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The effect of cool-mist humidifier on concentration of air pollutants and indoor environmental conditions

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ABSTRACT

Introduction: Indoor air pollution poses significant health risks, given the substantial time individuals spend indoors. Cool-mist humidifiers have been proposed as a potential intervention for enhancing indoor air quality by influencing pollutant concentrations. This study investigates the effects of gas dissolution in vapor particles generated by a cool-mist humidifier on indoor air pollutants.
Materials and methods: A controlled laboratory experiment was conducted within a 1 m^3 insulated plastic chamber to monitor key parameters, including Carbon monoxide (CO), Carbon dioxide (CO_2), Oxygen (O_2), Total Volatile Organic Compounds (TVOCs), temperature, and Relative Humidity (RH). Pollutants were introduced using a lit candle and formaldehyde, and air quality was measured using a digital gas analyzer (CEM GD-3803) and a TVOC analyzer (QB2000N/T). Baseline pollutant levels without humidification were compared to levels observed with a cool-mist humidifier operating at various humidification rates (110–370 mL/h) over an 8-h period.
Results: The results indicated consistent reductions in CO_2 and TVOC concentrations across all tested humidification rates, accompanied by increases in temperature and relative humidity. CO concentrations exhibited more variable behavior, with alternating increases and decreases over the testing periods.
Conclusion: These findings underscore the potential of cool-mist humidifiers as an effective strategy for reducing indoor air pollutants, particularly CO_2 and TVOCs. This has meaningful implications for enhancing indoor air quality and protecting public health.

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Introduction

With the industrialization of more and more cities, concerns about the impact of pollution on people's health have increased. Air pollution is consistently associated with disease and health in developed and developing countries [1]. In addition to the adverse effects of environmental pollution on the development process of countries, it can affect other quantitative and qualitative aspects of human life and life expectancy as an essential component of the human development index [2]. One of the most important types of air pollution is environmental indoor air pollution. Indoor pollutants are more widespread and diverse, and sources of air pollution in indoor environments (including gaseous and particulate pollutants) are among the most critical factors in reducing indoor air quality [3]. In indoor environments, air pollution increases due to the smaller area [4, 5]. According to studies, indoor air pollution is more important since people spend more time in closed places such as residential areas and workplaces. The lack of air movement and less air coming in from the outside has caused the concentration of pollutants in the indoor environment, which is the most crucial cause of indoor pollution. The humidity and high temperature also affect the concentration of pollutants and the increase of pollution [5].

Poor indoor air quality can cause asthma, headache, dry eyes, stuffy nose, nausea, and fatigue. According to Environmental Protection Agency (EPA) studies, the possibility of contracting a tumor by breathing in the chemicals in household cleaners is three times higher than outside air. According to the American college of allergy, half of the diseases are caused by indoor air pollution. Common indoor air pollutants include carbon dioxide, nitrogen dioxide, formaldehyde, carbon monoxide, and suspended particles. One of the major pollutants in the air of homes is formaldehyde. One of the most influential factors in cancer is formaldehyde, and the amount of Volatile Organic Compounds (VOC) in closed environments is 2 to 5 times more than in open environments [6].

Among other factors of indoor air quality and comfort is air humidity. After temperature, providing Relative Humidity (RH) inside closed spaces is one of the most critical factors of comfort conditions. Humans cannot understand changes in relative humidity due to the lack of humidity sensory receptors. Studies have shown that 40% relative humidity is better for the eyes and upper respiratory tract than less than 30% relative humidity. ASHRAE recommends a relative humidity standard of 30%-60%. Considering the ability of air pollutants to dissolve in water, especially in small concentrations that can generally be present in indoor air, the dissolution of air pollutants in vapor particles increases and leads to a change in the concentration of pollutants [7, 8]. This phenomenon is applied as the scrubbers in the air pollution control issues to elimination of various pollutants [9, 10].

Nowadays, the use of fumigators in closed environments has spread. The fumigator is divided into two types: cold and hot. One of the differences between hot and cold incense is the time, method, and duration of use. The cold vaporizer itself is divided into two types: evaporative and ultrasonic. The mode of operation of the evaporative type is that cold water is directed into a filter with the help of a fan, and then cold steam is obtained in the space of a room. The filter in this device was a wick; in its ultrasonic type, ultrasonic vibration evaporates water. A diaphragm in this device vibrates at a high speed and turns water into cold steam [11].

Due to the presence of various pollutants in indoor air and their impact on human health, any reduction in these pollutants can affect the quality of life and human health, also considering the expansion of use of the cold vapor humidifiers in indoor environments to increase the relative humidity of the air, the aim of this study was to determine effect of the devices on concentration of pollutants in indoor environments.

Materials and methods

Experimental setup

The experiments were conducted in a controlled laboratory setting using a wooden skeleton, covered and insulated with thick nylon sheet chamber, in a volume of 1 m^3 (length, width and height equal to 1 m). The chamber was equipped with a long enough glove attached to the wall to reach inside the chamber, an isolated openable window, two ducts for air inlet and outlet, one in the down close to corner and other one on the opposite side, in the opposite direction and up. The airflow was supported with a dry air pump and controlled with a needle valve equipped flowmeter. The chamber was specifically designed to enable precise measurements of multiple environmental parameters, including Carbon monoxide (CO), Carbon dioxide (CO_2), Oxygen (O_2), Total Volatile Organic Compounds (TVOCs), temperature, and Relative Humidity (RH%).

Pollutant generation and measurement devices

Pollutants were generated using a fixed source: a lit candle and a 50 mL beaker containing 20 mL of formaldehyde (Mojallali, Iran). The candle is a general CO, CO_2, and VOCs source which modeled as combustion pollution source and formaldehyde is a general indoor VOC which is insoluble in water and can represents the VOCs. Measurements were taken using a digital gas analyzer (CEM GD-3803) with comprehensive measurement capabilities: CO (0-1000 ppm), CO_2 (0-9999 ppm), O_2 (0-30% VOL), temperature (-20-70°C), and RH (0-100%). The analyzer demonstrated high measurement precision with accuracies of ±5% or ±10 ppm for CO, ±5% or ±75 ppm for CO_2, ±0.1% for O_2, ±1°C for temperature, and ±3.5% for RH. Additionally, a TVOC analyzer (QB2000N/T) with a measurement limit of 1 ppm and ±5% full-scale accuracy was employed to provide complementary air quality data. The sets were pre calibrated before the experiments and checked and zero calibrated prior to the experiments.

Procedure

The experimental protocol consisted of two distinct phases. The initial phase established baseline conditions by monitoring air quality parameters over an 8-h period with fixed least humidification rate and various air flow rates. During this control phase, hourly measurements of CO, CO_2, O_2, TVOCs, temperature, and RH were recorded from the pollutants generated by the candle and formaldehyde sources. The second phase introduced a cool-mist humidifier into the chamber to evaluate its impact on air quality across various humidification rates and a fixed air flow rate. Measurements were conducted at five discrete humidification rates: 110, 150, 190, 350, and 370 mL/h. At each rate, comprehensive air quality measurements were performed and compared against the baseline values.

