

Open Source System for Decontamination of PPE using Vaporized Hydrogen Peroxide

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Legal Notice: Patent Pending

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Summary

Due to the coronavirus pandemic there is a worldwide shortage of PPE including N95 masks. We present an improvised system to decontaminate PPE & equipment using vaporized hydrogen peroxide with commercial off the shelf hardware. Commercial hydrogen peroxide vapor generators are very expensive (\$50k+), proprietary, and often have long delivery times. These devices operate by producing vaporized hydrogen peroxide in the range of 200-1000 ppm over a specified amount of time, generally from 30 minutes to 180 minutes. In our testing we've found that we are able to achieve comparable levels and results using off the shelf components for a fraction of the cost. Our process was verified using *Bacillus atrophaeus* and *Geobacillus stearothermophilus* biological indicators. Vaporized Hydrogen Peroxide produced using commercial off the shelf humidifiers fills an emergency need for a cost effective and readily available way to decontaminate PPE and medical equipment.

Warning

VAPORIZED HYDROGEN PEROXIDE is an extremely harsh chemical and can cause SEVERE IRRITATION, BURNS, & DEATH. Anyone seeking to duplicate these results is advised to take appropriate precautions when handling materials. This information is being provided under Good Samaritan Law. The process described herein is not approved by the CDC, FDA, EPA, or any other government agency. We have made every effort to validate our claims but individual results may vary. The authors and OXYFOG claim no responsibility for damages or injury. This information is provided for INFORMATIONAL PURPOSES ONLY, DOES NOT CONSTITUTE THE PROVIDING OF MEDICAL ADVICE and IS NOT INTENDED TO BE A SUBSTITUTE FOR INDEPENDENT PROFESSIONAL MEDICAL JUDGMENT, ADVICE, DIAGNOSIS, OR TREATMENT. Use or reliance on any content provided by OXYFOG is SOLELY AT YOUR OWN RISK. THE AUTHORS MAKE NO REPRESENTATIONS OR WARRANTIES OF ANY KIND (EXPRESS OR IMPLIED) RELATING TO ACCURACY, COMPLETENESS, SAFETY, USEFULNESS, USABILITY, MARKETABILITY, PERFORMANCE, OR OTHERWISE OF THE CONTENT POSTED, EMAILED, TRANSMITTED, OR OTHERWISE MADE AVAILABLE. People or entities attempting to use the content, statements, or information provided by OXYFOG in any way, including creating products or offering services, assume all risk and responsibility related to those uses, including all legal and regulatory compliance, safety, efficacy, performance, design, marketability, title, and quality. The Authors assume no liability related to the actions of third parties and in respect of any infringement of any patent, copyright, or other right of third parties. Proceed with caution at your own risk.



STRONG OXIDIZER * CORROSIVE TO SKIN * IRRITANT

DANGER - VAPORIZED HYDROGEN PEROXIDE – DANGER

Hazard Statements

H318 - Causes serious eye damage

H302 - Harmful if swallowed

H332 - Harmful if inhaled

H335 - May cause respiratory irritation

H315 - Causes skin irritation

H270 - May cause or intensify fire; oxidizer

Precautionary Statements - Prevention

P271 - Use only outdoors or in a well-ventilated area

P261 - Avoid breathing mist/vapors/spray

P280 - Wear protective gloves/ protective clothing/ eye protection/ face protection

P210 - Keep away from heat/sparks/open flames/hot surfaces. - No smoking

P221 - Take any precaution to avoid mixing with combustibles/flammables

P220 - Keep/Store away from clothing/flammable materials/combustibles

Precautionary Statements - Response

P305 + P351 + P338 - IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing

P310 - Immediately call a POISON CENTER or doctor

P302 + P352 - IF ON SKIN: Wash with plenty of water and soap

P332 + P313 - If skin irritation occurs: Get medical advice/ attention

P362 + P364 - Take off all contaminated clothing and wash it before reuse

P304 + P340 - IF INHALED: Remove person to fresh air and keep comfortable for breathing

