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3615 HARDING AVE. • SUITE 308 • HONOLULU, HAWAII 96816
(808) 735-0422 • FAX (808) 735-0047
TECHNICAL EXPERTS CONSULTING IN
ENVIRONMENTAL • FORENSIC • OCCUPATIONAL AND LABORATORY SERVICES

16 November 1996

Visionsafe
PO Box 5011
Kaneohe, Hawaii 96744

Att'n: Mr. Bertil Werijefelt, President

Re: ***Oxygen canister generator tests***.

Dear Mr. Werijefelt:

We have completed our examination and laboratory testing of various 3-person oxygen generating canisters referenced above. We have focused our laboratory investigation on assaying the possibility or ***likelihood*** of these canisters playing a significant role in the initiation of the fire during their transportation or shipment in an airline cargo hold.

Specifically we addressed the ***likelihood*** of these canisters "activating" upon impact or movement during takeoff, and in the event of activation, their intrinsic potential to ignite and subsequently initiate sustainable combustion.

Our conclusions and opinions are based upon the finite scope of the experimental work described below, my broad, 20 year experience in arson investigation as a forensic chemist practicing in Honolulu, Hawaii, and my theoretical (my Doctorate is in chemistry) background in the field of chemistry.

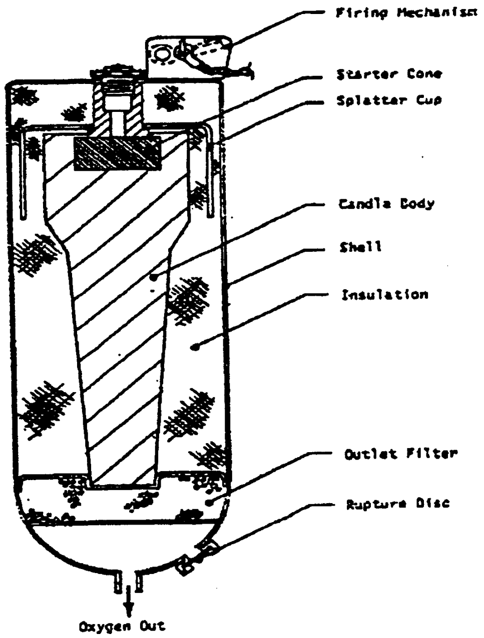
BACKGROUND

Chemical oxygen Supplies

The 3 person oxygen generating units examined are composed of an internal, carefully shaped sodium chlorate "candle". This "candle" is encased in a rigid, thermally insulated stainless steel housing. The candle is held at the top and the bottom for vibration and shock resistance . Once the generating unit is activated, through the action of a mechanical plunger impacting on a pre-formed "starting" button, the internal chlorate candle undergoes a slow, steady, self-sustaining, combustion. The geometrical properties of this candle are carefully adjusted to provide a controlled thermal decomposition of the chlorate, resulting in a steady, slowly decreasing flow rate, generation of oxygen. The nominal reaction rate of the candle is approximately ¼ inch of its overall length per minute of time.

Immediately upon activation, these 3-person oxygen units generate a flow rate of approximately 3 to 4 liters of oxygen per minute, slowly but discretely tapering off to approximately 0.1 to 0.2 liters per minute after 15 to 17 minutes.

A typical schematic diagram of the sodium chlorate "candle" 3 person canister is displayed figure one below. The dimensions are left unassigned because they are dependent upon the application and capacity (1, 3 or 5 person).



Typical Sodium Chlorate Based Oxygen Generation Canister.

Reliability and Safety

Chlorate based oxygen supplies have been safely stored, transported and utilized for many years. They have undergone extensive reliability testing in the aviation industry and are the subject of numerous technical evaluation reports. They have been commonly and reliably adapted for use in aviation since the mid-1 960's when they were first employed on removable, palletized, seats for military aircraft.

The canisters are equipped with pressure release mechanisms in case of mechanical blockage at the exit nozzle.

Upon exposure to an existing fire, chlorate oxygen canisters have been shown NOT to materially affect the character or progress of the fire. The canisters must be brought to their autoignition temperature (in excess of 400 F) by "heat soaking" prior to their activation. Heat soaking refers to a continuous, long term (several minutes, depending upon packaging or storage containers) intensely hot, completely encompassing fire. Once activated the oxygen is vented over a period of time, likely to be faster than the original programmed release but NOT as a single burst. Under these circumstances, over time, localized in the immediate vicinity of the exit port, focused fire intensity would be expected to increase, but NOT in a catastrophic fashion.