Statistical analysis

The results were processed and analyzed in Microsoft excel vr. 2019 and descriptive statistical analyses were performed on the collected data and regression to fit the curves on the issued results. To comparative criteria were established to evaluate quantitative changes in pollutant concentrations and overall air quality parameters between non-humidified and humidified conditions.

Results and discussion

Effect of airflows rate on the concentration of the pollutants

The experimental results demonstrated significant changes in multiple air quality parameters across different airflow rates over the 8-h testing period and constant humidification rate of 110 mL/h. The most notable improvements were observed in CO_2, CO, and TVOC concentrations, while temperature and relative humidity showed more modest variations.

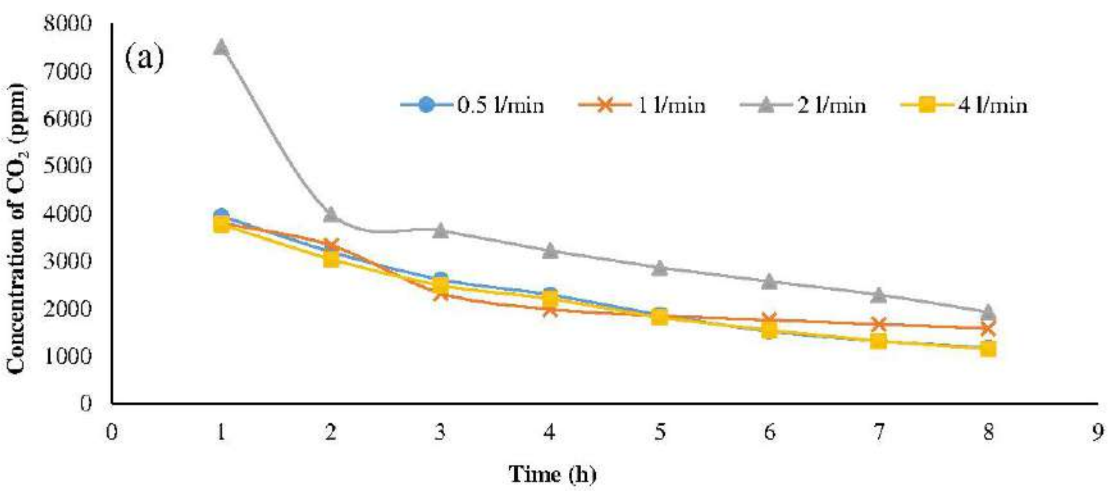
Carbon dioxide concentrations exhibited

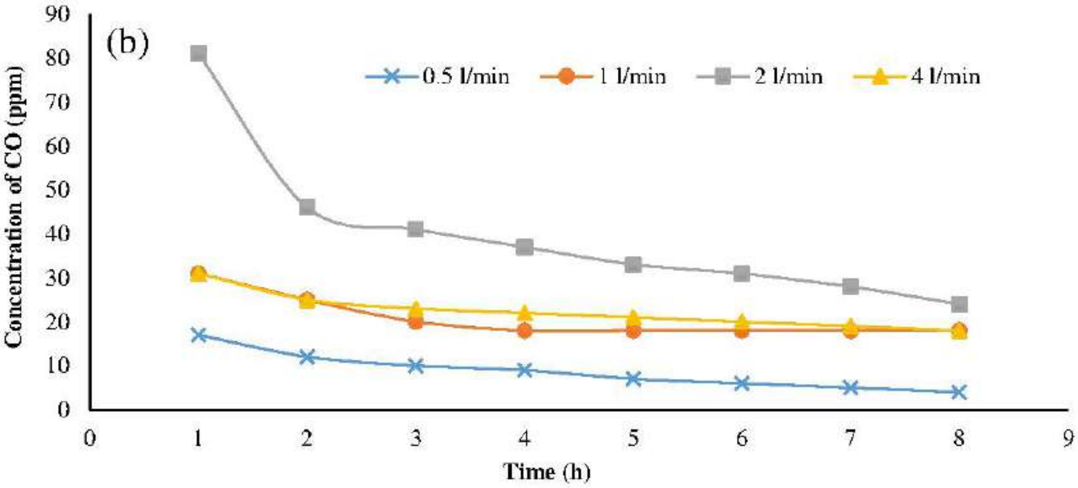
consistent reduction patterns across all tested airflow rates (0.5, 1, 2, and 4 L/min). Initial CO_2 levels of 3947, 3804, 7520, and 3773 ppm decreased to 1117, 1584, 1925, and 1150 ppm, respectively. The highest airflow rate of 4 L/min demonstrated the most efficient CO_2 removal from the chamber, suggesting a positive correlation between airflow rate and pollutant reduction efficiency (Fig. 1a). The observed reduction in CO_2 concentrations across all tested airflow rates is consistent with previous studies that have shown a direct correlation between increased ventilation and decreased CO_2 levels [12, 13]. The most efficient CO_2 removal at the highest airflow rate of 4 L/min supports the principle that higher air exchange rates lead to improved dilution and removal of indoor pollutants [14].

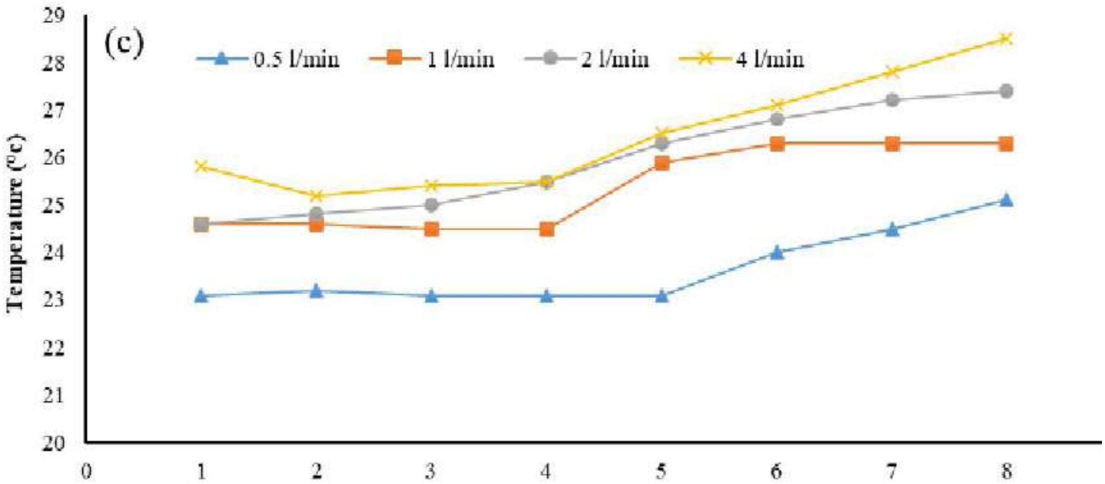
Carbon monoxide levels followed a similar declining trend, with initial concentrations of 17, 31, 81, and 31 ppm (at 0.5, 1, 2, and 4 L/min, respectively) decreasing to final values of 4, 18, 24, and 18 ppm. The most substantial CO reduction occurred during the first two hours, characterized by sharp drops across all flow rates. Subsequently, the reduction rate diminished, with CO levels stabilizing at 18 ppm during the final five hours at 1 L/min airflow (Fig. 1b). The declining trend in carbon monoxide levels, particularly the sharp drops during the first two hours, is in line with research on the effectiveness of ventilation in removing gaseous pollutants [15].