P312 - Call a POISON CENTER or doctor if you feel unwell

P301 + P312 - IF SWALLOWED: Call a POISON CENTER or doctor if you feel unwell

P330 - Rinse mouth

P370 + P378 - In case of fire: Use water for extinction

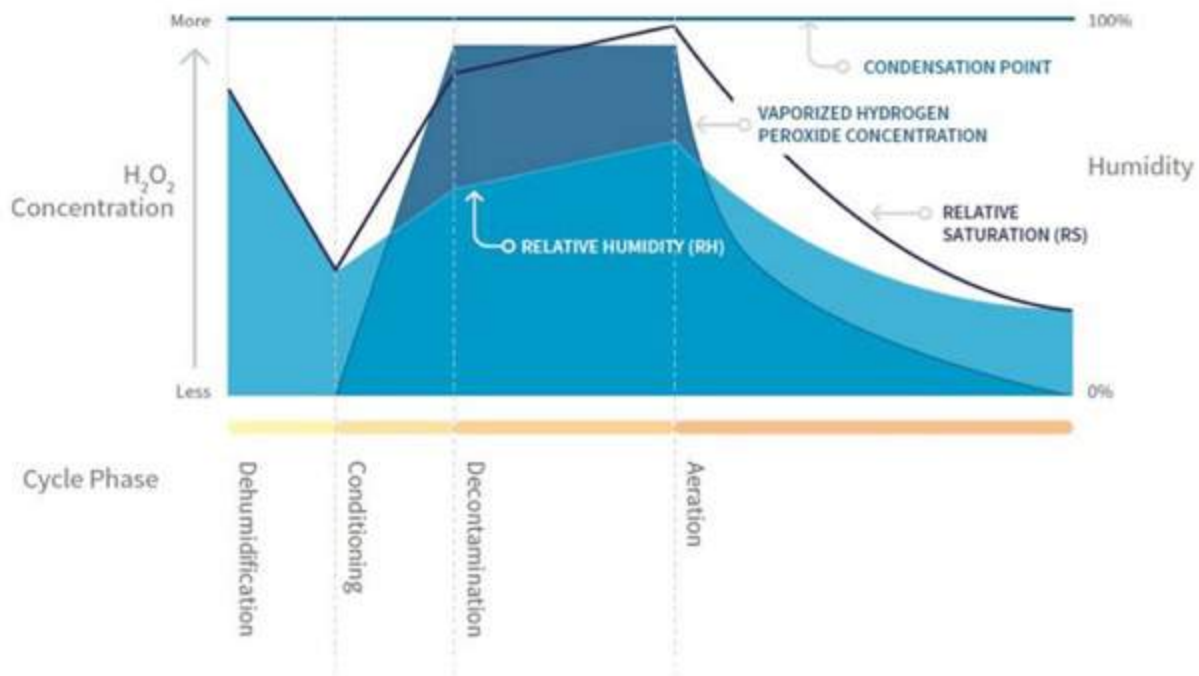
http://www.h2o2.com/files/PeroxyChem_35_SDS.PDF

Background

Hydrogen Peroxide (H_2O_2) has long been used as a disinfectant and is effective against viruses, bacteria, yeasts, and bacterial spores in vitro. H_2O_2 is an environmentally safe alternative to chlorine-based disinfectants, as it degrades to form oxygen and water and generally recognized by FDA as a safe antimicrobial agent. Hydrogen peroxide works by producing destructive hydroxyl free radicals that can attack membrane lipids, DNA, and other essential cell components. Vaporized hydrogen peroxide allows rapid decontamination without having to process a drying cycle and has been proven to decontaminate PPE while maintaining usability.

Process

Typically the biodecontamination cycle follows 4 steps. Dehumidification – getting the target environment to 25-50% relative humidity. Conditioning/Decontamination – Filling the target area with vaporized hydrogen peroxide. Dwell/Recharging – high saturation is lowered via dehumidifier and peroxide is re-added to the system. Aeration – removing the vapor from the container. The gambit is to keep the peroxide concentration high while remaining under the condensation point.



Biodecontamination process graphic from Vaisala.

Sterilant Safety

Of all of the commonly used vaporized chemical sterilants, hydrogen peroxide is generally considered the least toxic. Vaporized hydrogen peroxide leaves only water vapor and has no residue or toxic byproducts. Vaporized hydrogen peroxide works at low temperatures to kill all biological contaminants and is compatible with a wide variety of materials.

Why Vaporized H₂O₂?



