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Original Research

DURABILITY TESTING AND COMPARATIVE EVALUATION OF A PROTOTYPE DEVICE FOR AMBIENT AIR QUALITY SAMPLING

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ABSTRACT

Durability Testing and Comparative Evaluation of a Prototype Device for Ambient Air Quality Sampling. *Along with technological advancements and the rapid development of industrial areas, concerns have emerged regarding the deterioration of air quality due to increasing levels of air pollution. According to Government Regulation Number 41 of 1999 on Air Pollution Control, air pollution is defined as a decline in air quality that causes the air to no longer function in accordance with its intended use. Ambient air quality monitoring is generally conducted using two approaches, namely manual and automatic methods. The manual method involves the collection of air samples followed by laboratory analysis and can be further classified into passive and active sampling techniques. Ambient air sampling requires adequate equipment and appropriate sampling procedures that comply with established standards. However, the high cost of air quality monitoring instruments and their limited availability within relevant local institutions hinder the optimal implementation of air quality monitoring programs. Therefore, this study aims to design and develop an ambient air sampling device as well as a microbiological air sampling device using methods that comply with the Indonesian National Standard (SNI). The devices are constructed using materials that are readily available through online marketplaces and assembled in the workshop of Poltekkes Kemenkes Bengkulu. Following the assembly process, functional testing is conducted to evaluate device performance and to identify and correct any errors arising from the manufacturing process.*

INTRODUCTION

Ambient air quality monitoring is one of the key efforts to evaluate the effectiveness of air pollution control programs implemented by both central and local governments. The results of ambient air quality monitoring can be used as indicators for determining priority actions in air pollution control programs that need to be undertaken [(1)]. Currently, ambient air quality monitoring methods implemented by the Directorate of Air Pollution Control include continuous automatic monitoring using an Air Quality Monitoring System (AQMS) and manual methods, namely passive samplers [(2,3)].

Previous studies have reported the development of a micro-impinger sampling device as a portable instrument for nitrogen dioxide (NO_2) gas sampling, demonstrating high efficiency and the capability to operate without reliance on public electricity networks (4). In addition, bioaerosol sampling has been conducted using various approaches, including the use of impingers, which remain one of the primary active methods for air sample collection for laboratory analysis (5). Comparative performance studies of liquid impingers and other types of samplers have shown that each device exhibits distinct characteristics in terms of collection efficiency and air sample stability (6).

The passive sampler method was first developed in the United Kingdom using a Pb candle to adsorb sulfur dioxide (SO_2) pollutants in ambient air, which were subsequently analyzed in the laboratory to determine SO_2 concentrations (7,8). Along with technological advancements and increasing environmental awareness, the use of Pb was later discontinued and replaced with more environmentally friendly chemical materials (9). To date, passive sampler methods continue to be employed in ambient air quality monitoring and have been implemented in monitoring networks across various countries, including Japan, Australia, and several European nations through the EANET network (3,6).

In Indonesia, passive sampler methods have been used since 2008 and have been nationally integrated since 2015, with the number of monitoring sites increasing annually. Several advantages of the passive sampler method include the absence of electrical power requirements, relatively low operational costs, and ease of placement due to its compact size (10,11). However, this method has limitations, as it does not provide continuous measurements and is currently restricted to measuring only NO_2 and SO_2 parameters (12). At present, the Department of Environmental Engineering at Institut Teknologi Bandung (ITB) is developing a passive sampler method for monitoring particulate matter $PM_{2.5}$ (13).

In response to these challenges, the authors propose the development of an ambient air sampling device that can be used portably with relatively low production costs, making it accessible to both government agencies and educational institutions. The device is designed to be easy to operate, portable, and economical. The objectives of this study are to conduct durability testing to assess the resilience and stability of the device's performance during use, as well as to perform functional testing through comparative evaluation with existing or standardized ambient air sampling devices in order to assess performance compatibility and measurement reliability. Thus, the developed device is expected to support the broader and more equitable expansion of ambient air quality monitoring activities.

MATERIALS AND RESEARCH METHODS

Design constitutes the initial stage in a sequence of activities involved in the product development process. At this stage, a general framework is formulated to serve as the basis for implementation, including the determination of the working concept, selection of components, and establishment of appropriate technical specifications for the equipment. Proper selection of instruments, both in terms of quantity and specifications, is essential to ensure that the resulting product functions optimally and efficiently (4).

