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Comparative Analysis of CO_2 Content in Biogas and Synthetic Gas Using Chittick Titration Validated by Gas Chromatography

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ABSTRACT: This study demonstrates applicability of chittick titration as a practical and economical method for measuring carbon dioxide (CO_2) content in gas samples, validated against gas chromatography (GC) as the reference. Two types of gas were analyzed: biogas produced via anaerobic fermentation and synthetic CO_2/N_2 gas (40:60). Both methods were parallelly conducted to assess measurement agreement. Chittick titration recorded CO_2 contents of 39.71% (synthetic gas) and 30.16% (biogas), while GC measured 40.52% and 31.40%, respectively. Relative errors were 2.00% and 3.45%, statistically significant differences confirmed via t-tests ($p < 0.05$). The deviations were within acceptable limits for practical applications. It's supported by Bland–Altman analysis showed all measurements were within acceptable limits. The observed bias may be attributed to incomplete CO_2 absorption, interference from reactive gases such as H_2S, and manual endpoint detection. The method appears effectively in simplified settings, although its detection limits remain unverified and warrant further study. Notably, this study introduces comparative validation of Chittick titration for biogas analysis—a topic rarely addressed—highlighting its potential as an affordable alternative for CO2 measurement in laboratories with limited resources and educational settings. However, its broader implementation in industrial-scale gas analysis requires further direct evaluation under operational conditions.

Keywords: biogas; carbon dioxide; chittick titration; gas chromatography; synthetic gas

1. Introduction

Carbon dioxide (CO_2) is one of the primary greenhouse gases contributing to global climate change. Its increasing atmospheric concentration has become a central environmental concern due to its impact on rising global temperatures and related ecological consequences (Sussatrio et al., 2024). At the same time, CO_2 is also a key component in renewable gas mixtures such as biogas, which makes its accurate measurement essential not only for environmental monitoring but also for energy optimization.

Biogas is one of the renewable energies that is produced from anaerobic fermentation of organic materials by microorganisms (Grace Roma Artha Samosir & Merry Meryam Martgrita, 2021). Biogas main composition includes methane (CH_4), and carbon dioxide (CO_2). The CO_2 content in biogas commonly ranges from 22% to 45%, depending on the type of substrate, fermentation conditions, and process efficiency (Ramdiana, 2017). Methane is acclaimed as green combustible component and determined the calorific value of biogas (Soeprijanto et al., 2020). Therefore, accurate determination of CO_2 content is essential to evaluate biogas quality and improve upgrading efficiency.

Various analytical techniques are available to quantify CO_2, with gas chromatography (GC) considered the gold standard (Lestari et al., 2023). GC provides high precision, selectivity, and sensitivity in gas analysis (Hübschmann, 2025). However, GC instruments are costly, require skilled personnel, and demand routine calibration and maintenance—conditions that may be challenging for small laboratories or field-based operations (Sugiharto et al., 2022; Teonata et al., 2021).

As an alternative, the Chittick titration method offers a simpler and low-cost approach for CO_2 measurement. It relies on acid–base reactions between CO_2 absorbed in a basic solution (e.g., NaOH) and a titrant (e.g., HCl), with the volume change used to calculate CO_2 content. The Chittick titration method utilizes the reaction between carbon dioxide and sodium hydroxide, producing carbonate or bicarbonate species that can be quantified via titration. This principle is in line with previous studies on carbon capture, where NaOH demonstrated high reactivity and conversion efficiency for CO_2 sequestration in aqueous systems (Shim et al., 2016). However, when applied to complex gas mixtures such as biogas, the method's accuracy and reliability can be influenced by the presence of other reactive or interfering

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compounds, such as H_2S or volatile organics (Budianto, 2021; Nugroho et al., 2023).

Despite the method's wide use in academic contexts, limited research has validated the accuracy of Chittick titration compared to GC—especially for real biogas samples**.** Existing studies often focus on usage of chittick titration for absorption desorption studies on idealized or synthetic gas systems, which do not represent the chemical complexity of actual biogas (Intan Listiyana et al., 2018; Rahmawati et al., 2017, 2023). This lack of comparative validation creates uncertainty about the method's reliability in practical applications, particularly when used as a standalone tool in resource-constrained environments.

