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Calibration of Hydrogen Peroxide Vapour Sensor

Aateqah Zaib, Syeda Sabera Begum, Enrico Allegra

Test Labs, Inivos Ltd, Peterborough, UK
Email: Aateqah.zaib@testlabsuk.com

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Abstract

Hydrogen Peroxide vapour is becoming more popular to use as a method of decontamination, particularly for medical equipment and enclosures. It is highly effective in terms of microbiological kill rates and has a variety of uses in healthcare. Although it is environmentally acceptable as it spontaneously decomposes into water and oxygen, concentration of hydrogen peroxide in the air needs to be monitored and controlled. A method of calibrating hydrogen peroxide vapor sensors is described which is based on the concentration of hydrogen peroxide in saturated vapour over a solution in water at a defined temperature. The saturated vapour is generated by bubbling dry air into a solution of hydrogen peroxide at a defined concentration and temperature. A vapour at a concentration of 0.7 ppm was produced and used to successfully calibrate a hydrogen peroxide sensor.

Keywords

Hydrogen Peroxide, Vapour, Vapour Leak Detector Gun, Calibration, Sensor

1. Introduction

Hydrogen peroxide (H_2O_2) is a highly reactive chemical compound as part of a family of compounds known as "reactive oxygen species" (ROS). It can be used as an oxidiser, removing electrons from another chemical species, and becoming reduced in what is known as a redox reaction. This oxidising property of H_2O_2 is what promotes its biological toxicity, and high concentrations of H_2O_2 are known to cause cell damage through the oxidation of proteins [1] and DNA via the formation of hydroxyl radicals from a Fenton type reaction between H_2O_2 and iron [2] [3] [4].

Hydrogen peroxide was first studied as a disinfectant in 1891 by B. W. Richardson and has since become a popular biocide used for antisepsis, the disinfec-

tion of hard surfaces and medical devices, and for room fumigation [4] [5]. The importance of decontaminating surfaces within healthcare settings has only recently been realised with studies showing that transmission of nosocomial pathogens via contaminated surfaces has indeed contributed to an increase in healthcare-acquire infections [6]. Disinfecting rooms that had been occupied by infected patients reduces the risk of subsequent patients acquiring the same pathogens, however conventional disinfection/cleaning methods rely on human operation which comes with its own drawbacks. The development of decontamination technologies that are automated is a step towards addressing this problem and eliminates the reliance on a human operator correctly selecting, formulating, distributing, and deciding the contact time of the disinfectant agent [7]. Decontamination systems most used are vapourised H_2O_2 (VHP), aerosolised hydrogen peroxide (AHP), and ultra-violet (UV) light. In this study, technologies utilising VHP were considered.

Vapourised H_2O_2 was first considered for use in sterilisation technologies in the 1980s, whereby liquid H_2O_2 is converted into vapour by either heat or changes in pressure and then delivered into the room to decontaminate and sterilize [8]. There are two types of systems that use H_2O_2 vapour: condensing and non-condensing technologies. Technologies that use condensing systems work by injecting H_2O_2 into the enclosed room until the air is saturated and the H_2O_2 begins condensing onto the surfaces. With non-condensing technologies, the air in the room is first dehumidified by the generators before H_2O_2 that has been vaporised is released and circulated for a set period, and then finally the dry vapour is returned to the generator where it is broken down into water and oxygen [9]. The use of H_2O_2 vapour technologies has become a well-established form of bio-decontamination, with many studies showing effective efficacy against bacterial spores [10] and other microbes, generally achieving 6-log reduction [11] [12] [13]. As well as being highly effective in killing microbes, the decomposition of H_2O_2 into water and oxygen make it environmentally safer in comparison to other biocides like formaldehyde, ethylene oxide, and glutaraldehyde [14].

One of the limitations of using H_2O_2 vapour for decontamination of an enclosed space is ensuring the room is safe for re-entry and the operator does not inhale any vapour. The concentration of VHP is considered safe at <1 ppm, and immediately dangerous to life or health in humans at a concentration of 75 ppm [15] [16]. Therefore, it is essential that an accurate form of monitoring of the H_2O_2 level is achieved, which is typically checked using sensors. In this study the calibration of externally manufactured sensors to a higher degree of accuracy is developed. In order to do this, a H_2O_2 vapour of around 1 ppm [17] was created and exposed to the sensors to perform the calibration.

2. Method

The method described in the paper is based on the concentration of hydrogen peroxide in saturated vapour over a solution in water at a defined temperature. The saturated vapour is generated by bubbling dry air into a solution of hydro-

gen peroxide at a defined concentration and temperature as shown in Figure 1.

