# AIR-ACTIVATED CHEMICAL WARMING DEVICES: EFFECTS OF OXYGEN AND PRESSURE

G. RALEIGH, R. RIVARD, S. FABUS

Center for Comprehensive Wound Care and Hyperbaric Medicine, St. Luke's Medical Center, Milwaukee, WI 53215

Air-activated chemical warming devices use an exothermic chemical reaction of rapidly oxidizing iron to generate heat for therapeutic purposes. Placing these products in a hyperbaric oxygen environment greatly increases the supply of oxidant and thus increases the rate of reaction and maximum temperature. Testing for auto-ignition and maximum temperatures attained by ThermaCare™ Heat Wraps, Playtex™ Heat Therapy, and Heat Factory® disposable warm packs under ambient conditions and under conditions similar to those encountered during hyperbaric oxygen treatments in monoplace and multiplace hyperbaric chambers (3 atm abs and >95% oxygen) revealed a maximum temperature of 269°F (132°C) with no spontaneous ignition. The risk of thermal burn injury to adjacent skin may be significantly increased if these devices are used under conditions of hyperbaric oxygen.

**AIR-ACTIVATED CHEMICAL WARMING DEVICES: EFFECTS OF OXYGEN AND PRESSURE**

INTRODUCTION

Historically, fires in hyperbaric chambers have been catastrophic events. Chamber fires before 1980 were principally caused by electrical ignition. Since 1980, chamber fires have been primarily caused by prohibited sources of ignition that an occupant carried inside the chamber. The cause of at least one fire in an oxygen filled monoplace hyperbaric chamber has been attributed to a chemical hand warmer that the patient had taken into the chamber (1).

Air-activated chemical warmers consist of finely divided (powdered) iron, sodium chloride, and charcoal, enclosed in a gas permeable pouch. The pouch is stored inside an airtight wrapper until ready to use. When the wrapper is opened, air diffuses through the pouch, initiating an exothermic oxidation reaction between the iron and oxygen producing iron oxide (rust) and heat [$4Fe + 3O_2 \rightarrow 2Fe_2O_3$ + HEAT](2). The sodium chloride acts as a catalyst to speed up the rate of reaction. Charcoal is present to disperse the heat produced and to absorb odors. Some warmers also include a non-reactive insulator such as vermiculite to help retain heat and to promote diffusion of gas through the pouch by keeping the components from agglomerating.

The temperature attained by a warming device is largely dependant on the rate of the oxidative process. The rate is controlled by the amount of iron and oxygen available to react. Solid blocks of iron do oxidize, but do so slowly and release oxidative heat slowly. The small surface area of a solid limits how fast the iron is consumed by oxidation. Rust on the surface of the solid acts as a barrier to oxygen diffusion further inhibiting the reaction rate. By subdividing the solid block to a powder, the surface area is markedly increased making more iron molecules available to react and the reaction proceeds at an accelerated rate. Both the solid block and the powdered iron will be completely consumed by the oxidative process and ultimately release the same amount of heat. The powered iron will appear to give off more heat and attain a higher temperature because it is consumed by the heat producing exothermic process in a few hours as compared to years for the solid block. ThermaCare™ by Proctor & Gamble is engineered to achieve a maximum therapeutic temperature of 104°F (40°C). Oxygen diffusion is controlled by encapsulating the components in a perforated gas impermeable membrane (Ronald Stout MD, Medical Director, The Procter & Gamble Health Sciences Institute. E-mail to W.T. Workman, December 2, 2002).

The concept of air-activated warming devices has been around for many years. Historically they were used as hand and toe warmers for individuals observing or participating in winter sports. Recently, at least two major companies have designed and marketed air-activated warming devices for therapeutic purposes such as relief of muscular pain and stiffness, relief of menstrual cramp pain and associated back pain.

