REVIEW

Preventing explosions of hydrogen gas inhalers

Ryosuke Kurokawa[1,#], Shin-ichi Hirano[1,#], Yusuke Ichikawa[1], Goh Matsuo[1], Yoshiyasu Takefuji[2,*]
1 MiZ Company Limited, Kamakura, Kanagawa, Japan
2 Faculty of Environment and Information Studies, Keio University, Fujisawa, Japan

#These authors contributed equally to this work.
*Correspondence to: Yoshiyasu Takefuji, PhD, takefuji@sfc.keio.ac.jp.
orcid: 0000-0002-1826-742X (Yoshiyasu Takefuji)

Abstract

Production and excretion of hydrogen (H_2) gas in human was reported in 1969, since then it has been regarded as non-toxic molecule. For preventive and therapeutic medical uses, a possible treatment for cancer was reported and another article was published on how H_2 acts as a therapeutic antioxidant by selectively reducing cytotoxic oxygen radicals. A variety of H_2 gas inhalers have been available in the market for hospital and home uses. However, H_2 is odorless and flammable or explosive ignited by static electricity. We have examined the safety of a variety of H_2 gas concentrations from the viewpoint of flammability and explosion. We have also measured concentrations of H_2 gas inhalers in the market respectively. This paper also details how to control H_2 gas concentration for preventing explosions.

Key words: hydrogen gas; hydrogen concentration; explosion; detonation; flammability; static electricity; hydrogen gas inhaler; medical use; home use; market; safety

doi: 10.4103/2045-9912.266996
How to cite this article: Kurokawa R, Hirano S, Ichikawa Y, Matsuo G, Takefuji Y. Preventing explosions of hydrogen gas inhalers. Med Gas Res. 2019;9(3):160-162.

Introduction

Production and excretion of hydrogen (H_2) gas in human was reported in 1969, since then it has been regarded as non-toxic molecule.[1] H_2 was recently reported by Ohsawa et al.[2] as a preventive and therapeutic antioxidant. However, in 2005, 2 years ago of the Ohsawa's report, Yanagihara et al.[3] at our group reported that drinking of neutral H_2-rich water produced by electrolysis could effectively reduce the oxidative stress induced by chemical oxidant in rats, indicating that this is a pioneering research in H_2 medicine. H_2 has also been proposed for treatment in various oxidative stress-related diseases and damages.[4-9] A variety of H_2 gas inhalers have been available in the market for clinical and home uses. However, H_2 is odorless and flammable or explosive ignited by static electricity. In the present study, we examined the safety of a variety of H_2 gas concentrations from the viewpoint of flammability and explosion. In addition, we also measured concentrations of H_2 gas inhalers in the market respectively.

How does H_2 Gas Concentration Influence Explosion?

Taiyo Nippon Sanso Pure H_2 gas G2 (Tokyo, Japan) was used in the first experiment for testing explosions based on a variety of H_2 concentrations. The H_2 concentration was measured by New Cosmos Electric: XP-3140 (Osaka, Japan). In order to examine the H_2 gas concentrations with mixture of air, we have tested flammability and explosion under five H_2 concentrations respectively: 4%, 10%, 15%, 20%, and 100%. Under the H_2 concentration of 4% and 10%, no explosion/flammability was detected. Under the 15% and 100% H_2 concentration, a small explosion with small sound was detected which may not cause a severe damage to user. Under the 20% H_2 concentration, a large explosion (detonation) was detected which may cause a severe damage to user. From this H_2 concentration experiment, we understood that the H_2 concentration must be less than 10%. In addition, we did a systematic search of Google Scholar and PubMed using the search terms ("hydrogen gas" and "explosion" or "detonation" and "concentration") before initiating this study on December 5, 2015, and we repeated this search on August 5, 2019. In these searches, many papers described the explosive concentration of H_2 gas in the mixture of H_2 gas and air as 4 to 75%.[10,11] However, a few reports reported that H_2 does not explode if it is less than 10% when mixed with air or oxygen.[12-14] Therefore, our present experimental data are supported by the latter reports.

Measuring H_2 Concentration of H_2 Gas Inhalers

New Cosmos Electric XP-3140 was used for measuring H_2 concentrations of H_2 gas inhalers (15 products) in the market respectively. In the measurement of H_2 concentration, we used 5 apparatus and 1 apparatus for MHG-2000α and other 14 apparatus respectively. Additionally, we confirmed that the result of H_2 concentration is correct in each product catalog. **Table 1** shows the result of measured H_2 concentrations. Remember that H_2 gas concentration over 10% is explosive and dangerous. Consumer safety regulations for H_2 gas inhalers are immediately required for protecting users in order to avoid dangerous explosions.