Principles of Combustion

Various fundamental principles apply to the science of combustion. A the apex of these principles is the crucial fact that four "elements of combustion" must be present in order for a fire to occur:

1) Combustible fuel must be present.
2) An oxidizer (such as oxygen in the air) must be available in sufficient quantity (a limiting NOT catalyzing factor).
3) Energy of some means of ignition (e.g. a spark, an electrical source, heat must be applied.
4) The fuel and the oxidizer must interact in a self-sustaining manner.

In order for a fuel (e.g., packing material, paper, jet fuel, plastic wrapping) to combust (in the presence of an oxidizer) it temperature must be raised to the "ignition temperature" (sometimes referred to as the autoignition temperature"). This property of ignition temperature relates to the "energy threshold" or thermodynamic energy barrier which must be over come before the material will react with an oxidizer (e.g., oxygen in the air). Some examples of ignition temperatures are shown in the table below:

Table 1. Minimum Ignition Temperatures of Some Common Flammable Substances[1]

SUBSTANCE	IGNITION TEMPERATURE (°C)	IGNITION TEMPERATURE (°F)
Acetone	537	1000
Fuel oil #2	257	495
Gasoline (varies with grade)	280	536
Petroleum ether	288	550
Paper	230-260	440-500

Typically, ignition temperatures of common packing materials are greater than 230 °C (440°F).

An important, industry wide misconception, is that oxygen in and of itself effects the "ignition temperature" of solid or liquid fuels. The presence of oxygen is a necessary and *limiting* condition for combustion. However, oxygen DOES NOT in an of itself, make a fuel more susceptible to ignition, nor does it "lower" a material's fundamental ignition temperature. Whether at 20% (as in air) or at 100% concentrations, oxygen remains an oxidizer, simply a limiting "reactant" in the overall chemical equation for combustion . . . nothing more. Oxygen DOES NOT effect the thermodynamic energy barrier (the ignition temperature) of the reaction. Oxygen does not serve in a catalytic sense. It will not lower the fundamental activation energies of reactions.

To the lay person this translates to the following observation:

There is absolutely ***<u>no difference</u>*** in the ***potential for ignition*** of a flammable substance in contact with a heat source possessing a temperature ***below*** the ignition temperature of the substance, whether it be placed in ambient room air (with an oxygen concentration of 20%) or in a 100 % saturated oxygen environment. The substance will simply ***not ignite*** in ***either*** environment if the heat source temperature is *less* than the substance's fundamental ignition temperature.

OUR INVESTIGATION

Armed with the principles outlined above, we conducted a series of laboratory "challenges" employing the 3-person version of the chlorate candle based oxygen generating canisters. These challenges or experiments were conducted Honolulu, Hawaii during the first half of November.

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[1] Turner, C.F., and McCreery, J. W., *The Chemistry of Fire and Hazardous Material*, NFPA Fire Protection Guide on Hazardous Material, 9th ed. NFPA, Quincy, MA ,1986.

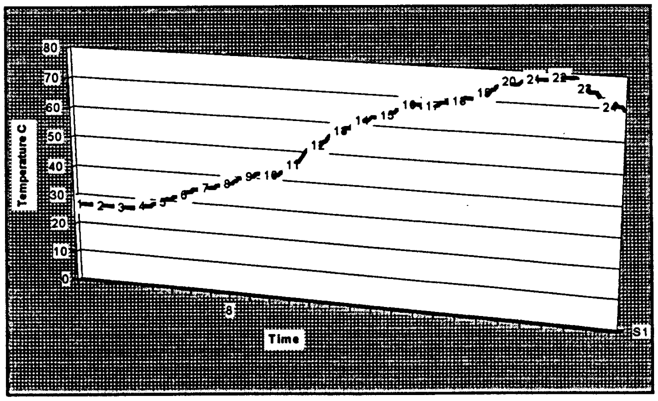
Three of the experiments consisted of activating the canisters and measuring various external temperatures with a thermocouple and computerized data capturing system (a Toshiba laptop microcomputer). The fourth experiment had to do with the mechanical abuse of a representative 3-person cylinder simulating agitation or movement upon landing or take-off. The prefix of each experiment has been labeled with the name "Kessler". There were four experiments conducted over a five day period. These were labeled Kessler 1 through 4.

The Experiments

⇒ Kessler 1

The experiment "Kessler 1" examined the temperature of the oxygen stream exiting directly out of the canisters delivery port as a function of time. The 3-person canister was placed in its cardboard shipping container and closely associated with various solid, flammable, packing materials (tissue paper, air filled polyethylene packing, paper and cardboard wrapping sheets). Once these items had been placed in intimate contact with the oxygen generating unit, the temperature probe was situated in the direct path of the oxygen outlet to measure the temperature of the eluant as it was generated. Upon removal of the canister activating pin (by forcefully pulling it from its safety position) the oxygen generation begins. The cardboard shipping container lid was then closed and taped lightly shut. This simulated a saturated oxygen filled environment, <u>intimate</u> contact with nonvolatile flammable, solids and an insulated confined space where possibilities for thermal convective cooling was significantly attenuated. The temperature vs. time was recorded, and the entire experiment (conducted in a fire resistant fume hood) was video taped. A chart of temperature vs. time is shown below. This experiment lasted approximately 24 minutes. The upper temperature of the exiting oxygen flow never exceeded 80 °C. Each minute is designated by numerical embodiment within the curve itself.