Agent	State	Residue	Validation quality	Safety (PEL)	Occupational challenge
Formaldehyde, CH ₂ O	Gaseous	Powder	Poor	0.5 ppm	Carcinogenic
Ethylene Oxide, EtO	Gaseous	Yes	Good +	1.0 ppm	Toxic, flammable, carcinogenic
Chlorine Dioxide, ClO ₂	Gaseous	None	Good	0.1 ppm	Severe respiratory irritant
Peracetic acid or blends (liquid)	Vaporized	Variable	Good	0.17 ppm (AEGL-1)	Very irritant to skin, eyes, lungs...
Ozone	Gaseous	None	Moderate	0.1 ppm	Toxic, air pollutant, genotoxic...
H ₂ O ₂ (liquid)	Vaporized	None	Good +	1.0 ppm	Skin / eye irritant

Page

Vaisala

Webinar

Vaporized hydrogen peroxide bio-decontamination in rooms

(<https://www.slideshare.net/VaisalaGroup/room-biodecontamination-with-vaporized-hydrogen-peroxide>)

Vaporized Hydrogen Peroxide is registered by the U.S. Environmental Protection Agency as a sterilant, which the EPA defines as "a substance that destroys or eliminates all forms of microbial life in the inanimate environment, including all forms of vegetative bacteria, bacterial spores, fungi, fungal spores, and viruses". Some microorganisms are harder to kill than others and bacterial spores are among the hardest. *Geobacillus Stearothermophilus* is a bacterial spore that is also a standard biological indicator that is industry accepted to verify decontamination. It's scientifically accepted that destroying *Geobacillus Stearothermophilus* means you've also destroyed every other microorganism present that is easier to kill. (Six log (99.9999) reduction of *Geobacillus stearothermophilus* is possible at short contact times 30-90 minutes at 250-400 ppm, 10 minutes at 1000ppm, etc.)

Biological Organism Resistance to Vaporized Hydrogen Peroxide

High
Resistance

Bacterial Spores

Geobacillus Stearothermophilus

Mycobacteria

Tuberculosis

Non-Enveloped/Non-Lipid Viruses

Parvo, Polio Type 1

Gram-Negative Vegetative Bacteria

E. Coli, Salmonella

Fungi

Black Mold, Candida

Large Non-Enveloped Viruses

Smallpox

Gram-Positive Bacteria

MRSA, Legionnaires

Enveloped, Lipid Viruses

Coronavirus, Influenza

Low
Resistance

Improvised Biodecontaminator Components

Dehumidifier:

Vivosun Electric Mini Dehumidifier 400ml/24hr

Ultrasonic Humidifier:

Vicks Filter Free Cool Mist Humidifier Model V4600D1

Elechomes Ultrasonic Mini Mist Humidifier 80ml/hr

Disinfectant:

35% Food Grade Hydrogen Peroxide from BulkPeroxide.com

Detectors:

Vaisala Hydrogen Peroxide Sensor HPP-272 (PN HPP272-AB0N0N) [New/Calibrated 03/09/2020]

Vaisala USB Service Cable M12-5F RS-485 (PN 242659)

SKZ Handheld H₂O₂ Detector (PN SKZ1050-H₂O₂)

Chemical Indicators

3M Comply Hydrogen Peroxide Chemical Indicator 1248 (Lot 202107DE Exp 2021-07-23)

SPS Medical VH₂O₂ Indicator Strip GPS-250R

Bartovation Hydrogen Peroxide Test Strips 0-100PPM, 0-400PPM, & 0-5000PPM.