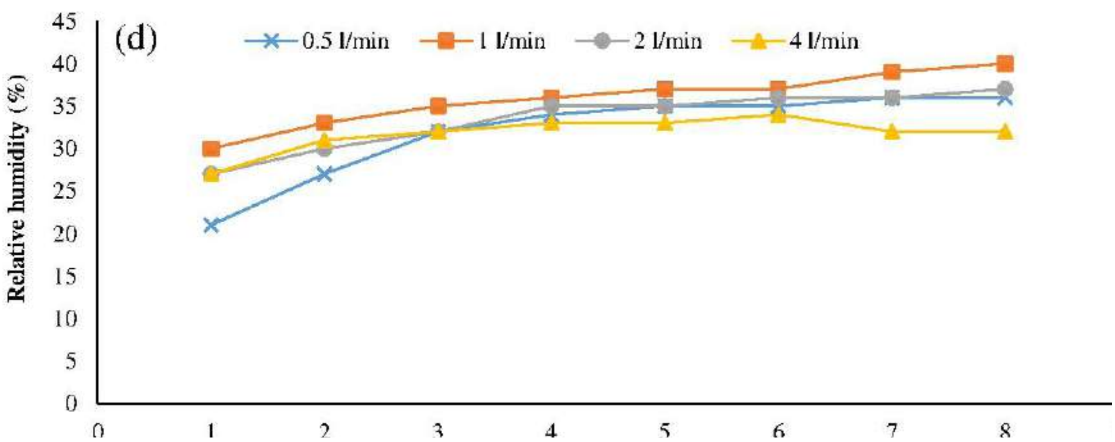
Environmental parameters showed more subtle variations throughout the experiment. Temperature demonstrated a gradual increase across all flow rates, rising from initial values of 23.1°C, 21.5°C, 21.8°C, and 21.5°C to final values of 25.1°C, 23.1°C, 22.9°C, and 23.1°C at 0.5, 1, 2, and 4 L/min, respectively. Lower flow rates exhibited more pronounced temperature increases, likely due to reduced heat dissipation (Fig. 1c). Relative humidity also showed an increasing trend, with initial levels of 21%, 30%, 27%, and 27% rising to 36%, 40%, 37%, and 32% across the respective flow rates. The highest flow rate (4 L/min) demonstrated the smallest RH increase, suggesting enhanced water vapor management at higher airflow rates (Fig. 1d).

TVOC concentrations showed remarkable reductions across all flow rates. Initial concentrations of 814, 463, 470, and 296 ppm (at 0.5, 1, 2, and 4 L/min) decreased to 0, 53, 0, and 0 ppm, respectively. This substantial reduction in TVOCs indicates the effectiveness of increased airflow and water vapor introduction in mitigating volatile organic compounds (Fig. 1e). The remarkable reductions in TVOC concentrations across all flow rates highlight the effectiveness of increased airflow and water vapor introduction in mitigating volatile organic compounds. This finding aligns with research on the impact of ventilation strategies on indoor air quality and the removal of VOCs [14, 16].




(b)
0.5 l/min
1 l/min
2 l/min
4 l/min
Concentration of CO (ppm)
Time (h)
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9


(c)
0.5 l/min
1 l/min
2 l/min
4 l/min
Temperature (°c)
29
28
27
26
25
24
23
22
21
20
0
1
2
3
4
5
6
7
8


(d)
0.5 l/min
1 l/min
2 l/min
4 l/min
Relative humidity (%)
45
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8

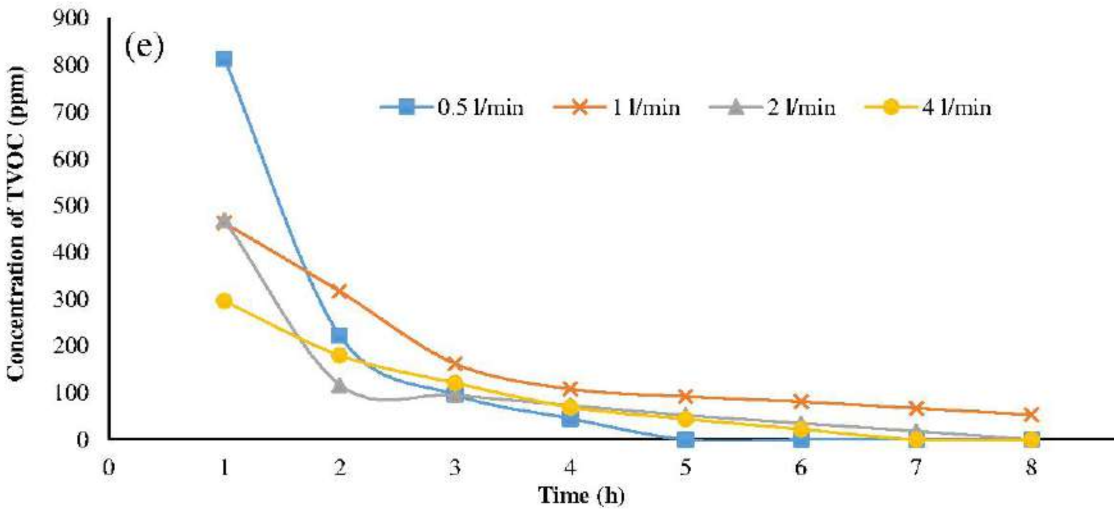


Fig. 1. Line plot of environmental variables based on vaporization rate of 110 mL/h and different airflows (a: CO_2 concentration changes; b: CO concentration changes; c: temperature changes; d: RH changes; e: TVOC concentration changes)

Effect of vaporization rate on the concentration of the pollutants

The experiments in this step were conducted in the various vaporization rates and a constant air flow rate (1 L/min) to the chamber. The results are presented for each water vaporization rate (cold vapor generation rate) as fallowing.

Concentration of the pollutants at the vaporization rate of 110 mL/h

The experimental findings demonstrate significant alignment with existing literature in the field of indoor air quality management. The results corroborate a research, which established that ventilation alone has limited effectiveness in controlling semi-volatile organic compound concentrations, as these are predominantly influenced by temperature fluctuations and surface absorption dynamics [17]. This understanding reinforces the complex relationship between temperature variation and pollutant concentration modifications. Furthermore, previous studies have highlighted the efficacy of balanced mechanical ventilation systems in reducing Particulate Matter (PM) concentrations, particularly in educational environments, presenting a viable approach for indoor air quality enhancement [17, 18].

Our experimental data revealed consistent trends in pollutant reduction over the 8-h testing period. Carbon dioxide concentrations showed a marked decrease from 4540 ppm to 3265 ppm (Fig. 2a). Concurrent significant reductions were observed in both TVOC and CO concentrations, with TVOC levels declining substantially from 441 ppm to 82 ppm, while CO concentrations exhibited a modest decrease from 24 ppm to 20 ppm (Fig. 2b). These reductions demonstrate the system's effectiveness in pollutant removal under controlled conditions.

