The Science Behind DHP™ (Dry Hydrogen Peroxide) Technology and the Synexis® BioDefense System

Background Information

The Synexis BioDefense System and DHP technology are the only antimicrobial technologies developed specifically as a countermeasure to bio-terrorism, outbreak, epidemic, and pandemic. Invented by a West Point graduate, Licensed Professional Chemical Engineer, and former US Army Chemical Corps Major, DHP technology is intended for Continuity of Government, Continuity of Business, and Workforce Protection.

In 2005, post-military service, James D. Lee, P.E. identified a critical bio-defense capability void while consulting for the world's largest insurance company in New York City's financial district. Though chemical and radiological hazards could both be detected and identified in real time, there was no available technology that could both detect the introduction of a biological material in real time and distinguish whether it was innocuous or pathogenic. Verifying this real time bio-detection/identification gap, Mr. Lee sought instead to develop a prophylactic solution for facilities using the following criterion to guide his development.

1. The device had to be capable of defeating or mitigating a bio-threat from the moment of its introduction, even if its introduction was unrecognized. This required that the solution operate continuously, 24/7/365.
2. The device had to be capable of defeating or mitigating a broad range of pathogens, including viruses, bacteria, and fungi.
3. The device had to be capable of defeating both airborne and surface contaminating microbes.
4. The device had to be safe for use in occupied areas on a continuous basis.
5. The device had to require little attention or maintenance.

After studying and rejecting ozone generators and ozone-producing photo-catalytic air purifiers as unsafe, Mr. Lee noted that the photo-catalytic air purifiers used humidity to produce a plasma containing halves of hydrogen peroxide molecules (hydroxyl radicals), but did not produce hydrogen peroxide, the plasma decaying back into humidity instead. To overcome this limitation, Mr. Lee invented a novel means of refining the plasma to separate the hydroxyl radicals from the subatomic particles, so that the hydroxyl radicals could then combine to form Hydrogen Peroxide Gas.

This resulted in the invention of DHP technology, which met all five of the design criteria he had established and, as development continued, additional unanticipated benefits of DHP technology were discovered. To date, Synexis® LLC has been granted 14 US patents covering methods of DHP production, DHP devices, and applications/uses of DHP, to include the use of DHP to kill both airborne and surface contaminating microbes in an environment.[1] An additional 16 US patents are pending. Synexis holds sole developer status for DHP and Hydrogen Peroxide Gas technology.

DHP Devices and Technology

Overview

Synexis is the first company to create and patent Dry Hydrogen Peroxide (DHP), the true gas form of hydrogen peroxide. Made from naturally occurring elements already in the air, DHP is designed to safely and effectively break down pathogens—flowing freely and continuously through indoor spaces to reduce the presence of microbes in the air and on surfaces, with no reliance on the exchange of air.

Every indoor environment naturally contains ambient oxygen and humidity. Synexis-patented DHP technology breaks these molecules apart into plasma, refines the plasma, and reassembles them into DHP. Since DHP molecules are polar, they are attracted to vulnerable polar functional groups on microbes and denatures them. DHP denatures exterior structures such as viral glycoproteins and breaks down a microbe’s lipid or cell membrane leading to its destruction.

Device Description

DHP devices use a proprietary photo-catalyst to produce DHP. The photo-catalyst is applied to a framed polyester fiber mesh, which is placed within a regulated airflow. Upstream of the photo-catalyst-coated mesh is an ultraviolet bulb operating in the UV-A range and centered on 363 nanometers. An electronic ballast housed within the device casing draws standard voltage and uses it to power the bulb.

DHP devices from Synexis can be mounted in heating, ventilation, and air conditioning (HVAC) systems (the Synexis product known as the Blade), or employed on a standalone basis (the Sentry and the Sphere). The HVAC-mounted device relies on the filters and fans of the HVAC system. Standalone units have their own on-board filters at the device air intake and fans within the device case between the filter and the bulb. A simple grille covers the output of the device (See **Figure 1** and **Figure 2**). DHP devices currently on the market are *Underwriters Laboratory* (UL) tested and approved to establish their safety and that they do not produce ozone.[2] New device models undergo UL testing as soon as development is complete.

