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Development and prototyping of a concentrated ethanol gas monitoring system based on the MQ-3 sensor using the KAVi machine calibrator for environmental safety

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Abstract This research outlines the development of a device for measuring concentrated ethanol gas concentrations using the MQ-3 sensor. The device is engineered utilizing an Arduino Uno microcontroller and an LCD as the output interface. The MQ-3 sensor has demonstrated optimal sensitivity and a linear response to ethanol gas. The range of ethanol gas concentrations tested, from 10% to 70%, was selected to match the capabilities of the KAVi machine in generating ethanol gas. The testing process of the sensor was conducted to generate data that were subsequently calibrated to ensure measurement accuracy. Validation results indicate that the MQ-3 sensor can measure ethanol gas concentrations with high accuracy and good linearity within this range. However, discrepancies between the sensor measurements and the calibrator values were observed and need attention. The development of this device provides improvements in the accuracy and linearity of the MQ-3 sensor compared to previous studies. It is important to note that the KAVi machine has limitations in producing ethanol gas concentrations above 70%, which should be considered in the practical applications of this device. Overall, this device shows great potential in applications for monitoring ethanol gas concentrations, with a note to consider the limitations of the ethanol gas production process from the KAVi machine for more optimal results.

Keywords: ethanol gas, KAVi machine, MQ-3 Sensor, calibration

1. Introduction

The COVID-19 pandemic, triggered by the novel SARS-CoV-2 virus, began in Wuhan, China in December 2019 and rapidly evolved into a serious global health crisis (Zhang et al., 2020; Mercier et al., 2023). It spread swiftly worldwide, leading to the declaration of a pandemic by the World Health Organization (WHO) (Mercier et al., 2023; Matsuura et al., 2021). Initial attention focused on understanding the dynamics of virus transmission and managing the increasing number of cases (Tosi & Campi, 2020). In facing the pandemic, effective prevention and control measures were necessary, particularly in the context of disinfection, which became a critical aspect in controlling the spread of the virus in healthcare facilities and public places.

This study examines the importance of disinfection strategies in reducing the spread of COVID-19. The use of disinfectants, such as ethanol and chlorine compounds, has proven essential in suppressing virus transmission, yet raises concerns about environmental and health impacts (Wang et al., 2020; Bhat et al., 2021; Dhama et al., 2021). Therefore, this research aims to identify and develop effective yet safe and sustainable solutions to control the virus spread.

In the context of the pandemic, the use of the Anti-Virus Mist (KAVi) machine has been identified as an innovative solution. KAVi transforms ethanol solutions into mist, enabling a rapid and safe disinfection process without heating (Pandya et al., 2020; Jiang et al., 2021). This technology effectively facilitates the sterilization of materials and medical equipment but still requires further development related to the monitoring and control of the produced ethanol concentration to ensure consistent effectiveness.

Despite KAVi's significant potential, there are gaps in the real-time monitoring of the ethanol concentrations produced, which are critical for disinfection effectiveness (Mohapatra et al., 2021; Steinemann et al., 2021). Previous research has not addressed the need for integrated sensors that can accurately monitor ethanol concentrations in the mist (Gharpure et al., 2020; Pramono & Indasah, 2022). This gap underscores an urgent need for the development of sensor technology that can be integrated with the KAVi system to ensure effective and accurate monitoring.

This study aims to develop a prototype for monitoring concentrated ethanol gas concentrations based on the MQ-3 gas sensor integrated with the KAVi machine, to optimize the use of ethanol in the disinfection process. This innovation offers a

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solution to overcome the shortcomings in current sterilization technology by providing real-time, accurate data on ethanol concentrations, enabling more efficient and effective use. The novelty of this research lies in the development of a sensor integrated with an existing disinfection machine, providing better control over the sterilization process. The scope of this research includes the development and validation of the sensor, as well as the evaluation of its impact on sterilization performance in various clinical and public settings, aiming to reduce health risks and environmental impacts associated with the use of conventional disinfectants. Thus, the use of the MQ-3 gas sensor in this prototype is expected to provide accurate and reliable information about concentrated ethanol gas concentrations, allowing users to control and adjust the sterilization process more efficiently and effectively. The integration of this gas sensor can also enhance understanding of the performance of the KAVi machine in generating concentrated ethanol gas, providing a solid foundation for the development and improvement of sterilization technology in the future.