The design of this impinger-type air sampler aims to produce an air sampling device that is simple, portable, and economical, so that it can be manufactured and utilized by non-specialist users. To ensure the validity of the device's performance, functional testing and comparative testing were conducted against a reference instrument that has been widely used and complies with standard methods. The reference instrument employed was a calibrated air sampling device with a valid calibration certificate, thereby ensuring that the measurement results are scientifically reliable. In addition, the air sampling procedure was carried out in accordance with relevant Indonesian National Standards (Standar Nasional Indonesia, SNI), including SNI 19-7119.3-2005 on Ambient Air Sampling Methods, as well as standards related to air sampling for microbiological analysis. Through this approach, the developed device is expected to meet the technical requirements for ambient air and microbiological air sampling, despite being produced at a lower manufacturing cost compared with commercially available equipment [2,14].

Figure 1. Research Design

The prototype air sampler was assembled using commonly available tools, including pliers, scissors, a cutter, acrylic glue, soldering equipment, and a drill. The main components of the device consisted of a Li-Ion battery, a Battery Management System (BMS), electrical cables, a rotameter, a digital voltmeter, a DC power supply, a vacuum pump, a midget impinger tube, and silicone tubing. These tools and materials were selected to enable a simple, portable, and cost-effective construction while ensuring proper functionality and accurate air sampling performance

Working Principle

This device operates semi-automatically when connected to a power source. The power supply functions to convert AC current into DC current, which is then delivered to the Battery Management System (BMS). The BMS regulates and protects the battery by charging the Li-Ion battery up to approximately 12.5 volts [4].

The voltage from the battery is subsequently routed to a step-down module to reduce it to around 6.5 volts, which is used to drive the vacuum motor. The vacuum pump, connected via silicone tubing, functions by drawing in air. The aspirated air is then channeled through the tubing to a rotameter, which regulates the airflow rate, and subsequently directed into a midget impinger tube containing an absorbing solution.

During operation, the battery voltage can be monitored using a digital display voltmeter. The device is then tested to evaluate its operational capability, particularly the battery endurance during air sampling under full battery conditions.

Device Fabrication Steps

The power supply or adapter is installed modularly using a DC–DC socket, then connected with two cables, positive (+) and negative (–), to the Battery Management System (BMS). The BMS regulates and protects the battery system.

From the BMS, the circuit is connected using six cables to a 3.7-volt Li-Ion battery arranged in series with three cells, resulting in a total voltage of 11.1 volts (3.7 V × 3). In electrical principle, current flows from higher to lower voltage. The power supply used has a voltage of 12 volts, suitable for charging the battery through the BMS.

The battery output is then connected via cable to a vacuum pump operating at 7.2 volts. A switch is installed in the circuit for ON/OFF control and a voltmeter to monitor the battery voltage during operation.

The vacuum pump is connected to the rotameter via silicone tubing. The rotameter regulates and controls the airflow entering the vacuum system. The rotameter inlet is then connected in series with the midget impinger tube.

For sampling duration control, the system is equipped with a timer that automatically cuts off the electric current according to the predetermined sampling time.

Device Design

The device fabrication involved several stages, including circuit design, procurement of readily available components, assembly, and functional testing. The first step was the schematic design of the device:

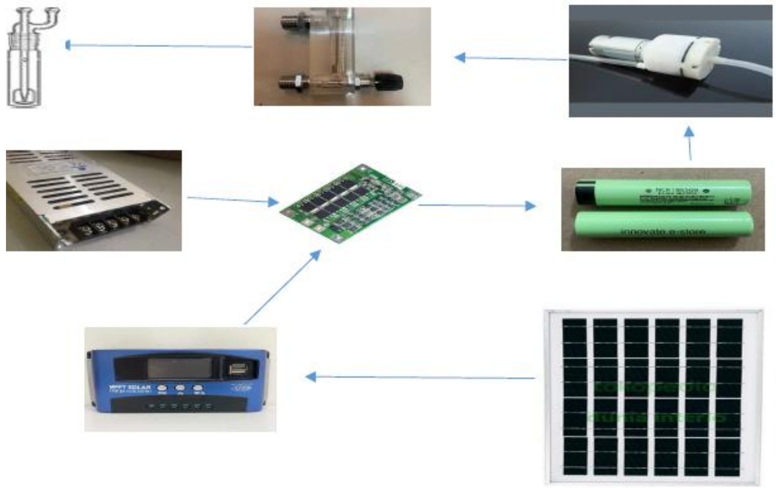

Figure 2. Schematic Arrangement of Prototype Device Components

Device Testing

At this stage, the device is connected to a power source, the airflow rate is adjusted via the rotameter, and the voltage supplied to the vacuum pump is set. During testing, the midget impinger tube is filled with water, and the system is operated. The formation of air bubbles in the impinger tube indicates that the airflow is functioning properly and that the device operates according to its working principle.