2.1. Study Concept

The theoretical hydrogen peroxide concentration in the saturated vapour is calculated from the saturated vapour composition over defined concentration of hydrogen peroxide in water at a controlled temperature.

To obtain a constant flow of saturated vapour, fine bubbles of dry air (from a compressed air cylinder) were passed through a narrow tube of hydrogen peroxide solution. Dry air was used to prevent condensation of water content in the air changing the concentration of solution. A constant concentration in the vapour was maintained in an airflow to a sensor. The concentration of hydrogen peroxide solution was varied to obtain a consistent vapour of around 1 ppm hydrogen peroxide at 20˚C using a water bath to maintain constant temperature.

The vapour was then calibrated by passing it at a known flow rate for a measured length of time through distilled water in a Dreschel bottle with a sintered vapour distributor. This solution was then titrated with standard sodium thiosulphate solution. The ppm of hydrogen peroxide in the vapour was calculated from the known volume of vapour bubbled through the solution in the set length of time.

2.2. Preliminary Study

In order to establish the correct parameters for the test, the conditions were varied, and results were obtained to find which method provides a consistent and stable vapour flow at around 1 ppm. Hydrogen peroxide solution was formulated at concentrations of 1%, 5% and 10% before being bubbled through the Dreschel bottle. Testing showed that a 10% hydrogen peroxide solution produced a vapour with a reading of 30 ppm. A 5% solution produced a vapour at around 14 ppm and a 1% hydrogen peroxide solution formed a vapour at 3 ppm. After taking this into consideration along with the calculation of the theoretical concentration at 20˚C, it was found that 0.42% hydrogen peroxide solution should give a reading of 1 ppm.

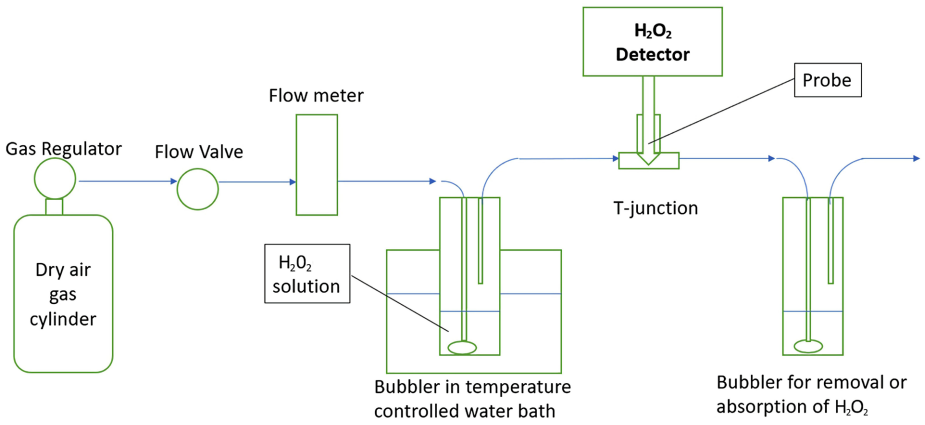

Figure 1. Vapour reference test set up.

For each solution, flow rates of 0.5, 0.7 and 1 L/min were tested, and results were recorded. Although the user manual for the gas leak detector gun used recommended a flow rate of 0.5 L/min, it was observed that a flow rate of 0.7 L/min produced a much more constant and steady vapour. Dry air was bubbled through a 0.42% hydrogen peroxide solution and connected with PTFE tubing. However, this was found to absorb hydrogen peroxide and in turn cause variability in results. The tubing was then changed to silicone which did not off gas any hydrogen peroxide and was thus suitable for the gas reference testing.

Furthermore, readings were taken using different hydrogen peroxide sensors/cells to see the variation of readings and the effect of this variation on final results. Different cells produced different readings whilst being exposed to the same vapour proving the fact that each gas leak detector gun produced different results. Drager tubes were also used to compare the readings produced and see how accurate each of them was. The results provided were very different to the results with the gas leak detector guns and therefore the titration method was adopted.

2.3. Final Test

After eliminating most forms of error and variation in results, final parameters were chosen to perform the gas reference test. A 0.42% hydrogen peroxide solution was prepared and titrated against potassium permanganate to confirm its concentration. Dry air was then bubbled through the solution at 0.7 L/min until a constant vapour of around 1 ppm was produced. Once the reading stayed constant for at least 10 minutes, the vapour was then collected in a second bubbler filled with distilled water for 2 hours. This collected sample was then titrated against sodium thiosulphate and calculations were applied to give the ppm of hydrogen vapour in the solution as well as the vapour produced.