2. Materials and Methods

This study focuses on the experimental design and fabrication of a sensor for measuring concentrated ethanol vapor concentrations produced by the KAVi machine. The sample used is ethanol gas generated by the KAVi machine. This sensor undergoes an initial calibration phase to regulate the ethanol gas output. By utilizing liquid ethanol inserted into the KAVi, the resulting mist is redistilled, and the concentration obtained during the liquid phase is manually measured. These measurement results are used as calibrators for this experimental measurement. Once the calibration process is completed, the fabricated sensor is reinstalled in the KAVi machine to monitor the ethanol gas concentration in real time. Thus, the development and use of this sensor within the KAVi machine are expected to enhance understanding and control over concentrated ethanol gas concentrations during the sterilization process, which in turn could improve the overall effectiveness and efficiency of the sterilization process.

2.1. Sample Preparation

This study requires various equipment and materials, including the MQ-3 sensor, Arduino Uno microcontroller, 10K resistors, red LEDs, single-layer PCB, male-to-male type USB extend cable, 16x2 character LCD keypad shield, I2C, multimeter, USB to Arduino connecting cable, 20K variable resistor, a computer with a Windows operating system, and liquid ethanol as the test material. These apparatus and materials are necessary for the development, fabrication, and calibration of the concentrated ethanol gas sensor, as well as for testing and real-time monitoring of gas concentration in the KAVi machine. With the appropriate use of these tools and materials, this study is expected to make a significant contribution to the development of sensor technology for better sterilization and environmental safety applications.

2.2. Design Experimental

In designing the sensor system, ethanol gas is detected by the MQ-3 sensor, while the Arduino Uno acts as the microcontroller, and the LCD serves as the output to display information. To test the feasibility of the planned system, a series of tests are conducted. These tests involve two aspects: hardware testing and software testing. Hardware testing consists of test steps on each component before assembly into the main circuit. Once all components are assembled and the device is formed, its functionality in responding to ethanol gas is tested. On the other hand, software testing aims to evaluate the performance of the tool according to the program set on the microcontroller. Before use, the tool is calibrated to ensure the sensor output values correspond to actual values. This testing process is crucial to ensure that the sensor system can function properly and accurately in monitoring the concentration of concentrated ethanol gas and to guarantee reliability and safety in its use in sterilization and environmental cleanliness applications.

3. Results and Discussion

Based on the hardware schematic provided (Figure 1), the prototype for monitoring ethanol concentration at the outlet of the KAVi machine using the MQ-3 sensor has been successfully developed. The hardware utilized in this prototype includes the KAVi machine for creating ethanol mist, the MQ-3 sensor for detecting ethanol concentration in the air, a power supply, an Atmega328 microcontroller (part of the Arduino Uno), and an LCD for real-time data display. The software used is the Arduino IDE, which is the standard development environment for programming Arduino microcontrollers. The MQ-3 sensor, known for its ability to detect alcohol and alcohol-based compounds in the air, is a key component in this system. The analog signal from the MQ-3 sensor is converted into digital data by the Analog-to-Digital Converter (ADC) on the microcontroller. This data is then processed by the microcontroller and displayed on the LCD, allowing for direct and real-time monitoring of ethanol gas concentration, and providing critical information for evaluating the effectiveness of the sterilization process.