Figure 1 – The Synexis Blade (In-line Device)

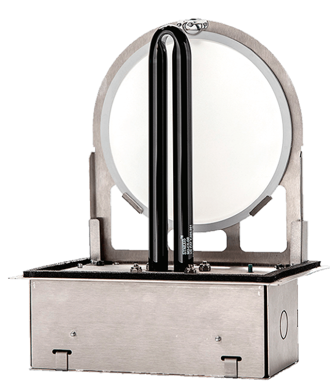

Figure 2 – The Synexis Sphere (Standalone Unit)

Device Chemistry

How DHP Is Created

First, a UV-A bulb is used to activate the catalyst. Photons from the bulb impart energy to electrons in the catalyst, promoting them out of valence band energy levels into conduction band energy levels, where they become free electrons (e^-) that can participate in chemical reactions. As a result, an absence of an electron, referred to as an electron hole (h^+), is created in the valence band for each electron promoted to the conduction band. The photocatalyst itself is not consumed.

$$2\text{Photons} + \text{Photo-Catalyst} \rightarrow \text{Photo-Catalyst} + 2e^- + 2h^+$$

The photo-catalyst is hydrophilic and absorbs ambient humidity from airstreams. Adsorbed water molecules naturally locate themselves at active sites on the catalyst. Electron holes migrate to the active sites and immediately scavenge electrons from the adsorbed water molecules located at the active sites. This fills the electron holes, preventing the electrons that were promoted to the conduction band from decaying back down into the lower energy valence band and holding the free electrons at the higher energy state, keeping them available for subsequent chemical reactions.

The removal of an electron from a water molecule also results in the release of a proton (also called a hydrogen ion, H^+) and the creation of a hydroxyl radical (OH^*, which is half of a hydrogen peroxide molecule).

$$2h^+ + 2H_2O \rightarrow 2H^+ + 2OH^*$$

The species now available on the photo-catalyst are the free electrons (e^-), the protons (H^+), and the hydroxyl radicals (OH^*). If these three species all remain in the same physical space, they will simply recombine and form water molecules again, which is the thermodynamically favored reaction, and is what happens in old photo-catalytic air purifier technology.

$$2e^- + 2H^+ + 2OH^* \rightarrow 2H_2O$$ *(undesired reaction taking place in older technology)*

Even though the unrefined plasma does contain halves of hydrogen peroxide molecules (2OH*), any putative hydrogen peroxide produced in the unrefined plasma will be immediately destroyed in favor of the production of water, the most thermodynamically stable product.

This can be viewed as an "If, then" scenario:

If: $2OH^* \rightarrow H_2O_2$ *(Theoretical formation of hydrogen peroxide in unrefined plasma)*
Then: $2e^- + 2H^+ + H_2O_2 \rightarrow 2H_2O$ *(Thermodynamically favored reaction in unrefined plasma)*

The fact that the laws of thermodynamics do not favor the formation of hydrogen peroxide from unrefined plasma is observable in nature. Even though hydroxyl radicals (OH*) can temporarily be formed from ambient humidity by environmental energy sources such as lightning and solar radiation, there is no accumulation of hydrogen peroxide either in our atmosphere, or in our lakes and oceans.

To overcome the thermodynamically favored reactions, which prevent the formation of stable DHP molecules that can be released into the environment, DHP technology physically separates or refines the plasma into two parts. Neutrally charged hydroxyl radicals (OH*) are separated from the catalyst without separating the charged subatomic particles along with them – the free electrons (e^-) and the protons (H^+) remain on the catalyst. **This is the breakthrough technical advance of DHP technology that sets it apart from other technologies.** By separating the plasma in this manner, it is now possible to make DHP by both oxidation and reduction reactions.

The hydroxyl radicals separated from the photo-catalyst simply combine to form DHP. This is the Oxidation reaction.

$2OH^* \rightarrow H_2O_2$ *(Oxidation reaction producing DHP in separated plasma)*

The corresponding reduction reaction is separately accomplished by using ambient oxygen in the air to collect the free electrons and the protons from the photo-catalyst, producing yet more DHP in the process.

$2e^- + 2H^+ + O_2 \rightarrow H_2O_2$ *(Reduction reaction producing DHP in separated plasma)*

How DHP Moves Through Indoor Spaces

The DHP produced in this manner is a true gas like oxygen or nitrogen and behaves in a near ideal manner because it is dilute. It is completely non-aqueous and becomes part of the air, transported by convection and diffusion like any other gas into an even distribution throughout the covered area. Also, DHP is not appreciably heavier or lighter than air. DHP's molar mass (34.016 grams per mole) is just 2.016 grams per mole greater than that of oxygen (32.00 grams per mole). DHP is actually closer in mass to oxygen than is nitrogen (28.135 grams per mole, 3.865 grams per mole lighter than oxygen). Because it is so close in molar mass to oxygen, DHP diffuses from floor to ceiling in a room.

