Preventing explosions of hydrogen gas inhalers

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Abstract
Production and excretion of hydrogen (H2) 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 H2 acts as a therapeutic antioxidant by selectively reducing cytotoxic oxygen radicals. A variety of H2 gas inhalers have been available in the market for hospital and home uses. However, H2 is odorless and flammable or explosive ignited by static electricity. We have examined the safety of a variety of H2 gas concentrations from the viewpoint of flammability and explosion. We have also measured concentrations of H2 gas inhalers in the market respectively. This paper also details how to control H2 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

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INTRODUCTION
Production and excretion of hydrogen (H2) gas in human was reported in 1969, since then it has been regarded as non-toxic molecule.1 H2 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 H2-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 H2 medicine. H2 has also been proposed for treatment in various oxidative stress-related diseases and damages.4-9 A variety of H2 gas inhalers have been available in the market for clinical and home uses. However, H2 is odorless and flammable or explosive ignited by static electricity. In the present study, we examined the safety of a variety of H2 gas concentrations from the viewpoint of flammability and explosion. In addition, we also measured concentrations of H2 gas inhalers in the market respectively.

HOW DOES H2 GAS CONCENTRATION INFLUENCE EXPLOSION?
Taiyo Nippon Sanso Pure H2 gas G2 (Tokyo, Japan) was used in the first experiment for testing explosions based on a variety of H2 concentrations. The H2 concentration was measured by New Cosmos Electric: XP-3140 (Osaka, Japan). In order to examine the H2 gas concentrations with mixture of air, we have tested flammability and explosion under five H2 concentrations respectively: 4%, 10%, 15%, 20%, and 100%. Under the H2 concentration of 4% and 10%, no explosion/flammability was detected. Under the 15% and 100% H2 concentration, a small explosion with small sound was detected which may not cause a severe damage to user. Under the 20% H2 concentration, a large explosion (detonation) was detected which may cause a severe damage to user. From this H2 concentration experiment, we understood that the H2 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 H2 gas in the mixture of H2 gas and air as 4 to 75%.10,11 However, a few reports reported that H2 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 H2 CONCENTRATION OF H2 GAS INHALERS
New Cosmos Electric XP-3140 was used for measuring H2 concentrations of H2 gas inhalers (15 products) in the market respectively. In the measurement of H2 concentration, we used 5 apparatus and 1 apparatus for MHG-2000α and other 14 apparatus respectively. Additionally, we confirmed that the result of H2 concentration is correct in each product catalog.

Table 1 shows the result of measured H2 concentrations. Remember that H2 gas concentration over 10% is explosive and dangerous. Consumer safety regulations for H2 gas inhalers are immediately required for protecting users in order to avoid dangerous explosions.

H2 GAS IGNITED BY STATIC ELECTRICITY
We must examine a risk of static electricity ignition. According to Danger of H2 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 H2 gas is 0.02 mJ.15 According to electrostatic sensitivity of H2 by Mizuki

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we recently demonstrated that the detonation limit is less than 10% by our experiment and literature search. Therefore, we developed the safe H₂ gas supply system (MHG-2000α). As shown in Figure 1, inhalation gas was prepared by mixing H₂ gas with air, where the H₂ 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 H₂ gas and air (below 10%). Moreover, this H₂ gas supply system consists of raw water in an electrolyzed chamber, the diaphragm and the electrode plate. H₂ 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 H₂ 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 H₂ gas concentration, calculated from the current value and diluent gas. When it will be more than 10% of H₂ gas concentration, the electrolysis of water will be stopped immediately for safe.

In usual conditions, H₂ gas does not explode at a concentration of 10% or less. Since H₂ is a colorless gas with no taste or odor, we do not know the actual concentration of H₂ gas produced by the H₂ gas inhaler. Therefore, using a H₂ gas inhaler carries a risk of explosion. In one inhaler such as Suisonia, we could not confirm H₂ gas generation at all. Most of H₂ gas 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 H₂ gas inhalers. We should be fully aware of the risks of H₂ gas inhalers to prevent serious accident involving human life. To our knowledge, this is the first paper demonstrating the explosion risk of H₂ gas inhalers in the market. The proposed results will be useful for the information of safe H₂ gas inhalers.

**Table 1: Hydrogen (H₂) gas inhalers (products) in the market**

<table>
<thead>
<tr>
<th>Product name</th>
<th>Supplier</th>
<th>H₂ concentration (%)</th>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHG-2000α</td>
<td>MIZ Co., Ltd., Kanagawa, Japan</td>
<td>6.6±0.2*</td>
<td>Electrolysis</td>
</tr>
<tr>
<td>Hycellvator</td>
<td>Helix Japan Co., Ltd., Tokyo, Japan</td>
<td>66*</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>H₂ Life</td>
<td>JWS International Corp., Tokyo, Japan</td>
<td>66*</td>
<td>Electrolysis</td>
</tr>
<tr>
<td>HydroPower</td>
<td>Brain Hokkaido Co., Ltd., Hokkaido, Japan</td>
<td>66*</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>HydroUni</td>
<td>Univers Co., Ltd., Tokyo, Japan</td>
<td>66*</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>Hydrogen Generator</td>
<td>OPS Inc., Tokyo, Japan</td>
<td>66*</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>AMS-H</td>
<td>Asklepios Medical Co., Ltd., Tokyo, Japan</td>
<td>66*</td>
<td>Evolutionary</td>
</tr>
<tr>
<td>La Briller Luxe</td>
<td>ISMZ Co., Ltd., Osaka, Japan</td>
<td>98</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>Hydrogen Inhaler (Table top type)</td>
<td>Kenko Shien Center Co., Ltd., Aichi, Japan</td>
<td>99</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>Suiso Care</td>
<td>Kenko Co., Ltd., Gifu, Japan</td>
<td>99</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>PHG-150TA</td>
<td>Eco Higashinippon Co., Ltd., Fukuoka, Japan</td>
<td>99</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>Suisonia</td>
<td>Earth Engineering Co., Ltd., Fukuoka, Japan</td>
<td>ND</td>
<td>Pyrolysis</td>
</tr>
<tr>
<td>HydroRich Pal Corporation, Tokyo, Japan</td>
<td>99</td>
<td>Chemical reaction</td>
<td></td>
</tr>
<tr>
<td>Hydrogen Generator</td>
<td>Kanon Co., Ltd., Osaka, Japan</td>
<td>99</td>
<td>Chemical reaction</td>
</tr>
<tr>
<td>MYC Hydro One</td>
<td>MYC Co., Ltd., Kumamoto, Japan</td>
<td>99</td>
<td>Chemical reaction</td>
</tr>
</tbody>
</table>

Note: *Data are expressed as the mean ± SD of 5 apparatus. #H₂ and O₂ gas mixed type. ND: Not detected.

*Figure 1: Apparatus for hydrogen (H₂) gas inhalation (MHG-2000α).
Note: The inhalation gas is prepared by mixing H₂ gas with air, where H₂ gas was produced by the electrolysis of water, and the concentration is controlled under the detonation limit of the mixture of H₂ gas and air.

**Controlling H₂ Gas Concentration**

Although it is well known that the H₂ gas concentration in detonation of the mixture of H₂ gas and air is less than 4%,
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**Author contributions**

Study design and data analysis: RK, SH; manuscript writing and figures preparation: SH, GM, YT; H₂ 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**

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