3.1. Ethanol Vapor Testing in the KAVi Chamber

In the KAVi machine, liquid ethanol is filled to specific concentrations, ranging from 10% to 70%. Each concentration of liquid ethanol is then converted into a gas phase by the machine. The conversion of liquid ethanol to gas in the KAVi machine utilizes an ultrasonic membrane. This ultrasonic membrane has a vibration frequency of 1.6 MHz, meaning this component vibrates approximately 1.6 million times per second. The liquid ethanol quickly changes into a gas phase with particle sizes around 1 micron. The ethanol vapor produced by the KAVi machine does not significantly alter the concentration of the sample compared to its liquid phase. This is evidenced by remeasuring the distilled ethanol gas in the liquid phase. The concentration of the produced ethanol gas closely matches the concentration of liquid ethanol injected into the KAVi tube. The difference between the liquid ethanol concentration and the gas product concentration is very minimal. In gas form, the ethanol concentration decreases by about 1%-2% (Figure 2). Subsequently, the ethanol gas produced by the KAVi machine is used to calibrate the MQ-3 gas sensor measurements. Thus, the results from the conversion process of liquid ethanol to gas by the KAVi machine provide accurate and appropriate outcomes, supporting the accuracy of the MQ-3 gas sensor measurements in monitoring ethanol concentration. There were 13 experiments, and the results suggest that this method might be efficient for achieving even distribution when used in disinfection applications. Indeed, the results show that the conversion of ethanol to gas by the KAVi is consistent and reliable, crucial for subsequent applications in calibrating the MQ-3 gas sensor.

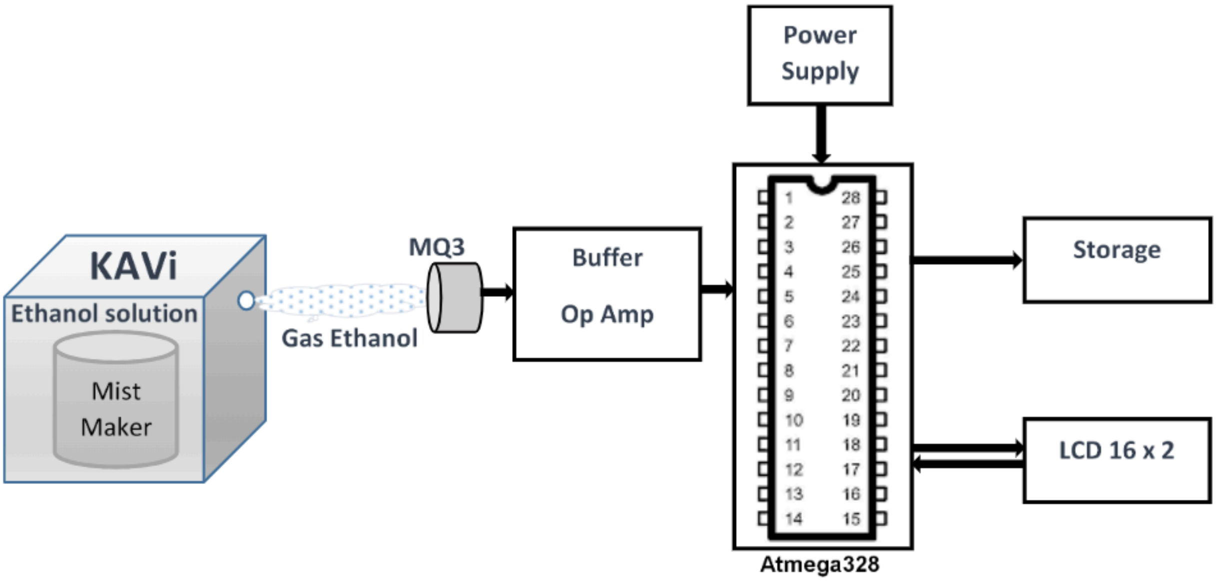

Figure 1 Hardware Diagram.