Environmental parameters displayed subtle variations throughout the experimental period. Temperature measurements indicated a gradual increase from 21.5°C to 23.1°C over the eight-hour duration. Relative Humidity (RH) demonstrated initial stability, rising marginally from 64% to 65% during the first two hours and maintaining 65% through the fourth hour, before slightly decreasing to 62% in the final four hours (Fig. 2c).

The results revealed that variations in temperature, RH, and CO concentration were minimal and did not reach significance. While the studies emphasize the role of ventilation in pollutant control, they also highlight the limitations and complexities involved. Factors such as temperature, humidity, and system design play crucial roles in the effectiveness of ventilation strategies. Therefore, a holistic approach that considers these variables alongside airflow and vaporization rates is essential for optimizing pollutant reduction in various environments [19-21].

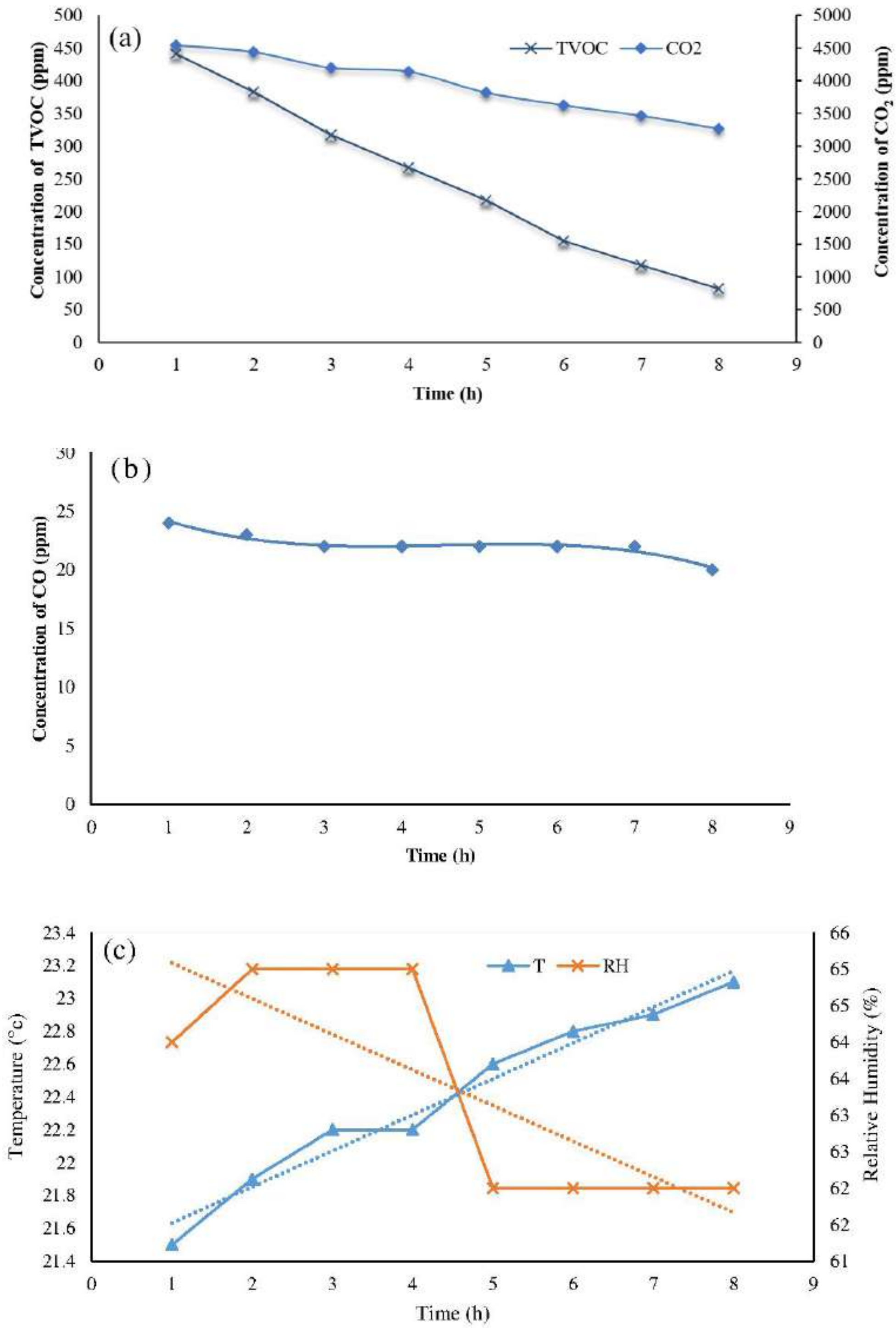


Fig. 2. Line plot of environmental variables based on vaporization rate of 110 mL/h and airflow rate of 1 L/min (a: CO_2 and TVOC concentration changes; b: CO concentration changes; c: temperature and RH changes)

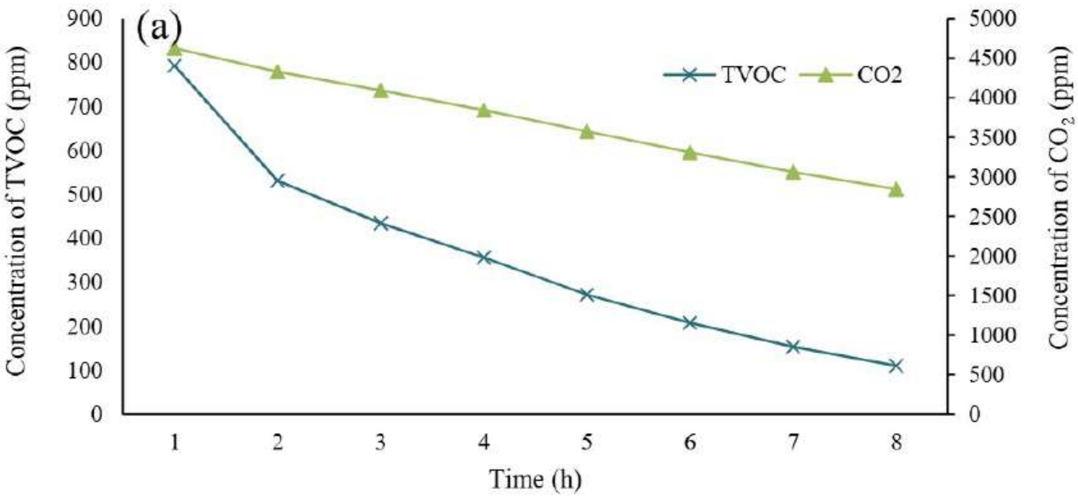
Concentration of the pollutants at the vaporization rate of 150 mL/h

The experimental trials demonstrated notable trends in air quality parameters over the 8-h testing period. Carbon dioxide concentrations exhibited a consistent and significant decline, decreasing from an initial concentration of 4626 ppm to 2843 ppm by the experiment's conclusion (Fig. 3a). Total Volatile Organic Compounds (TVOCs) showed a distinctive two-phase reduction pattern: an initial sharp decline from 793 ppm to 531 ppm during the first two hours, followed by a more gradual but steady decrease from 434 ppm in the third hour to 110 ppm by the experiment's end (Fig. 3a).