Our objective was to evaluate the relative safety of therapeutic air-activated warmers and similar chemical type hand-warming products under hyperbaric conditions. We tested three different brands of air-activated warming devices. Two therapeutic warmers were evaluated; ThermaCare™ Air Activated Heat Wraps by Proctor & Gamble and Playtex™ Heat Therapy™ heat patches. We speculated that some individuals might replace therapeutic warmers with less costly hand warmers so we also tested Warm Packs by Heat Factory®.

## METHODS

A cylindrical metal container with an internal volume of approximately 4 liters was used as a test vessel. A 1.5 inch (3.8 cm) diameter hole in the lid accommodated sighting for an infrared temperature sensor, and to prevent pressure buildup within the vessel. Each sample was placed on a 3 inch (7.6 cm) tripod in the center of the container to allow circulation of gas around the sample. A gas nipple for admitting oxygen into the container was located 3 inches (7.6 cm) from the bottom of the vessel. A second nipple to withdraw a gas sample for analyzing the oxygen content inside the test vessel was located on the opposite side 3 inches (7.6 cm) from the top. A gas sample was continuously extracted from the vessel, decompressed overboard, and analyzed for oxygen content by a MiniOX I oxygen analyzer (MSA Medical Products, Pittsburgh, PA).

Testing was performed in an 8 x 20 foot (2.4 x 6.1m), 7 atm abs, steel, multiplace hyperbaric chamber. Safety precautions included a fire suit and emergency air breathing mask for the chamber attendant, a fire deluge system, fire hose, and monitoring of the chamber's oxygen percentage. The temperature of the warming device was measured with a Raytek® Model RAYMX2U infrared thermometer, (Santa Cruz, CA, USA). Temperature readings were obtained from a distance of approximately 2 feet (60 cm) and the thermometer was targeted onto a small black dot that was drawn onto each warming device to insure consistency in sighting. The RAYTEKMX2U infrared thermometer has an accuracy of 2°F @73°F. Its accuracy is uncertain at elevated pressures. The manufacturer hypothesizes that values may be falsely low by less than 2 percent.(John Register, RAYTEK service manager, E-mail to the author, September 29, 2004). Temperature readings taken at ambient pressure and at 3 atm abs of ice water and human flesh varied less than the instrument's accuracy specifications

All three brands of warmers were tested twice at 1 atm abs and twice at 3 atm abs. The results reported here are the higher of the two tests. Serial measurements of temperature and oxygen percentage were obtained at one minute intervals throughout each test.

Test 1

The first test consisted of two parts and was conducted solely at 1 atm abs. It determined the product's normal temperature in air and in an environment of at least ninety five percent oxygen. A warming device was removed from its air tight packaging to begin the exothermic reaction and briefly shaken to loosen the components. It was placed inside the test vessel, the lid was closed, and the warming device was allowed to warm until a stable temperature was reached (15-20 min). Oxygen was then added to the container at a rate of 10 L/min. Temperature measurements were recorded until the rising temperature plateaued.