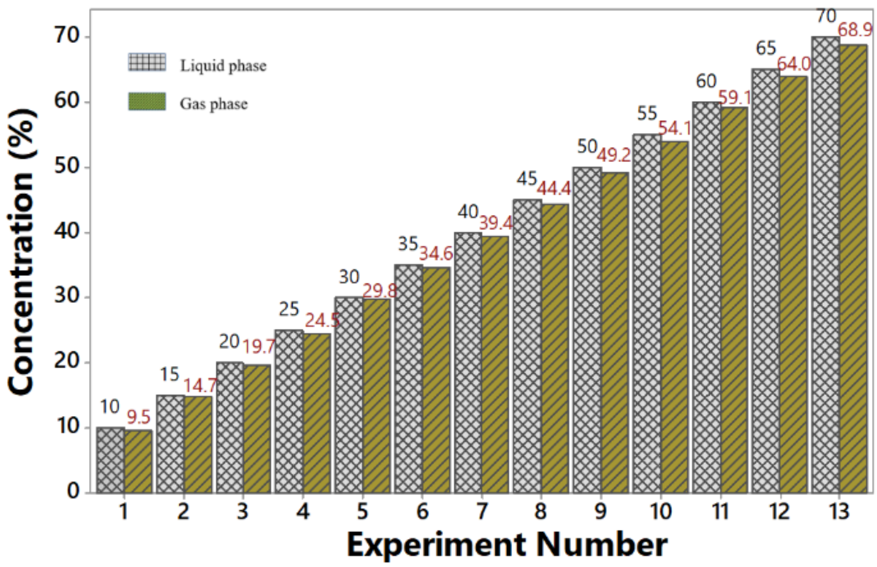

Figure 2 Results of the ethanol gas concentration test on the KAVi engine.

3.2. MQ-3 Sensor Testing for Calibration

Testing the MQ-3 sensor is a crucial step in evaluating the prototype that monitors ethanol concentration in the KAVi machine, aiming to determine if the instrument can accurately detect ethanol gas. The operating principle of the MQ-3 sensor is based on the change in resistance of the sensing element when exposed to ethanol gas. As the sensor encounters ethanol gas, the resistance of the sensing element significantly decreases. The magnitude of this resistance change correlates directly with the amount of ethanol detected by the sensor. The higher the ethanol gas concentration, the greater the change in resistance. Subsequently, the change in resistance in the sensing element is converted into an electrical signal that can be measured. This signal takes the form of a voltage that changes along with the resistance. The microcontroller then analyzes this signal to determine the ethanol gas concentration in the air. Thus, testing the MQ-3 sensor becomes a crucial step in validating the accuracy and performance of the sensor in monitoring ethanol gas concentration in the KAVi machine environment.

Pre-calibration checks are used to spontaneously read the liquid ethanol test material vaporized by the KAVi machine. Subsequently, the MQ-3 sensor is connected to the Arduino Uno microcontroller using a 10-bit resolution ADC. The output produced by the Arduino Uno's ADC microcontroller is as follows:

$$\text{Output ADC} = V\_in/V\_ref \ x1024 \quad (1)$$

Where Vin is the voltage output of the sensor and V ref is the reference voltage.

Based on the ethanol measurements, ADC data as listed in Table 1 were obtained. These measurements were conducted by maintaining the sensor distance to the KAVi machine output port at approximately 5 cm, and data were collected in a steady state at t = 30 seconds. The data obtained through these measurements are crucial for evaluating the sensor's response to ethanol concentrations and determining the sensor's performance under various operational conditions.

The measurement of ethanol gas concentration produced by the KAVi machine is expressed in the form of ADC voltage, as listed in Table 1. The ethanol gas concentration column, as indicated by the measurements in previous research, serves as the dependent variable. Conversely, the ADC output column becomes the independent variable. Subsequently, the regression value of the measurements can be determined, as shown in Figure 3. This regression equation serves as a calibrator in the Arduino IDE program. This process is necessary to convert the instrument's output from mVolt to ethanol concentration units (%), or ppm, approximating the actual concentration. Thus, using the regression equation as a calibrator allows the precise conversion of ADC voltage values to more accurate and appropriate ethanol gas concentrations.

Figure 3 presents a regression plot that illustrates the relationship between the MQ-3 sensor output (in millivolts) and ethanol concentration (in percentage). The displayed regression equation, y=0.3206x−60.935, with a coefficient of determination (R^2) of 0.9732, indicates a very strong correlation between the dependent and independent variables. This shows that the sensor output (millivolts) can be used to predict ethanol concentration with a high level of confidence. These results strengthen the argument that the MQ-3 sensor can be relied upon to detect ethanol concentrations in the air, which has been vaporized by the KAVi machine. According to the operating principles of the MQ-3 sensor, the change in resistance due to interaction with ethanol gas is converted into a measurable electrical signal. Testing this sensor is crucial to ensure that ethanol readings vaporized by the KAVi machine can be accurately measured, thereby supporting the effectiveness of disinfection applications.

Table 1 Testing of the MQ-3 data logger sensor against ethanol gas concentration.