DHP equilibrium concentrations in an environment (open room) measured by Interscan and Picarro sensors have an upper limit of approximately 25 parts per billion (ppb),[3] though transient concentrations as high as 40 ppb can be measured in close proximity to DHP production devices (within 2 feet). At a 10 ppb equilibrium concentration there is approximately one molecule of Dry Hydrogen Peroxide in every four cubic microns of air.* This means that there are 2.5 x 10^{17}, molecules of DHP in a cubic meter of air, or 250 billion DHP molecules in a cubic centimeter.

It should be noted that this DHP concentration is far lower than the concentration of hydrogen peroxide in an aqueous droplet (over 1 billion molecules per cubic micron for just a 3% solution), lower than the OSHA workplace safety limit (1 ppm Time Weighted Average over a 40 hour work week), lower than the continuous exposure safety limit (238 ppb Time Weighted Average), and even lower than the equilibrium concentration of hydrogen peroxide maintained in our airways, lungs, saliva, and tears by the lactoperoxidase enzyme system (10^{-6} Molar, or 602 molecules per cubic micron of lung secretion).

DHP acts on viruses and other microbes both in the air and on every surface in contact with the air. This action takes place continuously because DHP devices continuously produce DHP. This continuous action also constantly replaces DHP as it is consumed in the environment, maintaining an effective equilibrium concentration.

At 10 ppb of DHP in the air, a pathogen (including the known SARS-CoV-2 virus) will encounter 250 thousand molecules of DHP directly in its path as it moves one linear meter through the air. This is the equivalent of 2,500 DHP molecules per linear centimeter; 6,350 DHP molecules per linear inch; 76,200 DHP molecules per linear foot; and 457,200 DHP molecules per six feet (the recommended spacing for social distancing) of linear travel. Also, a virus will pass within a cubic micron of eight times as many additional DHP molecules occupying neighboring cubic microns of air (picture a virus passing through the center squares in a long series of a Tic-Tac-Toe puzzles with one DHP molecule in each center square and one in each of the eight surrounding squares of every other successive puzzle).

Another way to look at the distribution of DHP is that there are a trillion cubic microns per cubic centimeter and a cubic centimeter will contain 250 billion molecules of DHP at 10 ppb.

Further, DHP molecules have polar oxygen-hydrogen bonds, so they are attracted to polar functional groups on pathogens, actually causing the DHP molecules to draw closer to nearby viruses. Picture, for example, a submarine (the virus) passing through a dense magnetic minefield (the DHP molecules).

DHP molecules also depose onto all surfaces (top, bottom, sides, and exposed openings of a desk, bed, privacy curtain, or other object) that are in contact with the air in areas where DHP technology is in use. SARS-CoV-2 virus or other pathogens contaminating a surface are steadily and continuously bathed by DHP 24/7/365. At 10 ppb, the density of DHP molecules in the micron high layer of air immediately above a given surface is 25 million DHP molecules per square centimeter, with more DHP continuously diffusing toward the surface.