To address this gap, the present study offers a novel contribution by directly validating the Chittick titration method for measuring CO_2 content in both synthetic CO_2/N_2 gas mixtures and actual biogas samples. The synthetic gas serves as a controlled baseline, while the biogas represents a complex, real-world matrix with potential chemical interferences such as H_2S. These approaches enable more comprehensive assessment of the method's accuracy. Unlike previous works that focus primarily on idealized systems, this study provides direct comparative data with gas chromatography and evaluates statistical agreement, relative error, and practical feasibility. The findings aim to support the method's use in resource-constrained laboratories, especially in educational or rural contexts where access to advanced instrumentation is limited.

CO_2 concentration measurement is important to support the development of gas separation technologies, such as the use of polymeric membranes for carbon capture, which is showing significant trends in energy and environmental research (Nyamiati et al., 2023). Overall, this research contributed to the field of gas analysis, particularly in evaluating the applicability of alternative methods for CO_2 measurement in mixed gases. Through an empirical approach and direct evaluation, this research is expected to provide objective and useful information, both from a scientific and practical perspective.

2. Materials and Methods

This study used two types of gas as samples: synthetic CO_2/N_2 gas with a molar ratio of 40:60 and biogas from the anaerobic fermentation of organic waste. Chemical reagents used in the Chittick titration method include 1 N HCl made from concentrated HCl (37%, Merck, Germany), 1N NaOH made from NaOH solids (Merck, Germany), and a phenolphthalein (PP) indicator solution. All chemicals used were pro analysis grade (p.a.) without further purification and standardized to maintain concentration stability.

2.1. Chittick Titration

The Chittick method was performed using a modified Chittick titration apparatus for gas analysis. This analysis method can be applied not only to NaOH solvents but also to amine-based solvents because both types are widely used in CO_2 absorption processes, especially in gas purification and biogas upgrading systems. In this study, NaOH was selected as the absorbent due to its strong alkalinity, ability to irreversibly react with CO_2 to form stable carbonate and bicarbonate species, as well as its cost-effectiveness, availability, and ease of handling compared to amine solutions, particularly in laboratory-scale testing (Kuliyev et al., 2023).

Before performing the analysis, bubbling of a 1 N NaOH solution is carried out, the amount of which is determined by the estimated CO_2 gas content to be analyzed. Gas (40% CO_2 synthetic gas and biogas) will be flowed at a rate of 100 mL/min into the NaOH solution for 10 minutes to increase the accuracy of the readings. The components of the bubbling device consisted of a magnetic stirrer, a gas absorption chamber containing a NaOH solution, and a low-pressure gas.

Before titration process is carried out, levelling bulb and measuring burette calibrated by equalizing these levels. This ensured that the volume measurements during titration were not influenced by pressure differences. To verify airtight conditions and ensure measurement accuracy, a calibration check was conducted prior to each series of titrations. This was performed by adding a known volume of distilled water into an empty flat-bottom flask via the burette, then observing whether the volume change in the burette matched the water dispensed. If any discrepancy was noted, recalibration was performed by inspecting and realigning the sealing and leveling components.

Furthermore, the solution will be analyzed for CO_2 content using a Chittick titration set that shown in Figure 1, where a solvent sample with methyl orange indicator is placed into a flat bottom flask (2) connected to a titration burette (3) for titration procedures with stirring assisted by magnetic stirrer (1) and measuring burette (5) that contain saturated NaCl solution to measure CO_2 gas released which is connected to levelling bulb (6) that equalized the pressure within the titration system by adjusting the liquid level in the measuring burette. Titration was carried out using 1 N HCl solution until the colour changes from yellow to red.