Durability Testing

Durability testing is a continuation of the functional testing stage. At this stage, the battery is fully charged, indicated by a voltmeter reading of 12.5 volts. The device is then operated, and the airflow rate is continuously monitored via the rotameter. Durability testing is terminated when a significant reduction in airflow rate is observed, indicating that the battery can no longer sustain optimal vacuum pump performance. The operational time until a noticeable decrease in airflow is considered the effective working duration of the device.

RESEARCH RESULTS AND DISCUSSION

This study focuses on the design, fabrication, and functional testing of an ambient air pollution sampling device. The background of this research is based on the high cost of air samplers listed on the official government e-catalog (LKPP), ranging from IDR 47,000,000 to IDR 94,000,000. This cost poses a barrier for certain educational institutions and regional agencies with limited budgets to conduct routine ambient air quality monitoring.

Based on technical review and the researchers' experience, an ambient air sampling device operating on the impinger principle can be engineered at a production cost below IDR 7,000,000 without compromising its primary function as an air sampling tool. Therefore, this study proposes the development of a more economical prototype, accompanied by functional and durability testing to ensure reliable performance. The design was refined through the addition of power sources, including an internal battery and a solar panel as an alternative charging option. This approach aligns with the development of portable devices in similar studies that emphasize energy efficiency and power autonomy, particularly for sampling in locations distant from the electrical grid[4].

Operation and Durability Testing

Air sampling in this study was conducted at a flow rate of 0.5 L/min for a duration of 1 hour, following common practices for ambient air sampling using the impinger method as recommended in the Indonesian National Standard (SNI 19-7119.3-2005). Testing results demonstrated that the prototype could operate effectively for 1 hour without connection to an external power source or solar panel. Continuous testing indicated an operational durability of up to 4 hours using the internal battery.

The battery capacity employed in the prototype was 6 × 1,800 mAh, which proved sufficient for simultaneous sampling of four parameters over 4 hours. This operational duration is comparable to several commercially available battery-powered devices reported in similar studies, albeit at a significantly lower production cost. Furthermore, the inclusion of a solar panel allows for an extended measurement period under adequate sunlight intensity, reducing dependence on electrical generators and supporting a more environmentally sustainable monitoring concept.

Comparative Testing with Standard Equipment

Comparative testing was conducted at Poltekkes Kemenkes Padang by evaluating the performance of the developed prototype against a standard impinger air sampler owned by the institution, which has been used in practical exercises and routine air quality monitoring. The reference device was calibrated and operated according to standard operational procedures, making it suitable as a benchmark for prototype performance evaluation.

Testing was performed over two consecutive days alongside practical sessions for students of the D3 Sanitation Study Program. Operationally, the prototype was deemed more portable than the standard device because it does not require direct connection to the PLN electricity network, allowing greater flexibility for field use without a generator. Ambient air sampling was conducted for three pollutant parameters: carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), with a 1-hour sampling duration. Subsequently, absorbance values were measured, and concentrations of each parameter were calculated. Comparative results for NO_2 and SO_2 concentrations are presented in the following table.

Table 1. Comparative Absorbance Values

Sampler Type	Parameter	
	SO_2 (µg/Nm^3)	NO_2 (µg/Nm^3)
Prototype	5,37	3,71
Standard Device	5,53	3.69

From the table above, it can be observed that the results obtained from the prototype do not differ substantially from those of the standard device used at Poltekkes Kemenkes Padang.

Figure 3. Comparative Testing of the Prototype and Standard Devices

Based on the comparative testing, the concentrations of SO_2 and NO_2 obtained using the prototype device were relatively consistent with measurements from the standard device at Poltekkes Kemenkes Padang. The small differences observed remained within the technically acceptable range for active air sampling methods. These findings are in line with the study by Tang, Cape, and Sutton, which reported that minor discrepancies between active samplers may occur due to variations in airflow, device design, and absorption efficiency, but do not necessarily have a significant impact on measurement accuracy when sampling procedures are properly controlled(6,16). In support of this, comparative analyses of passive and active monitoring methods in tropical environments have shown that mean concentrations of NO_2 and SO_2 measured by passive samplers were in close agreement with those from continuous active monitoring, with no statistically significant differences observed over multiple sampling periods(21).