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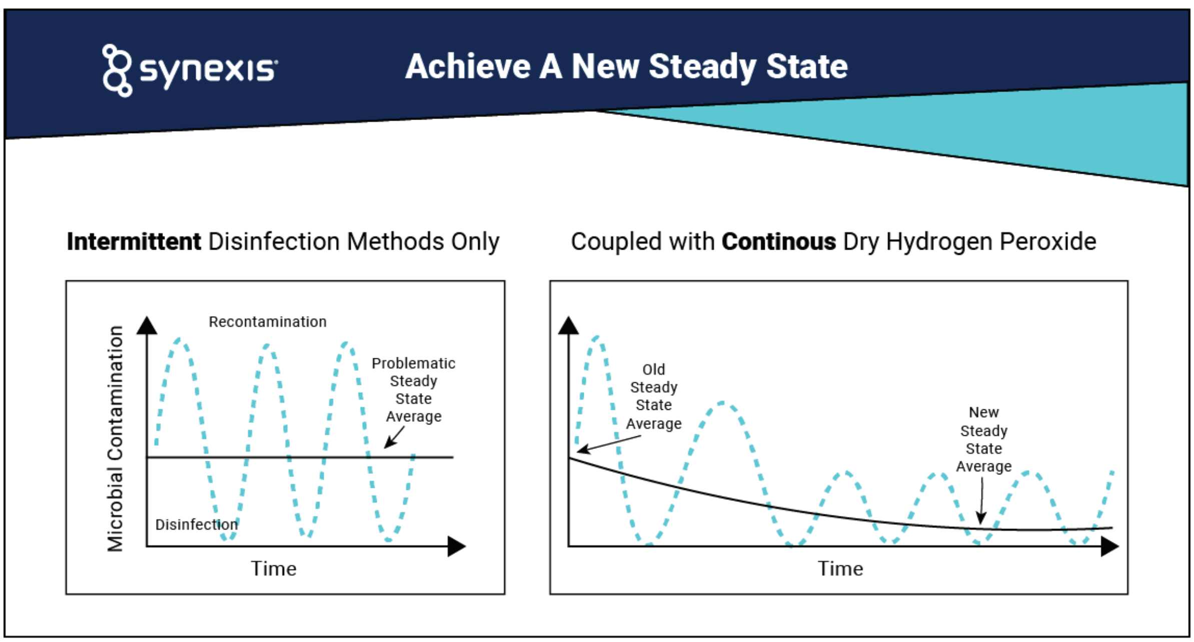
*Calculated using the Molar Gas Constant of 22.4 Liters per Mole at Standard Temperature and Pressure (0 Celsius, 1 atmosphere), then converting to room temperature at standard pressure using the Ideal Gas Law, giving approximately 24 liters per mole, then using dimensional analysis and Avogadro's Number to convert to molecules per cubic micron at 10 ppb.

The Benefits of DHP Technology

The greatest benefits of DHP in the environment are its ability to continuously reduce microbial contamination 24/7/365 and its ability to act on microbes both in the air and on surfaces. This off-sets the key disadvantages of registered disinfectants, specifically that they can only be used intermittently, and that they are primarily useful only on surfaces. The coupling, however, of a continuous, airborne, low concentration antimicrobial compound like DHP with the established intermittent surface use of registered disinfectants is both synergistic and powerful.

Because DHP devices work continuously in occupied environments over a broad area, they offset the key disadvantages inherent to registered disinfectants (that they are intermittently used and surface-focused). DHP is delivered through the air, and not only works continuously in the air, but also continuously on frequently cleaned surfaces between cleanings, on surfaces that are missed during cleanings, and on surfaces that are never cleaned at all. The result of using DHP continuously, coupled with the intermittent use of a registered disinfectant is a meaningful reduction in steady state surface bioburden by up to 99% compared to the baseline use of registered disinfectants alone. **Figure 3** provides a graphical representation of the observed reduction in steady state surface bioburden.

Figure 3 – Steady State Surface Bioburden



There is an understandable tendency to compare the rate of kill by DHP directly to the rate of kill of EPA registered disinfectants, but this is a false comparison. EPA registered disinfectants are designed to achieve rapid high log kills by means of a single, short application. They are, by nature and design, comparatively harsh and intended to be used only intermittently. By contrast, DHP technology is designed to be safe for continuous use in occupied spaces while providing steady kill everywhere. The two modes of action are exclusive to each other, yet complimentary, and there is a need for both. The synergy between the two modes of cleaning is significant, as shown in the steady state contamination graph above.

Deploying Synexis

Wherever air goes in an indoor facility, so too does Synexis-made DHP to safely reduce the presence of microbes in air and on surfaces, with no reliance on the exchange of air. Synexis is currently used across a variety of facilities, including government, industry, universities, food service, and healthcare—but it can be deployed in any occupied, indoor space.

From identifying the environmental issues of any facility to analyzing present cleaning practices, and assessing the proper placement of products, Synexis can design a plan to assure that any company or organization gets the right fit.

For more information, get in touch at Synexis.com.

References: 1. Synexis® LLC. (2020, December). *Patents.* https://synexis.com/patents **2.** Synexis® LLC (2020, December). *Underwriters Laboratory Approval.* **3.** Picarro. *PI2114 Gas Concentration Analyzer.* https://www.picarro.com/products/pi2114_gas_concentration_analyzer