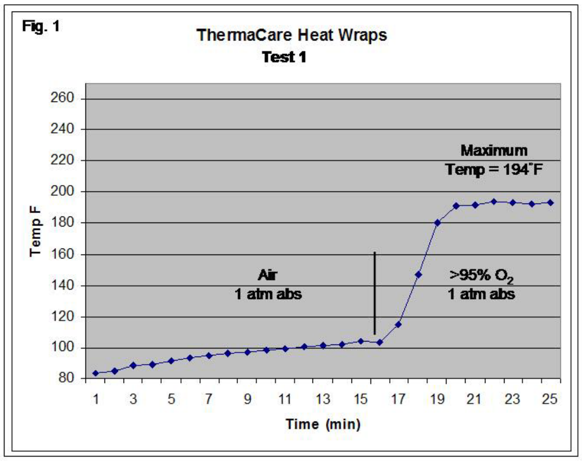
Test 2

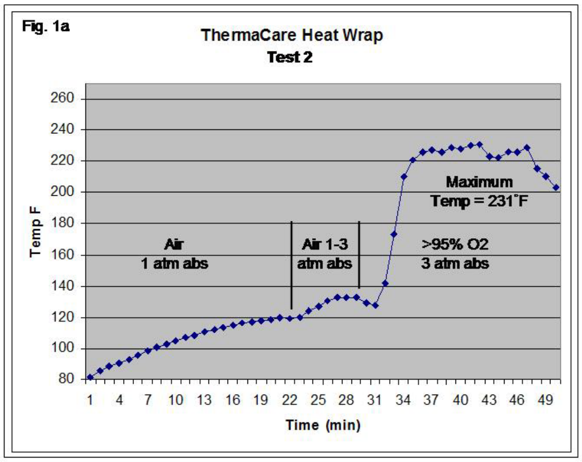
The second test repeated the product's initial warm up in air at 1 atm abs and it was then compressed in a hyperbaric chamber over five minutes to 3 atm abs. When the temperature stabilized, oxygen was added to the container at a rate of 10 L/min. until the temperature plateaued.

RESULTS

ThermaCare™

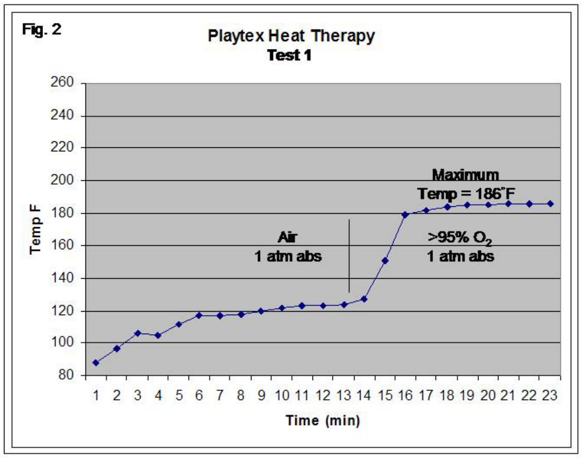
The maximum temperature at 1 atm abs in air was 48.9°C (120°F) and increased to 90°C (194°F) when exposed to at least 95% oxygen. Exposure to 3 atm abs air caused a minimal temperature increase to 55.5°C (132°F). A maximum temperature of 110.5°C (231°F) was measured at 3 atm abs and at least 95% oxygen.