Further, studies validating passive samplers against active sampling techniques demonstrated strong linear correlations (correlation coefficients > 0.8) between the two methods for both NO_2 and SO_2 in ambient air, indicating that passive techniques can reliably approximate active sampling results when appropriately calibrated and deployed(22). A comprehensive technical review of diffusive (passive) samplers also highlights that these devices can provide cost-effective, spatially dense measurements of gaseous pollutants and that their deployment alongside active methods enables effective comparative assessments(23).

A comparative evaluation of various active and passive samplers indicated that measurements from different devices can show good correlation despite differences in design and working mechanism when statistical analysis and co-location protocols are applied, reinforcing that multiple sampling strategies can converge on similar environmental measurements(17). Consistency in operational protocols and environmental conditions during sampling remains critical to ensuring agreement between devices, as differences in temperature, wind, or humidity can influence sampling rates and pollutant capture(24). Additionally, broader evaluations of passive samplers for volatile organic compounds found that passive methods produced atmospheric concentration estimates that compared favorably with active sampling results, further supporting passive sampling reliability(25).

The comparative testing of the prototype and the standard device further confirmed that the measured concentrations of the parameters were largely comparable. These results align with the findings of previous research(18), which reported a strong correlation between passive and active sampling methods for SO_2 and NO_2 in ambient air in Jakarta. In addition, a comparative evaluation of different air sampling techniques(19) indicated that various active and passive approaches can produce comparable concentration values under well-controlled conditions. For microbiological parameters, studies have also supported that both active and passive sampling methods can provide correlated results for airborne microbial contamination levels[20].

Overall, the comparative testing in this study indicates that the developed ambient air sampling prototype performs comparably to standard devices, despite being produced at a significantly lower cost. These findings reinforce the potential of the prototype as a portable, cost-effective, and feasible alternative for ambient air quality monitoring, particularly for educational institutions and regional agencies with limited budgets. The evaluation considered two aspects: physical characteristics and economic value. Physical evaluation included comparisons of size, weight, mobility, durability, and ease of operation, while economic evaluation compared production cost with market price. Physically, the prototype is slightly heavier—approximately 1 kg more than the standard device used at Poltekkes Kemenkes Bengkulu—due to the inclusion of an internal battery. However, in terms of mobility, the prototype is easier to transport for sampling in locations without electrical power, as it does not require carrying a generator, which can be cumbersome, heavy, and generate additional emissions around the sampling site. Economically, the prototype required a production cost of less than IDR 7,000,000, whereas commercially available devices are priced around IDR 47,000,000. Therefore, in both physical and economic terms, the prototype offers significant advantages over existing market devices.

Figure 4. Prototype Device for Ambient Air Quality Sampling

CONCLUSIONS AND RECOMMENDATIONS

The findings of this study indicate that, based on comparative testing with a calibrated standard device used at Poltekkes Kemenkes Padang, the developed prototype for ambient air sampling demonstrates performance comparable to commercially available devices while offering greater practicality in operation. However, the study has certain limitations, particularly regarding the absence of long-term accuracy evaluation and performance testing under a wider range of environmental conditions, such as variations in temperature, humidity, and wind speed. For further development and research, it is recommended to enhance the power supply capacity, either by increasing battery capacity or implementing a more efficient power management system, to extend the device’s operational duration for long-term or continuous ambient air quality monitoring. The integration of a solar panel should also be optimized to ensure efficient charging under varying sunlight conditions. Extended field testing under diverse environmental conditions is necessary to evaluate the stability, reliability, and durability of the device in repeated use. In addition, regular calibration and validation of the measurement components should be performed, with comparisons to nationally or internationally certified standard devices, to ensure measurement accuracy, precision, and consistency for routine monitoring purposes. Future improvements may also focus on expanding the device’s capability to measure additional air pollutants and incorporating an automated data logging system to facilitate the analysis and reporting of air quality monitoring results. Overall, the developed prototype represents a cost-effective, practical, and reliable alternative for ambient air sampling, particularly suitable for educational institutions and regional agencies with limited resources.

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