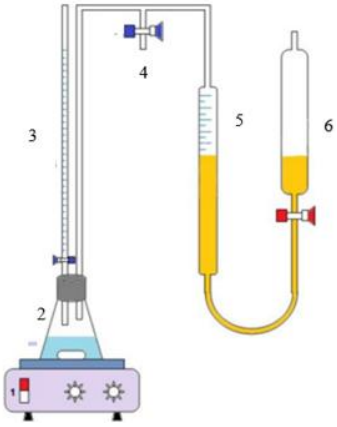

Figure 1. Chittick Titration Apparatus

Description:

1.	Magnetic stirrer	4.	Valve
2.	Flat-bottom flask	5.	Measuring burette
3.	Burette	6.	Levelling bulb

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The gas released from the titration process is CO_2, which has been captured or reacted with NaOH. Furthermore, it was used to determine the amount of CO_2 Loading (α) to quantify the number of moles captured per mole solvent using equation 1. We can also determine the moles of carbon dioxide by equation 2. In addition, the gas concentration can also be known using equation 3.

$$\alpha = \frac{(V_{measure} - V_{HCl}) \times T_{STP} \times P}{(V_{STP} \times P_{STP} \times T) \times C_{Solvent} \times V_{Solvent}} \quad (1)$$

$$n_{CO_2} = \alpha \times C_{Solvent} \times V_{Solvent} \quad (2)$$

$$[CO_2] = \frac{n_{CO_2} \times V_{STP}}{V_{gas}} \times 100\% \quad (3)$$

where:
α is carbon dioxide loading (mol CO_2/mol solvent),
$C_{Solvent}$ is concentration of solvent in mol/L,
$V_{Solvent}$ is the volume of the solvent that used to capture the CO_2 gas,
$V_{measure}$ is the measured gas volume at the measuring burette,
V_{HCl} is the volume contribution at tittration from HCl,
V_{STP} is the molar volume at standard temperature and pressure (STP),
P_{STP} is the molar Pressure at STP,
T_{STP} is temperature at STP,
P is experimental atmospheric pressure,
T is the absolute temperature of the experiments,
n_{CO2} is the number of CO_2 moles obtained from equation 2,
$[CO_2]$ is CO_2 percentage in the sample.

All titrations were conducted in triplicate (n = 3) under controlled laboratory conditions (303.15 K, 1 atm). All glassware was cleaned and dried before each run to minimize contamination. While the procedure followed established protocols, this study did not include independent method validation (such as low-level concentration of CO_2). Therefore, the accuracy and sensitivity of the Chittick titration under varying CO_2 concentrations remain to be evaluated in future research.

2.2. Gas Chromatography

Analysis of CO_2 content using gas chromatography (GC) carried out by third-party accredited laboratory (Energy and Enviromental ITS Laboratory) using a GC-TCD (Thermal Conductivity Detector) instrument merk Techcom 9700. The column used was a Porapak Q stainless steel column (2 m long, 2 mm ID) with an operating temperature of 80°C. The carrier gas flow was helium at a flow rate of 30 mL/min.

The sampling was performed by flowing the gas with a flowrate of 100 mL/min, as in the Chittick titration method, to 1000 mL aluminum sampling bag. Then, the gas to be analyzed will be injected into Gas Chromatography. The injection gas was taken as much as 1 mL using a Hamilton gas syringe and injected into the GC system. The GC analysis produces a chromatogram, where the y-axis represents the detector response (mV) and the x-axis shows the retention time (minutes). Each gas component, such as CO_2 or N_2, generates a distinct peak, with the retention time indicating the identity of the compound and the area under the peak (peak area) reflecting the quantity of the component.

Calibration was conducted by the laboratory using certified standard gas mixtures containing known high purity (99,99%) CO_2 concentrations. However, no formal multi-point calibration curve, regression data, or blank-based sensitivity analysis was provided. Therefore, this study does not include calculated values for the method's limit of detection (LOD) or limit of quantification (LOQ). The GC results were interpreted as operational reference values, based on the general analytical performance of the method and the use of high-purity gas standards. These values reflect the method's sensitivity under validated operating conditions.