H_2 Gas Ignited by Static Electricity

We must examine a risk of static electricity ignition. According to Danger of H_2 Gas Explosion, and Prevention Measures (Division of Gas Safety, Institute of Chemical Technology, National Institute of Advanced Industrial Sciences and Technology, Japan), the minimum ignition energy of H_2 gas is 0.02 mJ.[15] According to electrostatic sensitivity of H_2 by Mizuki

Table 1: Hydrogen (H_2) gas inhalers (products) in the market

Product name	Supplier	H_2 concentration (%)	Method
MHG-2000α	MiZ Co., Ltd., Kanagawa, Japan	6.6±0.2*	Electrolysis
Hycellvator	Helix Japan Co., Ltd., Tokyo, Japan	66#	
H_2 Life	JWS International Corp., Tokyo, Japan	66#	
HydroPower	Brain Hokkaido Co., Ltd., Hokkaido, Japan	66#	
HydroUni	Univers Co., Ltd., Tokyo, Japan	66#	
Hydrogen Generator	OPS Inc., Tokyo, Japan	66#	
AMS-H	Asklepios Medical Co., Ltd., Tokyo, Japan	66#	
La Briller Luxe	ISMZ Co., Ltd., Osaka, Japan	98	
Hydrogen Inhaler (Table top type)	Kenko Shien Center Co., Ltd., Aichi, Japan	99	
Suiso Care	Kenko Co., Ltd., Gifu, Japan	99	
PHG-150TA	Eco Higashinippon Co., Ltd., Fukushima, Japan	99	
Suisonia	Earth Engineering Co., Ltd., Fukuoka, Japan	ND	Pyrolysis
HydroRich	Pal Corporation, Tokyo, Japan	99	Chemical reaction
Hydrogen Generator	Kanon Co., Ltd., Osaka, Japan	99	
MYC Hydro One	MYC Co., Ltd., Kumamoto, Japan	99	

Note: *Data are expressed as the mean ± SD of 5 apparatus. #H_2 and O_2 gas mixed type. ND: Not detected.

Yamakuma (National Institute of Occupational Safety and Health, Japan), electrostatic charge of the human body is 0.05 mJ with 1.0 kV human charging potential.[16] When assuming human is a capacitor of 90 pF, 1.0 kV (0.05 mJ) to 2.5 kV (0.28 mJ) human charging potential cannot be sensed by us at all. In other words, it is highly possible to easily ignite H_2 gas by static electricity without our recognition. 0.02 mJ ignition energy can be easily satisfied in hospital and at home. In fact, we examined to observe if an explosion would occur by a lighter flame or static electricity close to the outlet of H_2 gas inhaler using H_2 life, La Briller Luxe, or HydRich respectively. As a result, large explosions (detonation) were detected with these three products (data not shown).

Controlling H_2 Gas Concentration

Although it is well known that the H_2 gas concentration in detonation of the mixture of H_2 gas and air is less than 4%, we recently demonstrated that the detonation limit is less than 10% by our experiment and literature search.[17] Therefore, we developed the safe H_2 gas supply system (MHG-2000α). As shown in **Figure 1**, inhalation gas was prepared by mixing H_2 gas with air, where the H_2 gas was produced 140 mL/min by the electrolysis of water, and the concentration was controlled about 6.0–7.0% under the detonation limit of the mixture of H_2 gas and air (below 10%). Moreover, this H_2 gas supply system consists of raw water in an electrolyzed chamber, the diaphragm and the electrode plate. H_2 gas is directly generated from the electrode plate and cathode, based on the interaction between the fan on the water surface, the cathode gas and the diluted air. Thus, the concentration of H_2 gas near the cathode during electrolysis is always maintained below 10%, the lower limit of explosion. MHG-2000α has the new remarkable function system, which is indicated H_2 gas concentration, calculated from the current value and diluent gas. When it will be more than 10% of H_2 gas concentration, the electrolysis of water will be stopped immediately for safe.

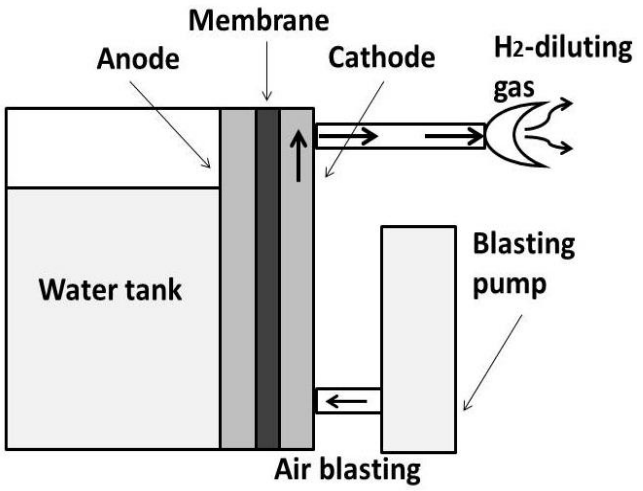

Figure 1: Apparatus for hydrogen (H_2) gas inhalation (MHG-2000α).
Note: The inhalation gas is prepared by mixing H_2 gas with air, where H_2 gas was produced by the electrolysis of water, and the concentration is controlled under the detonation limit of the mixture of H_2 gas and air.