Ethanol Gas Concentration (%)	ADC Output (mVolt)	Sensor Distance (cm)
10	216	5
20	258	5
30	274	5
40	333	5
50	355	5
60	371	5
70	397	5

3.3. MQ-3 Sensor Testing for Validation

Instrument testing was performed in a physical equipment laboratory under ideal conditions, where the KAVi machine was loaded with liquid ethanol at various concentrations, as recorded in Table 2. To ensure optimal precision, the experiment was repeated five times. This approach allows for the collection of consistent data and minimizes the possibility of experimental errors that could affect the measurement results.

Figure 4 displays a graph illustrating the average ethanol concentration measurements with various standard deviations across five repetitions. The measured data indicate ethanol concentrations from the KAVi machine and show relatively consistent variation with increasing concentration. The smallest deviation was recorded at a concentration of 19.76% with a value of 0.24%, while the largest deviation was noted at a concentration of 59.1% with a value of 1.26%. The average standard deviation from all measurements is 0.348%, indicating a high level of precision in the measurements. The relatively small deviations demonstrate that the measurement process is reliable and reproducible, an important indicator in scientific testing which demands accuracy and consistency. This precision is crucial when evaluating the effectiveness of disinfection, where the correct ethanol concentration is necessary to achieve effective sterilization without excess which could lead to wastage or additional negative impacts.

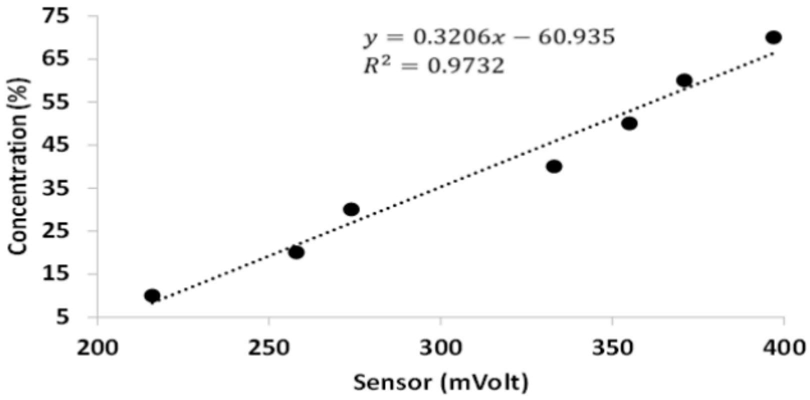

Figure 3 Calibration data regression results.

Table 2 Sensor Validation Measurements Post-Calibration.

Ethanol Gas (%)	Measurement (%)					Average	Delta
	1	2	3	4	5		
9.5	9.1	9.4	9.8	9.9	9.6	9.56	-0.06
19.7	19.6	19.8	19.9	20	19.5	19.76	-0.06
29.8	28.7	28.9	29.1	29.5	29.7	29.18	0.62
39.5	38.7	38.5	39.2	39.6	39	39	0.5
49.2	48.4	48.8	49.2	49.5	49.9	49.16	0.04
59.1	58.8	58.7	58.7	58.9	58.6	58.74	0.36
68.9	68.5	68.8	69.5	69.6	69.8	69.24	-0.34
						STDEV	0.348

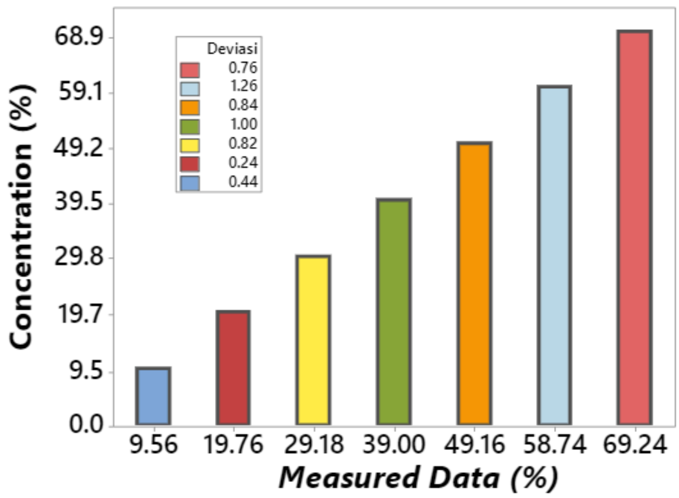

Figure 4 Graph of average measurements and deviations over five repetitions.