Carbon monoxide dynamics presented a unique temporal pattern characterized by an initial stability phase followed by gradual reduction. CO concentrations maintained a constant level of 29 ppm during the first three hours of experimentation, after which a gradual decline was observed, ultimately reaching 25 ppm in the final hour (Fig. 3b). This delayed response pattern suggests potential underlying mechanisms in CO removal dynamics under the experimental conditions.

Environmental parameters demonstrated modest variations throughout the testing period. Relative humidity exhibited initial elevation from 61% to 66% during the first two hours, followed by minor fluctuations between 62% and 66% for the remainder of the experiment. Temperature measurements revealed a gradual increasing trend from 21.8°C to 23.2°C through the seventh hour, with a slight decrease to 22.9°C in the final hour (Fig. 3c). The narrow range of these environmental parameter fluctuations validates the stability and reliability of the experimental setup.

These environmental conditions are important to consider, as they can influence the behavior of airborne pollutants. For instance, higher temperatures can increase the volatilization of certain compounds, while changes in humidity can affect the adsorption and desorption of pollutants on surfaces [22].



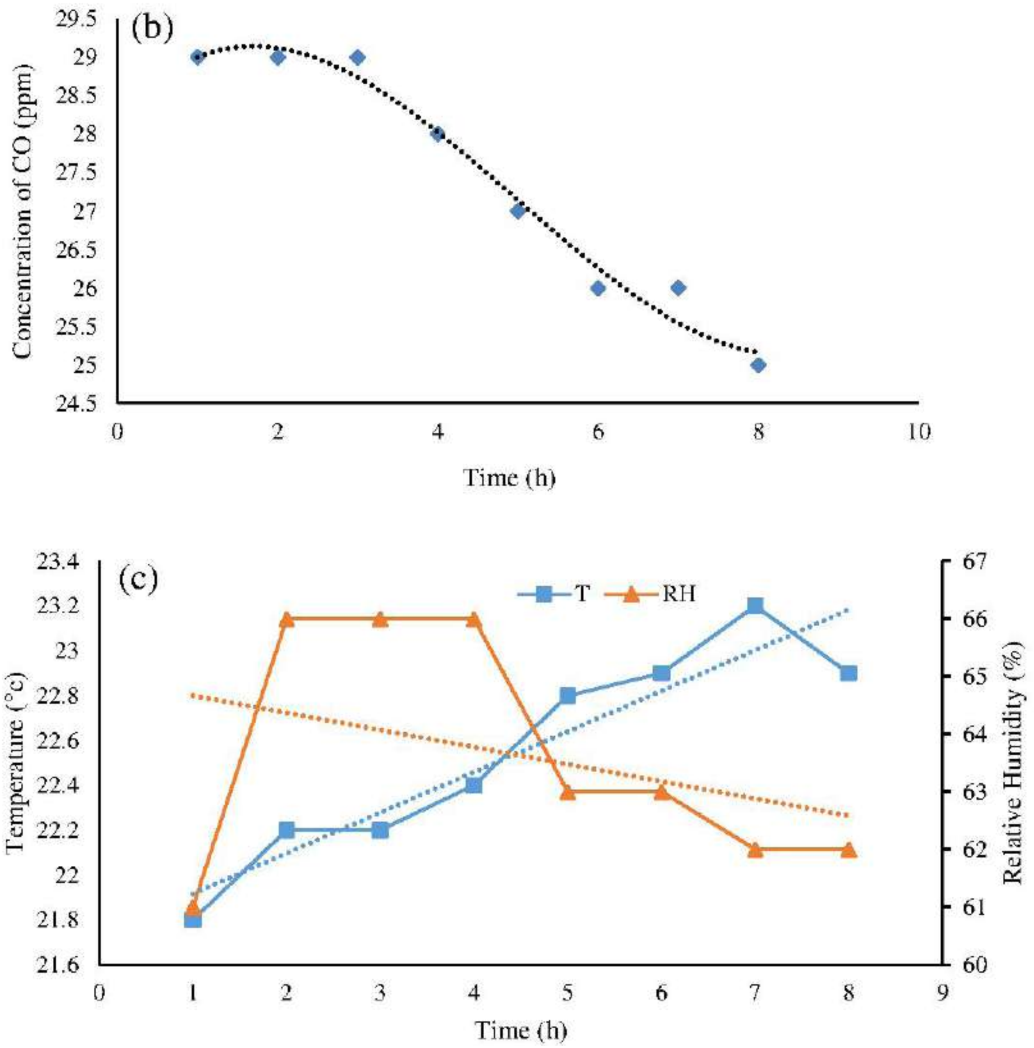


Fig. 3. Line plot of environmental variables based on vaporization rate of 150 mL/h and airflow rate of 1 L/min (a: CO_2 and TVOC concentration changes; b: CO concentration changes; c: temperature and RH changes)

Concentration of the pollutants at the vaporization rate of 190 mL/h

The short-duration trial revealed distinct patterns in pollutant reduction and environmental parameters over a 2-h period. Carbon dioxide concentrations demonstrated a notable decrease from 6020 ppm to 5443 ppm within the first two hours of experimentation (Fig. 4a). Experimental results show that CO_2 removal rates can vary significantly based on humidity levels, affecting overall pollutant capture efficiency [23].

Concurrent with this CO_2 reduction, TVOC levels exhibited a substantial decline from 435 ppm to 219 ppm during the same interval, suggesting effective pollutant removal through water vapor introduction.

Carbon monoxide concentrations displayed more complex dynamics, characterized by alternating increases and decreases throughout the testing period (Fig. 4b). This variability in CO levels indicates potential complexities in the interaction between water vapor and CO removal mechanisms under the experimental conditions. It can be said that the low solubility of CO in water can meaningfully limit the effect of the cold vapor on its concentration reduction trough the solution [24].

Environmental parameters showed gradual but consistent changes during the trial period. Relative humidity demonstrated a steady increase from an initial value of 59% to 65% by the second hour, indicating progressive moisture accumulation within the experimental chamber. Temperature measurements revealed a modest upward trend, rising from 21.7°C to 22.2°C over the 2 h duration (Fig. 4c). The limited range of these environmental fluctuations suggests stable experimental conditions.