Temperature of O2 exhaust vs. time



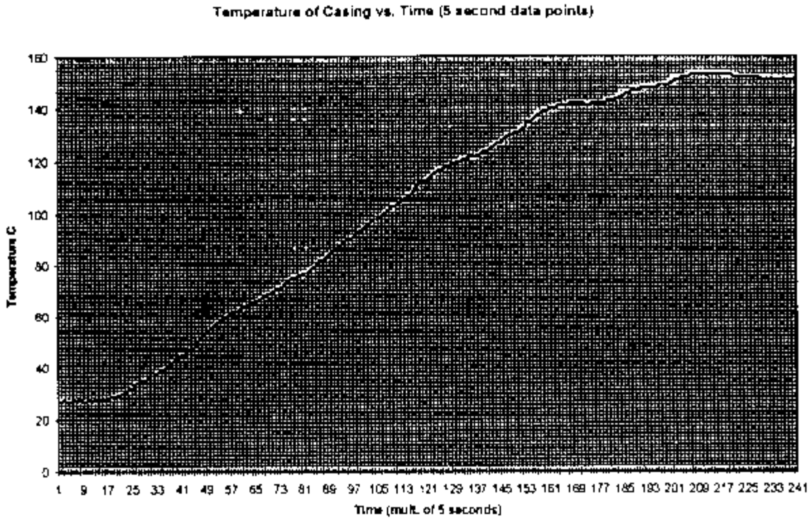
Throughout this experiment there were no fires or incidents of combustion noted.

=:> Kessler 2

The experiment “Kessler 2”was designed to examine variation of temperature of the outer stainless steel canister shell as a function of time. This time the 3-person canister was placed in its cardboard shipping container and deliberately “contaminated" with bearing grease (wheel bearing grease was chosen to simulate the unlikely occurrence of soiled hands, etc. rubbing copious amounts of wheel bearing grease on the outer surface of the oxygen canister itself). Additionally a variety of packing materials were placed in intimate contact with the canisters stainless steel shell and directly in line with the oxygen delivery port. These packing wares consisted of tissue paper, air filled polyethylene packaging material, paper and cardboard sheets and pieces. We also simulated contamination of these materials with a semivolatile, flammable, light, lubricating oil (WD-40) prior to packaging (it was "sprayed" on the packing materials). Once all of these items had been placed in intimate contact with the oxygen generating unit, the temperature probe was taped directly on the outer generator steel shell. In this manner the rise in temperature of the shell could be monitored as a function of time. The canister activating pin was forcefully pulled out from its safety position and the oxygen gas generation initiated. Upon initiation, the shipping container lid was closed, and taped lightly shut. Once again, this experiment simulated the effects of canister heat, a saturated oxygen filled environment, intimate contact with volatile and nonvolatile flammable, liquids and solids, and an insulated confined space where possibilities for thermal convection (providing cooling) was significantly attenuated or substantially eliminated. Temperature vs. time was recorded, and the entire experiment (conducted in a fire resistant fume hood) was video taped.

A chart of recorded temperature vs. time is displayed below. This experiment lasted approximately 20 minutes. Each minute is approximately 12 five second units displayed on the ordinate of the chart presented below. The upper temperature of this canisters outer shell reached approximately 155 OC before beginning to slowly decrease.

As with experiment Kessler 1 above, there were no fires or incidents of combustion noted.



=> Kessler 3

The experiment "Kessler 3" was also conducted to examine variation of temperature of the outer stainless steel canister shell as a function of time. However, this challenge was specifically designed to represent a worst possible case. In this experiment the 3-person canister was placed in its cardboard shipping container and "contaminated" with copious amounts of JET FUEL (A). As with experiments Kessler 1 and 2, a variety of JET FUEL soaked packing materials were placed in intimate contact with the canister stainless steel shell and directly in line with the oxygen delivery port. Once again these packing wares consisted of tissue paper, air filled polyethylene packing material, paper sheets and cardboard pieces. Once all of these items had been placed in intimate contact with the oxygen generating unit, the temperature probe was taped directly onto the outer generator steel shell. In this manner the rise in temperature of the shell could be monitored as a function of time. The canister activating pin was forcefully pulled out from its safety position and the oxygen gas generation initiated. Upon initiation, the shipping container lid was closed, and box with its contents (quite full this time) was taped tightly shut.