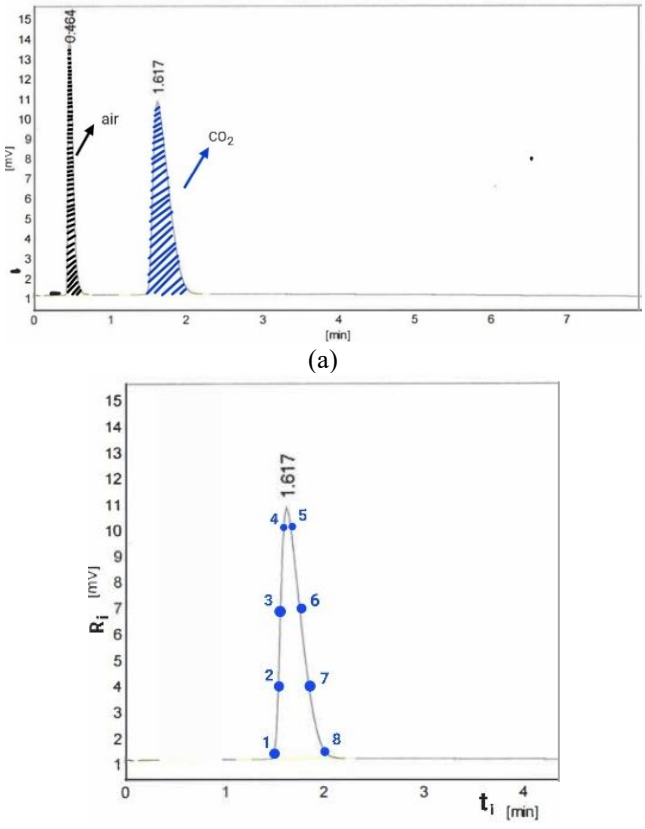

Figure 2. (a) Peak Area and (b) Integration point Illustration in the Gas Chromatography Result's Chromatogram

Figure 2 (a) gives the visualization, the peak area corresponding to the shaded region under each curve in the chromatogram, bounded by the baseline and detector signals across the retention time range. The first peak shows the peaks of air with several compositions, such as nitrogen, that have peak response at 0.464 mV. The second peak shows the

specific component peak of carbon dioxide (CO_2) have peak response at 1.617 mV.

Peak response's values may differ based on testing conditions or timing, but its range is about specific component's peak value. This variation does not significantly affect the analysis and only the peak area is considered for quantification, as it directly correlates with CO_2 concentration in the sample. The specific component's peak is known by the calibration standard. The calibration standard's tests are conducted in the same day with sample's testing to ensure the results are valid.

If the GC system does not directly provide the peak area values, they can be calculated manually by numerically integrating the detector response over time. A common method is the trapezoidal rule, expressed as equation 4.

$$\alpha = \sum_{i=1}^{n-1} \frac{(t_{i+1} - t_i)}{2} \times (R_i + R_{i+1}) \quad (4)$$

Where:
t_i is the retention time at point i,
R_i is the corresponding detector response.

For example, shown in Figure 2 (b) there are 8 points of integration. Then, the x-axis and y-axis values of the integration point can be determined using software or online webplot assistance. This method calculates the total area by summing the small trapezoidal sections formed between consecutive data points under the curve.

The quantification was performed by comparing the CO_2 peak area of the sample with the standard. The equation used to determine the concentration of CO_2 in gas samples can be seen in equation 5.

$$[CO_2]_{Sample} = \frac{(A_{CO_2})_{Sample}}{(A_{CO_2})_{Standard}} \times [CO_2]_{Standard} \quad (5)$$

Where:
$[CO_2]_{Sample}$ and $[CO_2]_{Standard}$ are percent composition of carbon dioxide content in the sample and standard,
$(A_{CO2})_{Sample}$ and $(A_{CO2})_{Standard}$ are the peak areas of carbon dioxide in the sample and standard.

All GC analyses were performed in triplicate (n = 3) for both gas types to ensure result consistency. The GC data were used to compare with the Chittick titration results to assess the practicality and potential application of the Chittick method in resource-limited settings.

3. Results and Discussion

3.1. Result Analysis of CO_2 Content using Gas Chromatography (GC) Method

Figure 1 shows analysis results using the Gas Chromatography (GC) on 40% CO_2/N_2 synthetic gas samples. It shows that the measured carbon dioxide (CO_2) content is in the range of 40.50% to 40.55%; with an average of 40.52% with a standard deviation of ±0.03%. These results show consistency between the value of the CO_2 content used of 40% and the experimental measurement results using GC. The low deviation indicates the stability and accuracy of the GC method in analyzing synthetic gas mixtures (Handri et al., 2022). Thus, it can be concluded that the GC method is quite accurate and reliable as a validation tool for measuring CO_2 content in mixed gases, and these results will later become a reference for comparing the accuracy of the Chittick titration method on the same sample (Teonata et al., 2021).