3.4. Discussion

The development and implementation of this prototype address the need for stricter control over the use of ethanol in sterilization processes, in line with recommendations for safe disinfection practices as highlighted by Gharpure et al. (2020). The integration of the MQ-3 sensor, recognized for its accuracy in detecting ethanol, ensures that the ethanol concentration remains within safe yet effective limits (Berry et al., 2022; Blanco et al., 2021; Zhao et al., 2021). This approach reflects a balance between disinfection efficacy and minimizing related risks, a focus emphasized in the literature on COVID-19 (Bhat et al., 2021).

In this study, a standard deviation of 0.348% indicates that the measurements taken have low variability. This means that the results from the MQ-3 sensor are consistently reliable when used to detect ethanol concentrations under the same conditions. From a precision standpoint, this sensor demonstrates the ability to produce consistent measurements across different trials, as evidenced by the small standard deviation. A standard deviation of 0.348% suggests that the MQ-3 sensor has high precision, meaning it can be trusted to deliver stable and accurate measurements. The small standard deviation also contributes to the validity of the measurements, indicating that the results are close to the true value of the ethanol concentration.

This accuracy is crucial because it ensures that the measurements not only are consistent but also truly reflect the actual ethanol concentration being measured. If a particular application requires ethanol concentration measurements with a tolerance of ±1%, then a standard deviation of 0.348% falls within this tolerance range, indicating that the MQ-3 sensor meets the required precision criteria. In industrial or research settings, measurements with a small standard deviation allow for more confident decision-making regarding ethanol concentrations. The high reliability of the sensor reduces the risk of errors in processes sensitive to ethanol levels, such as in fermentation, fuel quality control, or medical applications.

The importance of monitoring devices such as the MQ-3 sensor in ethanol gas monitoring is well supported in the literature. Compared to other studies that note the widespread and uncontrolled use of disinfectants (Wang et al., 2020), this prototype offers a method to ensure the correct concentration of disinfectants, minimizing environmental damage and health risks associated with such practices (Dang et al., 2023; Liu et al., 2022). The findings from this study have significant implications for disinfection practices during the COVID-19 pandemic. The ability to monitor ethanol concentration in real time allows for more precise usage and reduces the potential environmental impact and health risks posed by disinfectants (Guo et al., 2021; Jumlongkul, 2021; Wood et al., 2021). Additionally, this underscores the importance of sensor-fusion technology, as suggested by Pandya et al. (2020), in implementing smart technology to combat the spread of viruses. This balance supports a broader understanding of health crisis management as described by Zhang et al. (2020) and Mercier et al. (2023), emphasizing the need for an informed and responsible response to global health challenges.

Sterilization technology plays a crucial role across various industries, ensuring the safety and quality of products and environments by eliminating harmful microorganisms. Technologies such as mist technology, UV irradiation, plasma activation, and gamma irradiation provide efficient and effective means for sterilizing bacteria and viruses (Zhou et al., 2022; Yan et al., 2021; Al-Adhami et al., 2007; Feng et al., 2011; Han et al., 2016). Ethanol, particularly in concentrations of 60% to 70%, has been identified as a highly effective agent for antimicrobial efficacy, often used in healthcare and research for sterilizing bioactive materials and complex surfaces (Kampf & Krämer, 2004; Huebsch et al., 2005; Kummer et al., 2013; Siritientong et al., 2011).

4. Conclusions

The study results demonstrate that the MQ-3 sensor exhibits optimal sensitivity to ethanol gas and shows a linear response, as expected. The range of ethanol gas concentrations used in the testing, 10% to 70%, was chosen to match the capabilities of the KAVi machine in producing ethanol gas. The testing process of the sensor was conducted to generate data that were then calibrated to ensure measurement accuracy. Validation results indicate that the MQ-3 sensor can measure ethanol gas concentrations with high accuracy and good linearity within this range. However, it is important to note that the KAVi machine has limitations in producing ethanol gas concentrations above 70%, which should be considered in the practical application of this device. Overall, this device shows great potential in applications for monitoring ethanol gas concentrations, with a note to consider limitations on the ethanol gas production process from the KAVi machine for more optimal results.

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Ethical considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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