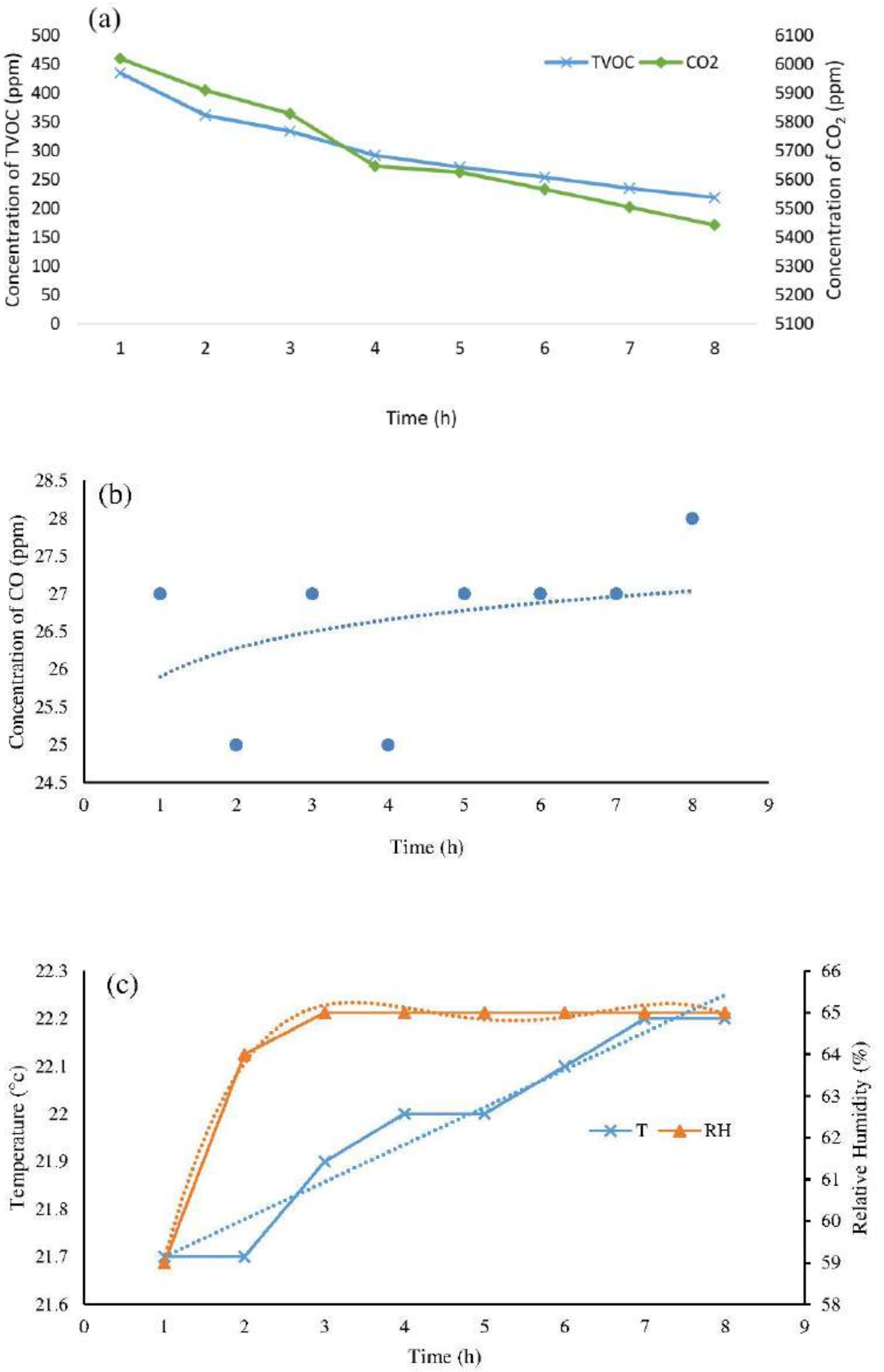


Fig. 4. Line plot of environmental variables based on vaporization rate of 190 mL/h and airflow rate of 1 L/min (a: CO_2 and TVOC concentration changes; b: CO concentration changes; c: temperature and RH changes)

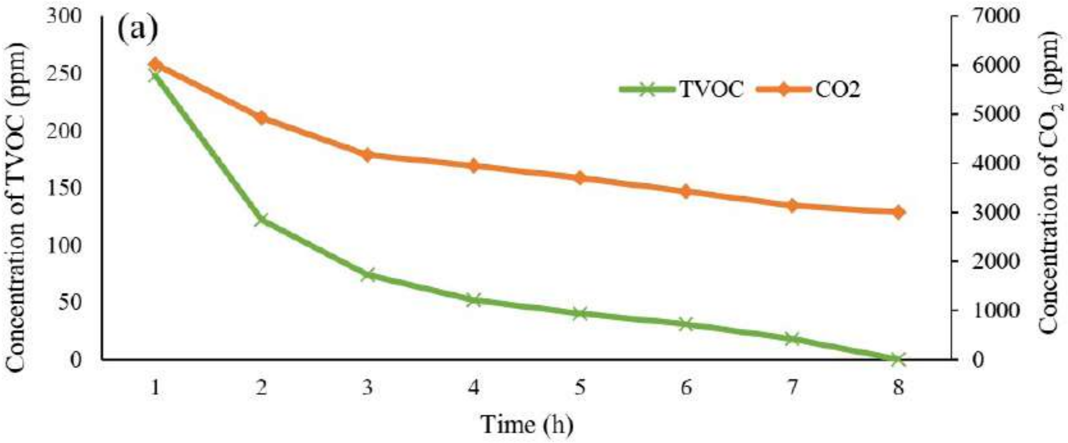
Concentration of the pollutants at the vaporization rate of 350 mL/h

Analysis of the experimental data at a vaporization rate of 350 mL/h revealed substantial improvements in air quality parameters over the 8-h testing period. Carbon dioxide concentrations exhibited a marked reduction from 6017 ppm to 3000 ppm (Fig. 5a), representing a 50.1% decrease in ambient CO_2 levels. Total volatile organic compounds demonstrated exceptional removal efficiency, with concentrations declining from an initial 248 ppm to undetectable levels by the experiment's conclusion, indicating complete TVOC elimination under these conditions.

Carbon monoxide levels showed consistent reduction throughout the experimental period, decreasing from 26 ppm to 18 ppm (Fig. 5b). This 30.8% reduction in CO concentration suggests effective removal of this pollutant, albeit at a more moderate rate compared to CO_2 and TVOCs.

Environmental parameters maintained relatively stable conditions throughout the trial. Relative humidity demonstrated a biphasic pattern: an initial increase from 62% to 65% during the first six hours, followed by a slight decrease and stabilization at 64% for the final two hours (Fig. 5c). Temperature measurements showed a gradual increase from 20.4°C to 22.2°C over the 8-h period, representing a modest 1.8°C rise that remained within acceptable experimental parameters.

The comprehensive results at 350 mL/h vaporization rate demonstrate significant pollutant removal efficiency, particularly for CO_2 and TVOCs. The complete elimination of TVOCs and substantial reduction in CO_2 concentrations suggest optimal conditions for air quality improvement. The moderate changes in environmental parameters, coupled with the steady decrease in CO levels, indicate that the experimental conditions maintained stability while effectively reducing target pollutants.