Table 1. Gas Chromatography (GC) Method Results of 40% CO_2/N_2 Synthetic Gas

Experiment repetition	1	2	3
$[CO_2]$ (%)	40.52%	40.50%	40.55%
Mean		**40.52%**	
Deviation		±0.03%	

The results of analysis with the Gas Chromatography (GC) method on biogas samples showed that carbon dioxide (CO_2) content was 31.40% as shown in Table 2. Measurements were made three times and produced consistent values, as evidenced by the relatively small standard deviation of ±0.10%. The measured gas composition reflects the general characteristics of biogas which has CO_2 content in it resulting from the anaerobic fermentation process of organic matter. The accuracy and precision of these results show that the GC method is effective in quantitatively analysing the main components of biogas and can be used as a reference in comparing the accuracy of the Chittick titration method on the same gas samples.

Table 2. Gas Chromatography (GC) Method Results of Biogas

Experiment repetition	1	2	3
$[CO_2]$ (%)	31.29%	31.40%	31.49%
Mean		**31.40%**	
Deviation		±0.10%	

Several sources of uncertainty may influence the results, although GC is considered a high-precision method. Instrumental uncertainty includes the accuracy and repeatability of the detector response. Procedural uncertainty may still arise from manual injection using a gas-tight syringe, where slight deviations in injection volume or timing can occur. Additionally, slight temperature fluctuations in the GC oven can affect retention time or signal intensity. However, due to the controlled and automated nature of GC operation, the combined uncertainty remains relatively low estimated by the laboratory to be within ±0.10% for biogas and ±0.05% for synthetic gas measurements.

3.2. Result Analysis of CO_2 Content using Chittick Titration Method

Calculation of carbon dioxide (CO_2) component was calculated using the Chittick titration method with reference to the following experimental parameters: NaOH solution,

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gas sample volume flowed into solution as much as 100 mL/minute for 10 minutes (equivalent to 1000 mL or 1 L) to ensure the results and avoid deviation because of fluctuation time, with environmental conditions at a temperature of 303.15 K and a pressure of 1 atm. The concentration of the HCl titrant solution was 1 N. The analysis was carried out using the same procedure for both synthetic and biogas.

For the synthetic gas sample with a nominal composition of 40% CO_2, the measurement results showed an average value of 39.71% with a deviation of ±0.20% from three repetitions. The results are shown in Table 3. These results show that the Chittick titration method can provide stable and consistent data on gas systems that have relatively simple compositions (Akimoto et al., 2025). Synthetic gas is categorized as having a relatively simple composition because it consists of only two main components, those are CO_2 and N_2, with no other interfering compounds such as water vapor or volatile organic compounds (Shakir et al., 2021). This property allows the CO_2 absorption process by the base solution to run more efficiently, so that the analysis results are more reproducible with low variation between replicates.

Table 3. Chittick Titration Method Results of 40% CO_2/N_2 Synthetic Gas

Experiment repetition	1	2	3
[CO_2] (%)	39.87%	39.72%	39.55%
Mean		**39.71%**	
Deviation		±0.20%	

Meanwhile, in the biogas samples results are shown in Table 4. The average CO_2 content measured was 29.84% with a deviation of ±0.38%. This value was obtained from three repetitions which showed consistency of results despite slight variations. Biogas has a more complex composition as it contains various other components such as methane (CH_4), nitrogen (N_2), hydrogen sulfide (H_2S) and water vapor, which can affect the efficiency of CO_2 absorption in the titration analysis (Awe et al., 2017). Nevertheless, the variation between replicates remained within an acceptable range, indicating that the Chittick titration method can still be used for the analysis of natural gas mixtures.