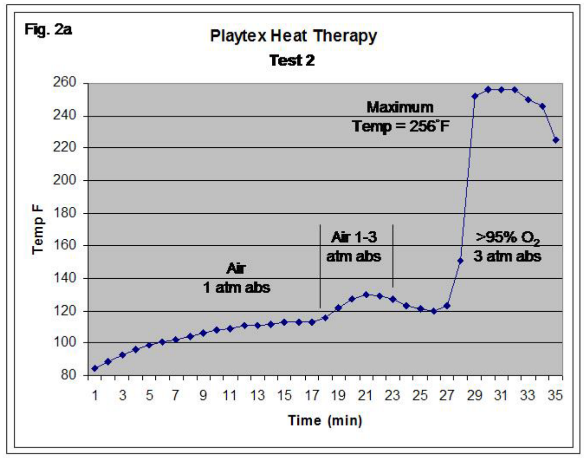


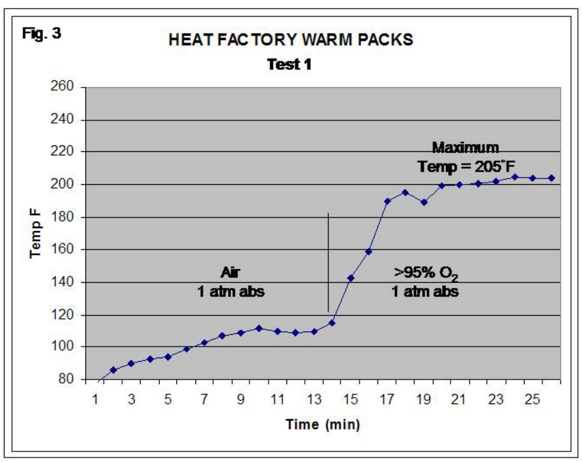

Playtex™ Heat Therapy™

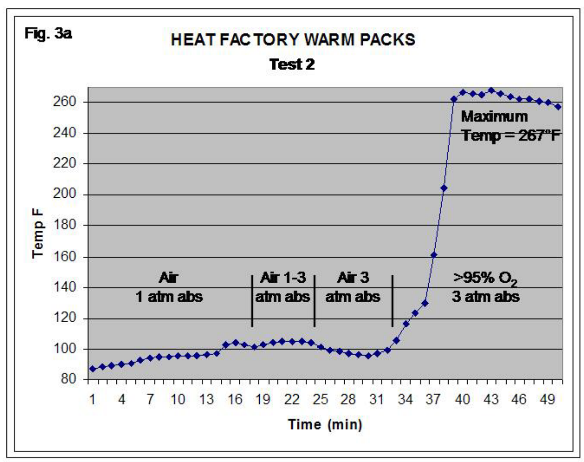
At 1 atm abs in air the greatest temperature was 51.1°C (124°F). When exposed to at least 95% oxygen the temperature rose to 85.5°C (186°F). When pressurized to 3 atm abs in air the maximum temperature rose to 53.8°C (129°F). At 3 atm abs and at least 95% oxygen the maximum temperature was 124.4°C (256°F).

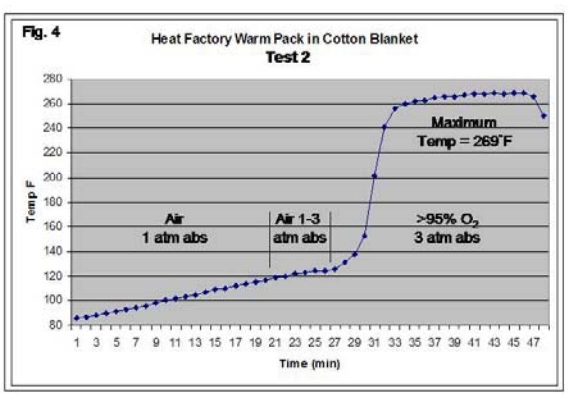



Heat Therapy™: At 1 atm abs in air the highest temperature was 44.4°C (112°F) and dropped to 36.1°C (97°F) at 3 atm abs. In at least 95% oxygen at 1 atm abs the temperature was 96.1°C (205°F) and 130.5°C (267°F) at 3 atm abs.



| **Table 1 Temperatures attained by air-activated chemical warmers under normal, hyperoxic and hyperbaric conditions** | | | | |
|---|---|---|---|---|
| | 1 atm abs<br>Air | 3 atm abs<br>AIR | 1 atm abs<br>>95% Oxygen | 3 atm abs<br>>95% Oxygen |
| ThermaCare™<br>Heat Wraps | 48.9°C<br>120°F | 55.5°C<br>132°F | 90.0°C<br>194°F | 110.5°C<br>231°F |
| Playtex™<br>Heat Therapy | 51.1°C<br>124°F | 53.8°C<br>129°F | 85.5°C<br>186°F | 124.4°C<br>256°F |
| Heat Factory®<br>Warm Packs | 44.4°C<br>112°F | 36.1°C<br>97°F | 96.1°C<br>205°F | 130.5°C<br>267°F |

DISCUSSION

Our tests indicate that raising the ambient pressure to 3 atm abs without increasing the oxygen percentage caused a minimal change in temperature, however all of the products we tested exceeded 110°C (231°F) when exposed to 3 atm abs and at least ninety five percent oxygen. The maximum temperature obtained by any product was 131.6°C (269°F). No spontaneous ignition of the warming devices occurred during any of our tests.