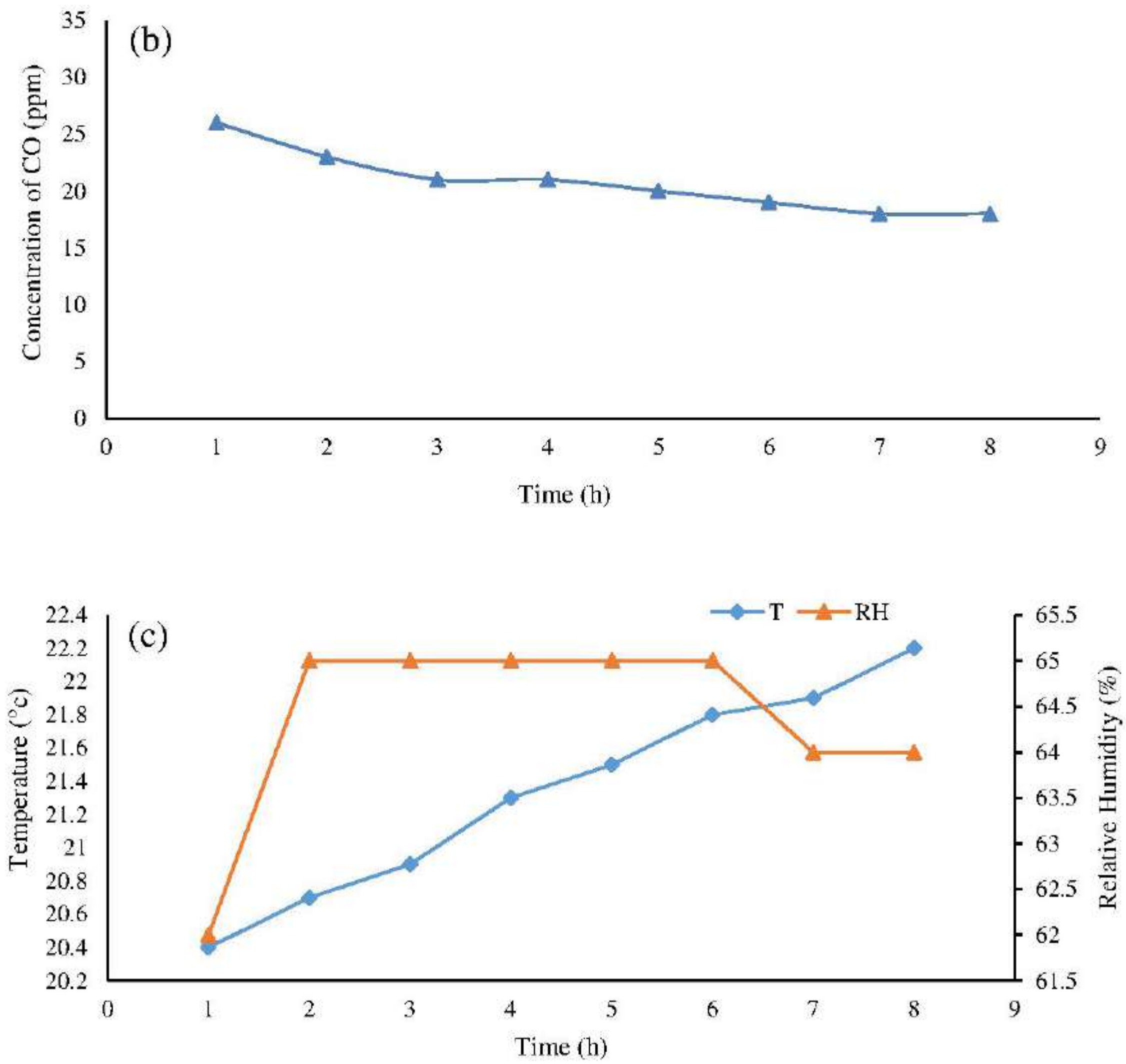


Fig. 5. Line plot of environmental variables based on vaporization rate of 350 mL/h and airflow rate of 1 L/min (a: CO_2 and TVOC concentration changes; b: CO concentration changes; c: temperature and RH changes)

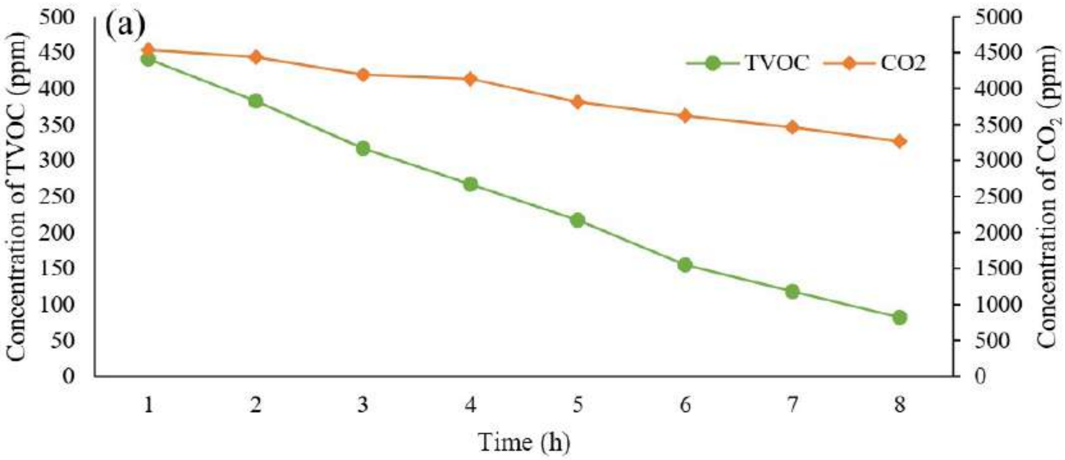
Concentration of the pollutants at the vaporization rate of 370 mL/h

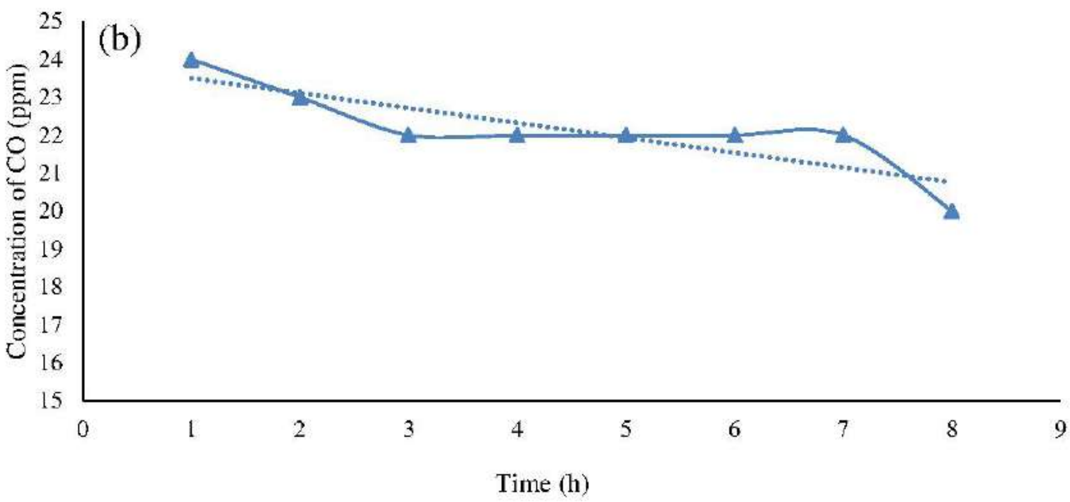
The experiment utilizing modified vaporization rate yielded notable changes in air quality parameters over the 8-h testing period. Carbon dioxide concentrations demonstrated a consistent reduction from 4540 ppm to 3265 ppm, representing a 28.1% decrease in ambient CO_2 levels. Total volatile organic compounds exhibited particularly significant removal efficiency, with concentrations declining from 441 ppm to 82 ppm (Fig. 6a). The pronounced TVOC reduction under these conditions suggests a positive correlation between elevated vaporization rates, increased humidity levels, and enhanced TVOC removal efficiency.