Table 4. Chittick Titration Method Results of Biogas

Experiment repetition	1	2	3
[CO_2] (%)	29.48%	30.21%	29.83%
Mean		**29.84%**	
Deviation		±0.38%	

In addition to standard deviation, it is important to consider several potential sources of uncertainty in the Chittick titration method. These include variations in gas bubbling rate, mixing efficiency during absorption, and titration endpoint determination, particularly if the color change is not sharply observed. Operator handling, timing between gas absorption and titration, and possible interference from reactive gas species (e.g., H_2S, N_2) can also introduce procedural uncertainty. While not quantified in this study, these factors may contribute to the observed deviation and should be addressed in future uncertainty analyses.

3.3. Validation of CO_2 Content Analysis Results

As part of the validation process, a comparative analysis of the measurement results of carbon dioxide (CO_2) content using the Chittick titration method against Gas Chromatography (GC) was carried out on two types of samples: synthetic CO_2/N_2 gas and biogas. Based on the results presented in Table 5, the average CO_2 content of synthetic gas measured by Chittick titration was 39.71% ± 0.2%, whereas GC recorded an average of 40.52% ± 0.03%. The difference in the results obtained between the methods was 0.81%, with a relative error compared to GC of 2.00%. In the biogas sample, Chittick titration showed an average CO_2 content of 30.16% ± 0.37%, whereas GC recorded 31.40% ± 0.10%. The difference in measurement results reached 1.55%, with a relative error of 3.45% compared to gas chromatography.

These differences in values reflect the systematic deviation between the two methods, where the Chittick titration tends to give slightly less composition than GC. This can be explained by the different working principles of the two methods: GC utilises high-sensitivity gas component separation-based detection (Arias et al., 2025), while Chittick titration relies on the efficiency of the chemical reaction between CO_2 and the base solution, which is susceptible to being affected by experimental factors, such as gas flow rate, sealing conditions, or the presence of other gas components in the sample (Rose & Hemery, 2023).

Table 5. Comparison of CO_2 Content Analysis Results between Chittick Titration and Gas Chromatography. Mean values are shown. Standard deviation is shown after ± symbol

Parameter	**[CO_2] (%)**	
	Synthetic Gas	**Biogas**
Chittick Titration	39.71% ± 0.20%	30.16% ± 0.37%
Gas Chromatography	40.52% ± 0.03%	31.40% ± 0.10%
Difference	**0.81%**	**1.55%**
Error compared to GC	**2.00%**	**3.45%**

The Chittick titration method showed a consistent tendency to underestimate CO_2 concentration compared to GC. This discrepancy is primarily due to the incomplete absorption of CO_2 during the bubbling stage, which is critical in the Chittick process. The chemical reaction

between CO_2 and NaOH, as shown in equation 6 and 7, is rapid and occurs in milliseconds to seconds.

$$CO_2 + NaOH \rightarrow NaHCO_3 \quad (6)$$
$$NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O \quad (7)$$

Even though these reactions are happening in millisecond to some second, the overall efficiency also depends on gas–liquid mass transfer and mixing characteristic (Wang et al., 2013). Moreover, volatile CO_2 loss may occur during the short delay between bubbling and titration.

In addition to incomplete absorption and volatilization, interfering gases in biogas such as hydrogen sulfide (H2S) may also react with NaOH during the absorption step, partially consuming the reagent and altering the titration stoichiometry. Methane (CH_4), while non-reactive in alkaline solution, may still influence gas flow dynamics during bubbling (Kouzi et al., 2020). These factors introduce additional uncertainty and may contribute to the systematic underestimation observed in the Chittick method when applied to complex gas mixtures. No pre-treatment or gas scrubbing steps were implemented in this study; therefore, the effect of these interferences was not isolated but should be addressed in future work.

However, the relative errors recorded for both synthetic gas (2.00%) and biogas (3.45%) suggest that the deviations are within a reasonable range (Khomsatun, 2016). With these results, Chittick titration can be validated as a reasonably reliable alternative method for CO_2 content estimation, especially in laboratories that do not have access to chromatographic instruments (Tomczak et al., 2024). This validation reinforces the potential of using simple methods such as the Chittick titration, provided they are applied with a good understanding of their limitations (Lestari et al., 2023; Sugiharto et al., 2022).