Upon completion of testing we reviewed our testing procedure and concluded that the results may not be reflective of the actual maximum temperature due to heat loss from a lack of thermal insulation. To remedy this perceived test flaw we wrapped a Heat Factory® Warm pack in four layers of cloth obtained from a hospital blanket (100% cotton). We used a Fluke digital thermometer (Fluke Biomedical Corp, Carson City, NV) because the infrared thermometer is not able to measure surface temperature while the warmer was enclosed within the cotton wrap. The thermocouple of the Fluke thermometer was attached directly to the warming device and both were wrapped with the blanket. The test at 3 atm abs and at least ninety five percent oxygen was repeated and the maximum temperature obtained was 131.6°C (269°F), essentially unchanged from the tests without insulation.

## CONCLUSION

When exposed to 3 atm abs pressure and at least ninety five percent oxygen, all of the warming devices exhibited a rapid temperature rise and exceeded 110°C (231°F). Maximum temperatures when exposed to elevated oxygen levels vastly exceed the therapeutic temperature and significantly increase the risk for skin burns. Trans-epidermal necrosis can occur in less than one second if the skin surface temperature reaches 70°C (158°F) and higher (3). It is imperative that health care professionals administering hyperbaric oxygen therapy educate their patients to the potential for thermal burns if these devices were to be used within a hyperbaric oxygen chamber. With manufacturers designing and advertising therapeutic warmers that can be used discretely, chamber operators must remain vigilant to prevent introduction of these devices into their hyperbaric chambers.

Auto ignition temperatures for many materials are known for air environments at 1 atm abs, however less is known for pressurized oxygen environments (4). In general the minimum ignition energy varies inversely with the concentration of oxygen, and also varies inversely with the square of the pressure (5). Therefore the auto ignition temperature goes down as the pressure and oxygen concentration increases. Materials in an oxygen enriched environment that is below their auto ignition temperature do not ignite without an ignition source (6). Exothermic chemical reactions are a potential ignition source when in an oxygen enriched environment (5). Although we did not witness spontaneous combustion during our limited testing, we must emphasize that fire remains a major concern if air-activated chemical warmers are placed in hyperbaric oxygen environments.

REFERENCES:

1. Sheffield PJ, Desautels DA. Hyperbaric and hypobaric chamber fires: a 73-year analysis. Undersea Hyper Med 1997, 24(3):153-164.

2. Barrow G. The heat absorbed or given off in chemical reactions. In: General Chemistry. Belmont CA: Wadsworth Publishing, 1972:446-465

3. Moritz A, Herriques F. Studies of thermal injury: The relative importance of time and surface temperature in the causation of cutaneous burns. Am J Pathol 1947;23:695-720

4. National Fire Protection Association Technical Committee on Oxygen-Enriched Atmospheres, Appendix F Material for Use in Oxygen Enriched Atmospheres, paragraph F-2.1 In: NFPA 53 Materials, Equipment, and Systems Used in Oxygen Enriched Atmospheres, Bryan CJ, (chair), Quincy, MA: National Fire Protection Association, 1999

5. National Fire Protection Association Technical Committee on Oxygen-Enriched Atmospheres, Appendix E Fundamentals of Ignition and Combustion in Oxygen-Enriched Atmospheres, paragraphs E-3.2.2 and E-3.1.4 In: NFPA 53 Materials, Equipment, and Systems Used in Oxygen Enriched Atmospheres, Bryan CJ, (chair), Quincy, MA: National Fire Protection Association, 1999

6. National Fire Protection Association Technical Committee on Oxygen-Enriched Atmospheres, Appendix A Explanatory Material, paragraph A-3-2.2 In: NFPA 53 Materials, Equipment, and Systems Used in Oxygen Enriched Atmospheres, Bryan CJ, (chair), Quincy, MA: National Fire Protection Association, 1999