To prove that results were repeatable, a 3-day validation study took place. A solution of 0.42% hydrogen peroxide was prepared daily and titrated to confirm its concentration. Each sample involved a 2-hour collection of vapour, and the concentration of the vapour was checked in between the collection of all 3 samples. This was to ensure that the vapour was still saturated and had not changed in concentration as air was passed through the solution. Although this change in concentration may be insignificant for a single run, it demonstrates the desirability of using a fresh solution of hydrogen peroxide daily. Therefore, this practice was implemented. On each day of analysis, 3 samples were collected, and an average was calculated.

2.4. Method Verification

The newly developed calibration method was compared to the current outsourced method to calibrate hydrogen peroxide vapour sensor cells in portable gas leak detector guns. A 2-stage verification process was performed as a comparison between cells calibrated by this method against those calibrated externally.

The first stage of verification of the method involved setting up a constant flow of hydrogen peroxide vapour. The concentration of this vapour was measured using 4 different cells, one calibrated internally and 3 calibrated externally, and the results were compared. This was performed in triplicates.

The second stage of the verification of the method involved running decontamination cycles inside test chambers using an HPV fogging device. Two cycles were run inside a small test chamber (11.5 m^3) and three cycles were run inside a large test chamber (67.5 m^3). After each cycle, the levels of hydrogen peroxide in the test chamber were measured to compare results once again between the cells.

3. Results and Discussion

The results from the 3-day validation study are shown in Table 1. These results show that the concentration of the freshly prepared Hydrogen Peroxide solutions used for the study were between 0.43% and 0.45%. Table 2 shows the concentrations of the hydrogen peroxide vapours formed by the solutions in Table 1.

Table 1. 3 day validation study results of hydrogen peroxide solution %.

Sample type/Lot	Replicate number	Grams of tested solution	$KMnO_4$ Molarity	Total volume of $KMnO_4$ (mL)	Result % H_2O_2	Average of triplicate
21/205	1	0.866	0.02	2.3	0.45	0.45
	2	1.021	0.02	2.7	0.45	
	3	0.886	0.02	2.3	0.44	
21/207	1	0.997	0.02	2.5	0.43	0.43
	2	0.933	0.02	2.4	0.44	
	3	1.028	0.02	2.6	0.43	
21/209	1	1.101	0.02	2.8	0.43	0.44
	2	0.972	0.02	2.5	0.44	
	3	1.074	0.02	2.8	0.44	

Table 2. 3 day validation study results of hydrogen peroxide vapour ppm.

Sample type/Lot	Tested solution (g)	$Na_2S_2O_3$ Molarity	Total volume of $Na_2S_2O_3$ (mL)	Result % H_2O_2 solution	ppm H_2O_2 vapour	Average of triplicate
S21/080	151.784	0.001	5	0.000056	0.7	0.7
S21/081	145.407	0.001	5.2	0.000061	0.7	
S21/082	158.537	0.001	5.1	0.000055	0.7	
S21/083	136.094	0.001	5.5	0.000069	0.8	0.8
S21/084	138.672	0.001	6	0.000074	0.9	
S21/085	150.263	0.001	5.6	0.000063	0.8	
S21/086	159.109	0.001	5.4	0.000058	0.8	0.8
S21/087	144.237	0.001	5.6	0.000066	0.8	
S21/088	143.873	0.001	5.5	0.000065	0.8	

An average of triplicate samples showed that the concentration of the vapour was between 0.7 and 0.8 ppm.

This variation is expected due to the nature of how vapours are formed. The vapour formed is dependent on the hydrogen peroxide solution and its concentration. Although a 0.42% solution was made up, results show that the exact concentrations of the solutions were between 0.43% and 0.45%. This error is due to the balance used for weighing, making up to volume using diluent, as well as the titration procedure and other human errors. All validation testing and reporting takes into consideration the exact concentration of solution rather than the theoretical concentration to ensure accurate reporting.

Over the 3 days of testing, Table 2 shows that results of 0.7 and 0.8 ppm were obtained. An average of the 9 readings taken gave a result of 0.78 ppm which would give a reading of 0.8 ppm on the gas leak detector gun due to rounding. These standard deviation for these datasets was calculated to be 0.04 which shows low variability and reliable results. Overall, the slight difference in validation results have no suspected impact on calibration of Hydrogen Peroxide cells as a titration test will always be performed prior to calibrating the cell to ensure the cell is being calibrated to the exact concentration of the vapour. Therefore, these validation results are sufficient to prove robustness of the method and confidence in calibrating the Hydrogen peroxide sensors.