Despite the practicality and cost-effectiveness of the Chittick titration method in laboratory-scale settings, its applicability in industrial-scale gas analysis is limited. Industrial operations typically require higher analytical precision, automated sampling, and real-time monitoring capabilities, which the manual Chittick setup cannot accommodate. The method's reliance on visual endpoint detection, manual titration, and sensitivity to operator technique introduce inter-user variability that may compromise reproducibility at scale.

Furthermore, the titration process is not easily integrated with automated process control systems, making it less suitable for continuous industrial monitoring. Therefore, while Chittick titration is well-suited for preliminary assessments, teaching purposes, or use in resource-constrained laboratories, it should be complemented or replaced by advanced instrumentation like GC or NDIR sensors in industrial settings requiring strict analytical standards(Wei et al., 2023).

3.4. Agreement Analysis using Bland-Altman Plot

To complement comparison between Chittick titration and Gas Chromatography (GC), a Bland-Altman analysis was performed to assess the level of agreement and detect systematic bias between the two methods. Bland-Altman plot provides a visual and quantitative interpretation of how closely two measurement methods agree across their entire range (Möller et al., 2021). This is especially important when evaluating interchangeability of methods in practical applications. This analysis plots the difference between measurements (GC – Chittick) against their average for each gas sample tested.

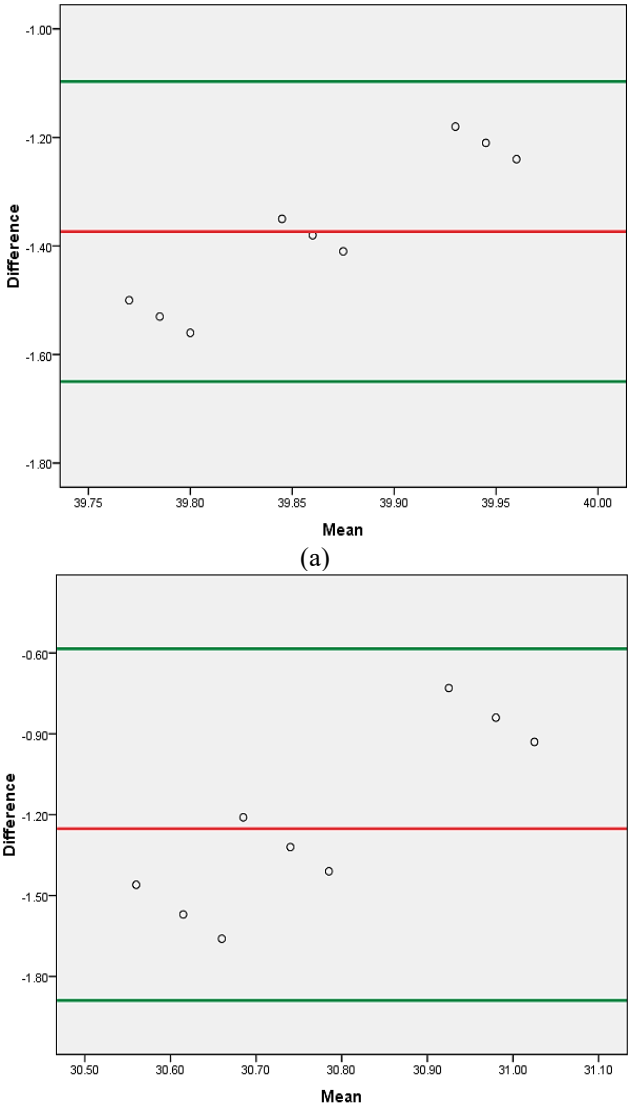

Figure 3. Bland-Altman plots Synthetic Gas (a) and Biogas(b)

Figure 3 illustrates the Bland-Altman plots for both synthetic gas (a) and biogas (b). Each plot displays each data difference between CO_2 concentrations measured by GC and Chittick titration (GC – Chittick) on the y-axis against the average of both methods on the x-axis. The red line represents the mean difference (bias), while the green lines indicate the 95% limits of agreement (mean ± 1.96 × SD).

For synthetic gas (Figure 3a), the mean difference (bias) was approximately -1.37%, with 95% limits of

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agreement between -1.65% and -1.10%. For biogas (Figure 3b), the bias was approximately -1.24%, with limits of agreement from -1.89% to -0.58%. The 95% limits of agreement were calculated as the mean difference ±1.96 × standard deviation of the differences. All measurement points fell within these limits, suggesting no outliers or extreme disagreement (Giavarina, 2015).