Carbon monoxide concentrations showed modest but steady reduction throughout the experimental period, decreasing from 24 ppm to 20 ppm (Fig. 6b). This 16.7% reduction in CO levels indicates consistent pollutant removal, albeit at a more moderate rate compared to other measured contaminants.

Environmental parameters exhibited controlled variations throughout the trial. Relative humidity demonstrated a three-phase pattern: an initial increase from 60% to 66% during the first four hours, followed by a slight decrease to 63% in the fifth hour, and subsequent stabilization at this level for the remainder of the experiment (Fig. 6c). Temperature measurements revealed a gradual increase from 21.4°C to 23.0°C over the 8-h period, representing a modest 1.6°C rise that remained within acceptable experimental parameters.

The results demonstrate the effectiveness of increased vaporization rates in pollutant removal, particularly for TVOCs. The stability of environmental parameters throughout the experiment, coupled with consistent reductions in all measured pollutants, suggests that the modified conditions maintained experimental integrity while achieving desired air quality improvements.





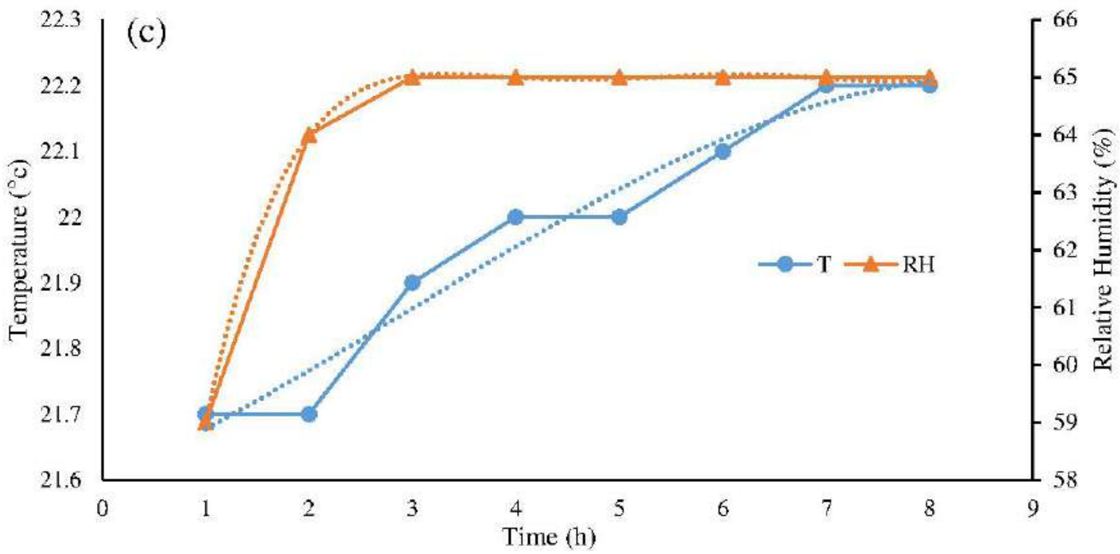


Fig. 6. Line plot of environmental variables based on vaporization rate of 370 mL/h and airflow rate of 1 L/min (a: CO_2 and TVOC concentration changes; b: CO concentration changes; c: temperature and RH changes)

The experimental findings demonstrate significant alignment with existing literature in the field of pollutant removal mechanisms. Our results corroborate the work of many researchers., who established that water droplet interaction with gas streams enhances pollutant removal through violent collisions and subsequent absorption into the liquid phase, achieving notable improvements in SO_2 removal efficiency from 50% to 83% [25]. Similarly, in a research, it has been demonstrated the effectiveness of water vapor introduction in reducing NO, CO, and CO_2 concentrations during combustion processes and turbine operation [26].

The observed pollutant reduction patterns can be further understood through the lens of heat and mass transfer dynamics. Previous studies have established that steam penetration in ambient air significantly influences both heat transfer rates and moisture dispersion patterns [27]. While convective processes primarily govern heat transfer, the interaction between water vapor and airborne pollutants plays a crucial role in determining pollutant concentration reduction and removal efficiency [27].

Our findings contribute to the broader understanding of ventilation optimization strategies for indoor air quality management. The results emphasize the critical balance between maintaining acceptable air quality standards and considering energy consumption and occupant comfort parameters. Future research directions could productively explore several key areas: the long-term impact of sustained elevated ventilation rates on building materials, comprehensive energy efficiency analyses, and the development of adaptive ventilation systems incorporating real-time air quality monitoring capabilities [28, 29].

Conclusion

This investigation examined the efficacy of water vapor combined with varying airflow rates in reducing indoor air pollutants, specifically CO_2, CO, and TVOCs. The experimental results demonstrate significant pollutant reduction capabilities, particularly under conditions of elevated airflow and water vapor introduction. The most substantial reductions in TVOC concentrations were achieved at a vaporization rate of 370 mL/h, indicating that increased humidity levels facilitate enhanced pollutant removal mechanisms. Carbon dioxide concentrations showed marked reductions at higher airflow rates, while CO levels demonstrated more modest responses, maintaining relative stability throughout the experimental period.

Environmental parameters remained well-controlled throughout the study. Temperature variations were minimal and displayed no significant trends, while relative humidity showed predictable, gradual increases during water vapor introduction. These findings suggest that the combination of water vapor and controlled airflow can effectively improve indoor air quality while maintaining stable environmental conditions.

The observed correlation between increased airflow rates and enhanced pollutant reduction, particularly for CO_2 and TVOCs, aligns with established literature on ventilation dynamics in indoor environments. However, the limited response in CO concentrations to the water vapor treatment suggests potential specificity in pollutant-vapor interactions that warrants further investigation.

The practical implications of this research extend to various indoor environments, particularly residential and small office spaces where cool-mist humidification systems could be implemented. While the results demonstrate promising pollutant reduction capabilities, further research is necessary to evaluate system efficacy in larger-scale or more complex environments where pollutant profiles may differ significantly.

These findings contribute to the broader understanding of indoor air quality management and have potential implications for environmental health standards. The demonstrated reduction in TVOC and CO_2 concentrations suggests positive implications for occupant health in confined spaces. However, the limited impact on CO levels indicates that comprehensive air quality management may require multiple intervention strategies.

This study establishes the effectiveness of combined water vapor and airflow approaches in indoor pollutant reduction while highlighting the importance of considering pollutant-specific responses and environmental conditions in practical applications. Future research directions should focus on long-term efficacy assessment, scale-up considerations, and the development of integrated air quality management strategies.

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Competing interests

The authors, Maryam Malekbala, Zahra Heydari, Seyde Fateme Mousavi, Zahra

Arshian Far, Zeinab Khalilnezhad, Roohollah Rostami certify that they have no affiliation with or financial interest in the subject matter or materials discussed in this research.

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Ethical considerations

“Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob-served by the authors.”

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