Table 3 shows results from the first stage of the verification of the method. Cells 2443, 2444 and 2445 were all calibrated externally and a significant variation in results was observed. Cell 2443 produced readings almost double that of 2444 and 2445. The internally calibrated cell (2447) however, produced more reliable and repeatable results. This cell produced consistent results of 0.8 ppm at each of the 3 readings which showed no variation. A reading of 0.8 ppm is also the closest value to the theoretical and titration concentration of the hydrogen peroxide vapour produced.

The results from the second stage of the verification process are shown in Table 4 and Table 5. In both the small and the large test chamber, the difference of results showed the variability of externally calibrated hydrogen peroxide cells. The use of the small and large test chamber showed the real-life comparison to using the cells in hospitals or other healthcare environments. The two initial decontamination cycles in the small test chamber showed a reading of 0.4 ppm on both occasions using the internally calibrated cell. On the other hand, the other 3

Table 3. Stage 1 verification of method (constant vapour flow measurements).

Reading number	Theoretical concentration (ppm)	Titration concentration (ppm)	Externally calibrated cell 2443 reading (ppm)	Externally calibrated cell 2444 reading (ppm)	Externally calibrated cell 2445 reading (ppm)	Internally calibrated cell 2447 reading (ppm)
1			2.1	1.2	1.3	0.8
2	1.0	0.7	2.1	1.5	1.6	0.8
3			1.9	1.5	1.6	0.8

Table 4. Small test chamber—hydrogen peroxide concentration after decontamination cycle.

Validation run number		Externally calibrated cell 2443 reading (ppm)	Externally calibrated cell 2444 reading (ppm)	Externally calibrated cell 2445 reading (ppm)	Internally calibrated cell 2447 reading (ppm)
1	Reading after decontamination cycle (ppm)	0.7	0.5	0.4	0.4
2		0.8	0.6	0.7	0.4
Mean		0.8	0.6	0.6	0.4
1	Reading after 1 extra deactivation cycle (ppm)	0.6	0.4	0.4	0.4
2		0.7	0.6	0.4	0.2
Mean		0.7	0.5	0.4	0.3
1	Reading after 2 extra deactivation cycle (ppm)	0.6	0.5	0.2	0.3
2		0.5	0.5	0.4	0.3
Mean		0.6	0.5	0.3	0.3

Table 5. Large test chamber—hydrogen peroxide concentration after decontamination cycle.

Validation run number		Externally calibrated cell 2443 reading (ppm)	Externally calibrated cell 2444 reading (ppm)	Externally calibrated cell 2445 reading (ppm)	Internally calibrated cell 2447 reading (ppm)
1	Reading after decontamination cycle (ppm)	0.8	0.6	0.7	0.4
2		1.3	1.0	0.5	0.7
3		1.2	1.1	1.0	0.6
Mean		1.1	0.9	0.7	0.6
1	Reading after 1 extra deactivation cycle (ppm)	0.5	0.4	0.4	0.3
2		1.3	1.0	0.2	0.5
3		1.2	1.0	1.2	0.6
Mean		1.0	0.8	0.6	0.5
1	Reading after 2 extra deactivation cycle (ppm)	0.7	0.5	0.6	0.3
2		0.8	0.8	0	0.5
3		1.1	0.8	0.6	0.5
Mean		0.9	0.7	0.4	0.4

cells showed a difference of results between both runs with readings varying from 0.4 ppm to 0.8 ppm.

4. Conclusions

A method for calibrating hydrogen peroxide vapour sensors at around 1 ppm can be achieved by the evaporation of aqueous hydrogen peroxide at 0.42% w/w solution. This method was validated by a well-known quantitative iodometric analysis technique to confirm the concentration of the vapour produced. The method was then verified by comparing manufacturer calibrated cells to cells that

had been calibrated by the method described in this paper.