The Bland-Altman analysis supports the idea that Chittick titration, while less precise compared to GC, may still be used as a practical alternative to GC for CO_2 quantification in non-critical settings, such as teaching laboratories or resource-limited environments.

3.5. T-test Statistical Analysis

To validate the measurement results of CO_2 content using the Chittick titration method, two independent sample t-tests (Welch's t-test) were conducted using Gas Chromatography (GC) as a comparison. The test was conducted separately for each gas type, namely biogas and synthetic gas, so that the measured differences can be interpreted correctly without the influence of variations between gas types.

Before analyzing t-test, we need to assure the normality of data distribution. Normality of the dataset was assessed using the Kolmogorov–Smirnov test with Lilliefors correction, as implemented in SPSS. This test was chosen due to its applicability to small sample sizes and its robustness for assessing empirical data against a normal distribution prior to conducting parametric statistical tests. Results show that both datasets follow a normal distribution, with p-values of 0.072 (Chittick) and 0.058 (GC), respectively. These results support the appropriateness of using a paired t-test to compare CO_2 concentrations measured by both methods.

Table 6. Results of t-test comparing CO_2 concentration for synthetic gas and biogas samples.

Sample	t-value	df	p-value
Biogas	5.574	2.29	0.022
Synthetic Gas	14.603	2.14	0.004

Statistical comparison using t-test was conducted to evaluate the significance of differences in CO_2 concentration results between the Chittick and GC methods for both gas types. As summarized in Table 6, the p-values for both synthetic gas and biogas samples were below 0.05, indicating statistically significant differences with a 95% confidence level.

This finding reinforces the conclusion that statistically, the Chittick titration method produces different results than GC for both synthetic gas and biogas. However, it is important to note that although a statistically significant difference was detected, the magnitude of the relative deviation remained within the practically acceptable range. Thus, the Chittick titration method can still be validated as an alternative method for CO_2 content estimation, especially when access to advanced chromatography equipment is limited.

4. Conclusions

This study successfully validated the Chittick titration method as an alternative for measuring carbon dioxide (CO_2) content, using Gas Chromatography (GC) as the reference method. Analyses were conducted on two types of gases: synthetic CO_2/N_2 and biogas. When compared with gas chromatography (GC), the Chittick method produced relative errors of 2.00% and 3.45%, for synthetic gas and biogas respectively. Bland–Altman analysis revealed some systematic bias across all samples, but the differences remained within acceptable agreement limits, indicating that the Chittick method can be a reliable low-cost alternative in non-critical applications. Statistical t-tests showed significant differences ($p < 0.05$) between the two methods for both gas types, indicating that although the results were not identical, the recorded deviations remained within acceptable limits for small-scale laboratory applications.

Therefore, the Chittick titration method can be considered a practical, economical, and reasonably reliable alternative for estimating CO_2 content, particularly in laboratories without access to gas chromatography equipment. These findings are expected to serve as a reference for educational or small laboratories in selecting simple valid gas analysis methods. Moving forward, further studies are encouraged to refine the Chittick titration process by improving absorption efficiency, minimizing operator-dependent variation, and adapting the method for semi-automated systems. The integration of pre-treatment steps (e.g., H_2S scrubbing) or coupling the technique with low-cost sensors could enhance selectivity and enable broader use in biogas upgrading or industrial CO_2 monitoring. Additionally, validating this method across a wider range of CO_2 concentrations and gas matrices will support its scalability and robustness for various real-world applications.

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Credit authorship contribution statement

Alfian Wisnu Pambudi: Writing – review & editing, Writing – original draft, Visualization, Validation, Resources, Investigation, Formal analysis, Conceptualization. **Yeni Rahmawati:** Writing – review & editing, Validation, Resources, Formal analysis, Conceptualization**. Fadlilatul Taufany:** Conceptualization, Resources, Funding acquisition, Supervision. **Ali Altway**: Conceptualization, Validation, Resources, Software. **Susianto**: Methodology, Data curation, Validation, Supervision.

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