This experiment / challenge simulated the worst possible case, e.g., a saturated oxygen filled environment, intimate contact with volatile and nonvolatile flammable JET FUEL and solids, and an insulated confined space where possibilities for thermal convection were substantially eliminated. Temperature vs. time was recorded, and the entire experiment (conducted in a fire resistant fume hood) was video taped. The temperature vs. time curve was very similar to Kessler 2 with the important exception that in the highly confined, thermally insulated and sealed box the temperature of the outer shell reached 2070C and held temperature for approximately 7 minutes longer before beginning to taper off and decrease.

Once again, as with experiments Kessler 1 and 2, *in addition* to experiencing highly unlikely and severe circumstances as described above, there were no fires or incidents of combustion noted.

=> **Kessler 4**

The experiment "Kessler 4" was conducted to assay the mechanical integrity of the oxygen generating canisters. A single canister was held at an approximate 6 foot height and dropped to the floor. It was dropped four times, each time positioned on a different axis prior to release and subsequent impact. This experiment was conducted to simulate substantial mechanical abuse (occurring during takeoff and or landing on an aircraft) and its potential for activation of the units. Both ends were severely bent and damaged after the repetitive 6 foot falls and subsequent impact, but in no instances was the generator activated.

RESULTS

The oxygen generating canisters examined were ***incapable*** of initiating or igniting any of the fuels (including JET FUEL) we examined even under severe, and unlikely circumstances involving confinement, saturated oxygen atmospheres, intimate thermal contact and heated insulated circumstances.

The oxygen generating canisters tested were simply not susceptible to inadvertent "activations through substantial physical abuse. The outer stainless steel canister, the highly insulated "starting button", the rigidly positioned activating pin and the adequately supported internal sodium chlorate "candle" were unaffected by repeated impact after falling from a six foot height.

DISCUSSION

The canisters are incapable of initiating or igniting fuels which possess ignition temperatures in excess of the upper canister shell temperature maximum. This is thermodynamic effect and is true regardless of the oxygen concentration surrounding the fuel. The oxygen acts as a necessary and limiting reactant in the oxidation of "fuel” to carbon dioxide, water and other trace gaseous constituents formed upon combustion.

Because of the extremely rugged, steel construction and the highly insulated nature of the oxygen generating units, inadvertent "activation" due to moderate physical abuse is considered to be extremely unlikely.

Even in the unlikely event that one or more cylinders were activated by some as yet unknown and unlikely process we have shown with our experiments above that the oxygen canisters could not initiate a fire, even in intimate, insulated, oxygen saturated contact with JET FUEL.

CONCLUSION

We suspect that with respect to the Valuejet disaster, other more plausible and likely possibilities for fire ignition and initiation are to be considered. We are uncertain which of many distinct possibilities are most likely (and therefore responsible), but <u>certainly</u> electrical origin, other cargo of a potentially hazardous nature, mechanical initiation, or even criminal activity should still be actively pursued. It is noteworthy to observe that fires involving electrical wire insulation typically generate copious amounts of soot and smoke for small masses of highly pyrolyzed insulation material. Substantial insight into the cause and origin of the fire on board the Valuejet may be gleaned from the chemical analysis of the soot noted to be present on debris collected from the crash site.

The common, popular, misconception (one typically accepted by the Press and Newscasters) is that the mere presence of oxygen and any fuel spells immediate and certain disaster. This common misconception must be discarded in light of the thermodynamic reality of the situation.

Just because a reaction can occur does not mean it will occur unless fundamental energy thresholds are achieved. The energy barrier to the reaction, whether it be the oxidation of iron (rusting) in air or the oxidation of paper (fire) in a 100% oxygen environment, must be exceeded before combustion can occur.

The summation of one improbable event (the inadvertent mechanical activation of one or more canisters) with a second (the possibility of severe contamination, or the direct, intimate contact with, a low ignition point fuel), and with a third (the common misunderstanding of an immediate and catastrophic, phantom "catalytic effect of oxygen) makes the overall probability of the oxygen generation canister involvement about as likely as a snow storm in Miami.

I hope that as you read through this Analytical Brief of our work, you realize it is of a preliminary nature. Once again, our conclusions and opinions are based upon the finite scope of the experimental work described above, my broad, 20 year experience as a practicing forensic chemist and examiner in arson investigation in the State of Hawaii, and our theoretical and applied background in chemistry.

Further work may be necessary to adequately address all issues and variables involved in this very complex situation.

Should you have any questions regarding the results presented above, the experimental methodology employed for obtaining those results or the theoretical basis for our opinions, please don't hesitate to contact me directly.

Sincerely,

Mark R. Hagadone, Ph.D., BCFE
For INALAB, INC.