In principle, validation and verification processes showed that the calibration procedure developed internally to calibrate Hydrogen Peroxide cells in gas leak detector guns was successfully implemented.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Nestor, U., Frodouard, H. and Theoneste, M. (2021) A Brief Review of How to Construct an Enzyme-Based H_2O_2 Sensor Involved in Nanomaterials. *Advances in Nanoparticles*, **10**, 1-25. https://doi.org/10.4236/anp.2021.101001

[2] Plaine, H.L. (1955) The Effect of Oxygen and of Hydrogen Peroxide on the Action of a Specific Gene and on Tumor Induction in Drosophila Melanovapourter. *Genetics*, **40**, 268-280. https://doi.org/10.1093/genetics/40.2.268

[3] Mello Filho, A.C., Hoffmann, M.E. and Meneghini, R. (1984) Cell Killing and DNA Damage by Hydrogen Peroxide Are Mediated by Intracellular Iron. *The Biochemical Journal*, **218**, 273-275. https://doi.org/10.1042/bj2180273

[4] Linley, E., Denyer, S.P., McDonnell, G., Simons, C. and Maillard, J.Y. (2012) Use of Hydrogen Peroxide as a Biocide: New Consideration of Its Mechanisms of Biocidal Action. *The Journal of Antimicrobial Chemotherapy*, **67**, 1589-1596. https://doi.org/10.1093/jac/dks129

[5] Richardson, B.W. (1891) On Peroxide of Hydrogen, or Ozone Water, as a Remedy: Continued from a Research Commenced in the Year 1858. *The Lancet*, **137**, 707-709. https://doi.org/10.1016/S0140-6736(02)19675-9

[6] Otter, J., Yezli, S. and French, G. (2011) The Role Played by Contaminated Surfaces in the Transmission of Nosocomial Pathogens. *Infection Control & Hospital Epidemiology*, **32**, 687-699. https://doi.org/10.1086/660363

[7] Otter, J.A., Yezli, S., Perl, T.M., Barbut, F. and French, G.L. (2013) The Role of "No-Touch" Automated Room Disinfection Systems in Infection Prevention and Control. *Journal of Hospital Infection*, **83**, 1-13. https://doi.org/10.1016/j.jhin.2012.10.002

[8] Lerouge, S. (2012) Non-Traditional Sterilization Techniques for Biomaterials and Medical Devices. In: Lerouge, S. and Simmons, A., Eds., *Sterilisation of Biomaterials and Medical Devices*, Woodhead Publishing, 97-116. https://doi.org/10.1533/9780857096265.97

[9] Goyal, S.M., Chander, Y., Yezli, S. and Otter, J.A. (2014) Evaluating the Virucidal Efficacy of Hydrogen Peroxide Vapour. *The Journal of Hospital Infection*, **86**, 255-259. https://doi.org/10.1016/j.jhin.2014.02.003

[10] Otter, J.A., Yezli, S., Schouten, M.A., van Zanten, A.R., Houmes-Zielman, G. and Nohlmans-Paulssen, M.K. (2010) Hydrogen Peroxide Vapor Decontamination of an Intensive Care Unit to Remove Environmental Reservoirs of Multidrug-Resistant Gram-Negative Rods during an Outbreak. *American Journal of Infection Control*, **38**, 754-756. https://doi.org/10.1016/j.ajic.2010.03.010

[11] Fu, T.Y., Gent, P. and Kumar, V. (2012) Efficacy, Efficiency and Safety Aspects of Hydrogen Peroxide Vapour and Aerosolized Hydrogen Peroxide Room Disinfec-

tion Systems. *Journal of Hospital Infection*, **80**, 199-205. https://doi.org/10.1016/j.jhin.2011.11.019

[12] Falavapour, M.E., Thomaidis, P.C., Kotsantis, I.K., Sgouros, K., Samonis, G. and Karageorgopoulos, D.E. (2011) Airborne Hydrogen Peroxide for Disinfection of the Hospital Environment and Infection Control: A Systematic Review. *Journal of Hospital Infection*, **78**, 171-177. https://doi.org/10.1016/j.jhin.2010.12.006

[13] Rutala, W.A. and Weber, D.J. (2015) 301—Disinfection, Sterilization, and Control of Hospital Waste. *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases* (*Eighth Edition*), **2**, 3294-3309. https://doi.org/10.1016/B978-1-4557-4801-3.00301-5

[14] IWT: A Tecniplast Company (2016) Hydrogen Peroxide Decontamination: Vapour and Aerosol Comparison.

[15] Hydrogen Peroxide (OSHA Method 1019) (1977) United States Department of Labor, Occupational Safety and Health Administration Web Site.

[16] Ludwig, H.R., Cairelli, S.G. and Whalen, J.J. (1994) Documentation for Immediately Dangerous to Life or Health Concentrations (IDLHs).

[17] Webb, B.C. (2001) A Validated Calibration Method for Hydrogen Peroxide Vapour Sensors. *PDA Journal of Pharmaceutical Science and Technology*, **55**, 49-54.