eCO2.

References

Add references