In usual conditions, H_2 gas does not explode at a concentration of 10% or less. Since H_2 is a colorless gas with no taste or odor, we do not know the actual concentration of H_2 gas produced by the H_2 gas inhaler. Therefore, using a H_2 gas inhaler carries a risk of explosion. In one inhaler such as Suisonia, we could not confirm H_2 gas generation at all. Most of H_2gas inhalers have some risks of explosion except MHG-2000α and Suisonia. As of today, there is no legislation to regulate proper production and/or use of H_2 gas inhalers. We should be fully aware of the risks of H_2 gas inhalers to prevent serious accident involving human life. To our knowledge, this is the first paper demonstrating the explosion risk of H_2 gas inhalers in the market. The proposed results will be useful for the information of safe H_2 gas inhalers.

Acknowledgements
The authors are grateful to Mr. Fumitake Satoh, Ms. Yoko Satoh, Dr.

Yi-Da Hsieh and Mr. Masatsugu Saitou (MiZ Co. Ltd., Japan) for their excellent advices in the writing of this manuscript.

Author contributions

Study design and data analysis: RK, SH; manuscript writing and figures preparation: SH, GM, YT; H_2 gas inhaler preparation and measurement: RK; data collection and study guidance: YT, YI, GM. All authors read and approved the final manuscript.

Conflicts of interest

The authors have no conflicts of interests to declare.

Financial support

None.

References

1. Levitt MD. Production and excretion of hydrogen gas in man. *N Engl J Med.* 1969;281:122-127.
2. Ohsawa I, Ishikawa M, Takahashi K, et al. Hydrogen acts as a therapeutic antioxidant by selectively reducing cytotoxic oxygen radicals. *Nat Med.* 2007;13:688-694.
3. Yanagihara T, Arai K, Miyamae K, et al. Electrolyzed hydrogen-saturated water for drinking use elicits an antioxidative effect: a feeding test with rats. *Biosci Biotechnol Biochem.* 2005;69:1985-1987.
4. Dole M, Wilson FR, Fife WP. Hyperbaric hydrogen therapy: a possible treatment for cancer. *Science.* 1975;190:152-154.
5. Nakao A, Toyoda Y, Sharma P, Evans M, Guthrie N. Effectiveness of hydrogen rich water on antioxidant status of subjects with potential metabolic syndrome-an open label pilot study. *J Clin Biochem Nutr.* 2010;46:140-149.
6. Yoritaka A, Takanashi M, Hirayama M, Nakahara T, Ohta S, Hattori N. Pilot study of H(2) therapy in Parkinson's disease: a randomized double-blind placebo-controlled trial. *Mov Disord.* 2013;28:836-839.
7. Nishimaki K, Asada T, Ohsawa I, et al. Effects of molecular hydrogen assessed by an animal model and a randomized clinical study on mild cognitive impairment. *Curr Alzheimer Res.* 2018;15:482-492.
8. Chuai Y, Gao F, Li B, et al. Hydrogen-rich saline attenuates radiation-induced male germ cell loss in mice through reducing hydroxyl radicals. *Biochem J.* 2012;442:49-56.
9. Yang Y, Li B, Liu C, et al. Hydrogen-rich saline protects immunocytes from radiation-induced apoptosis. *Med Sci Monit.* 2012;18:Br144-148.
10. The Engineering ToolBox. Gases - Explosion and flammability concentration Limits. https://wwwengineeringtoolboxcom/explosive-concentration-limits-d_423html.
11. Yaws CL. *Matheson Gas Data Book, 7th ed.* McGraw-Hill Professional; 2001.
12. Thomas GO. Flame acceleration and the development of detonation in fuel-oxygen mixtures at elevated temperatures and pressures. *J Hazard Mater.* 2009;163:783-794.
13. Yagyu S, Matsui H, Masuda T, Yamamoto H. Study on the explosion risk of hydrogen (1st Report). Effect of pressure on the explosive limit of hydrogen. *Research Report of National Institute for Industrial Safety.* 1969;RIIS-RR-18-1:3-5.
14. Yagyu S, Masuda T, Yamamoto H. Study on the explosion danger of hydrogen (2nd Report). Explosion pressure of hydrogen-air mixture. *Research Report of National Institute for Industrial Safety*. 1973;RIIS-RR-21-4:3-5.
15. Danger of Hydrogen Gas Explosion, and Prevention Measures. Division of Gas Safety, Institute of Chemical Technology, National Institute of Advanced Industrial Sciences and Technology. http://www.hess.jp/Search/data/14-02-018.pdf.
16. Yamakuma M. Hydrogen electrostatic sensitivity. *Safety Eng.* 2005;44:386-390.
17. Kurokawa R, Komachi F, Seo T, Hirano S. Explosive concentration of hydrogen gas and safety of hydrogen gas inhaler. 7th Meeting of the Japanese Biomedical Association of Molecular Hydrogen; 2017; Nagoya.

Received: May 29, 2019
Reviewed: May 30, 2019
Accepted: July 29, 2019