Biological Indicators

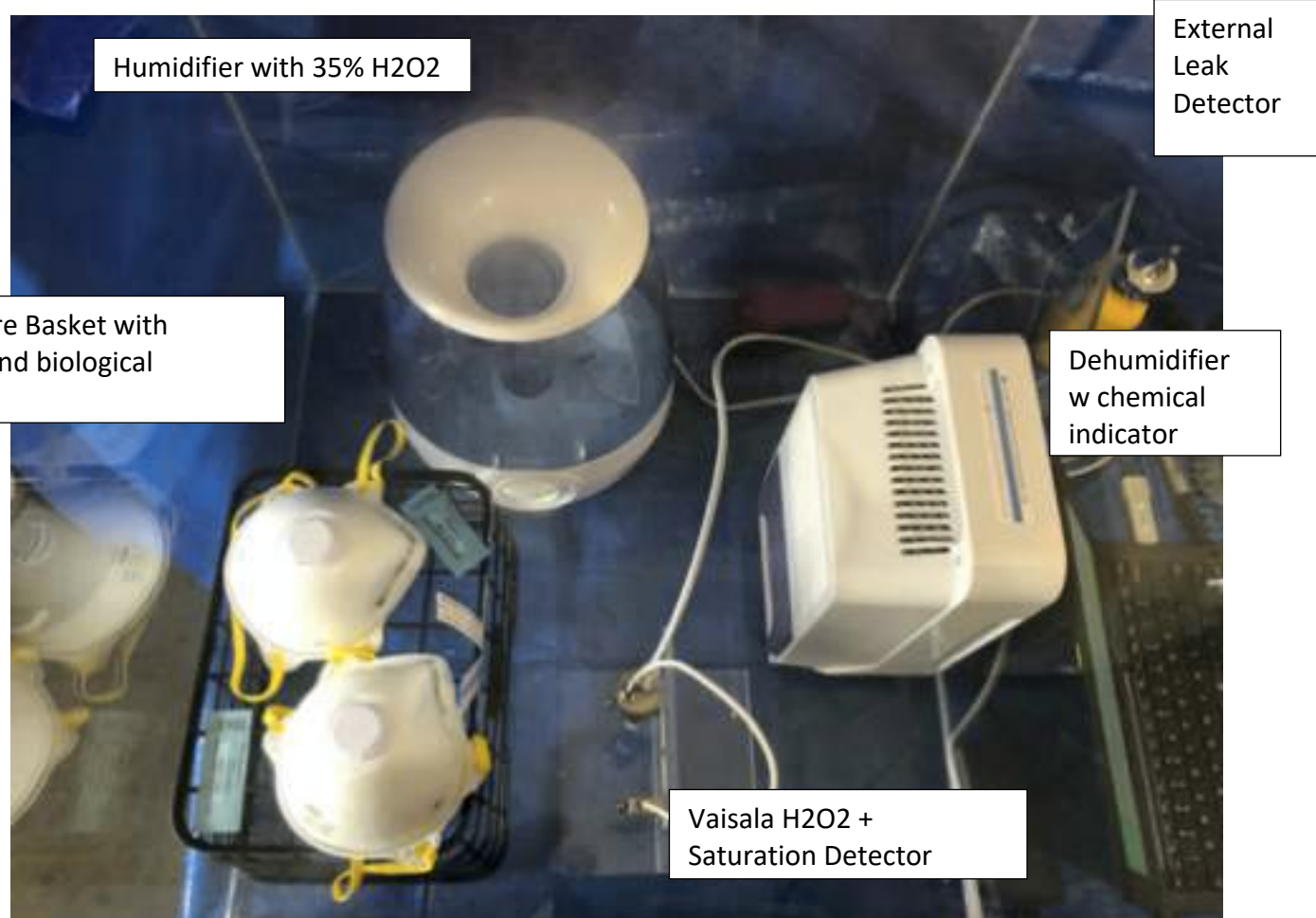
Geobacillus stearothermophilus is a bacteria that is more biologically resistant than enveloped viruses like coronavirus and is also commonly used to verify sterilization. Commercial vaporized hydrogen peroxide systems also use *Geobacillus stearothermophilus* to verify their process is effective. For our experiments we used Proper Manufacturing Biological Indicator Test Strips (*Bacillus atrophaeus* & *Geobacillus stearothermophilus*) [Lot P119 Exp 12/20]

Disinfection Container:

A cube was constructed of Acrycast with dimensions of 24" on each side and a free floating lid. Small holes were fabricated to allow pass through of power and diagnostic cables. The cables are fed through the box to the outside. The cable pass through is sealed with masking tape. The power switches for the humidifier and dehumidifier are set to ON but they are not connected to power until the biodecontamination is ready to start.

Biodecontamination Process

35% hydrogen peroxide is added to the humidifier. The equipment and chemical indicators are put into the box. The lid is placed onto the box. The lid sits on a rubberized weatherstrip. The lid is then taped down to the box and painters tape is applied around the edge of the lid to secure the seal. The computer begins recording measurements for Hydrogen Peroxide Concentration & Relative Saturation from the Vaisala detector. The dehumidifier is then connected to A/C power. The external detector is powered up to monitor for leaks (1 ppm).

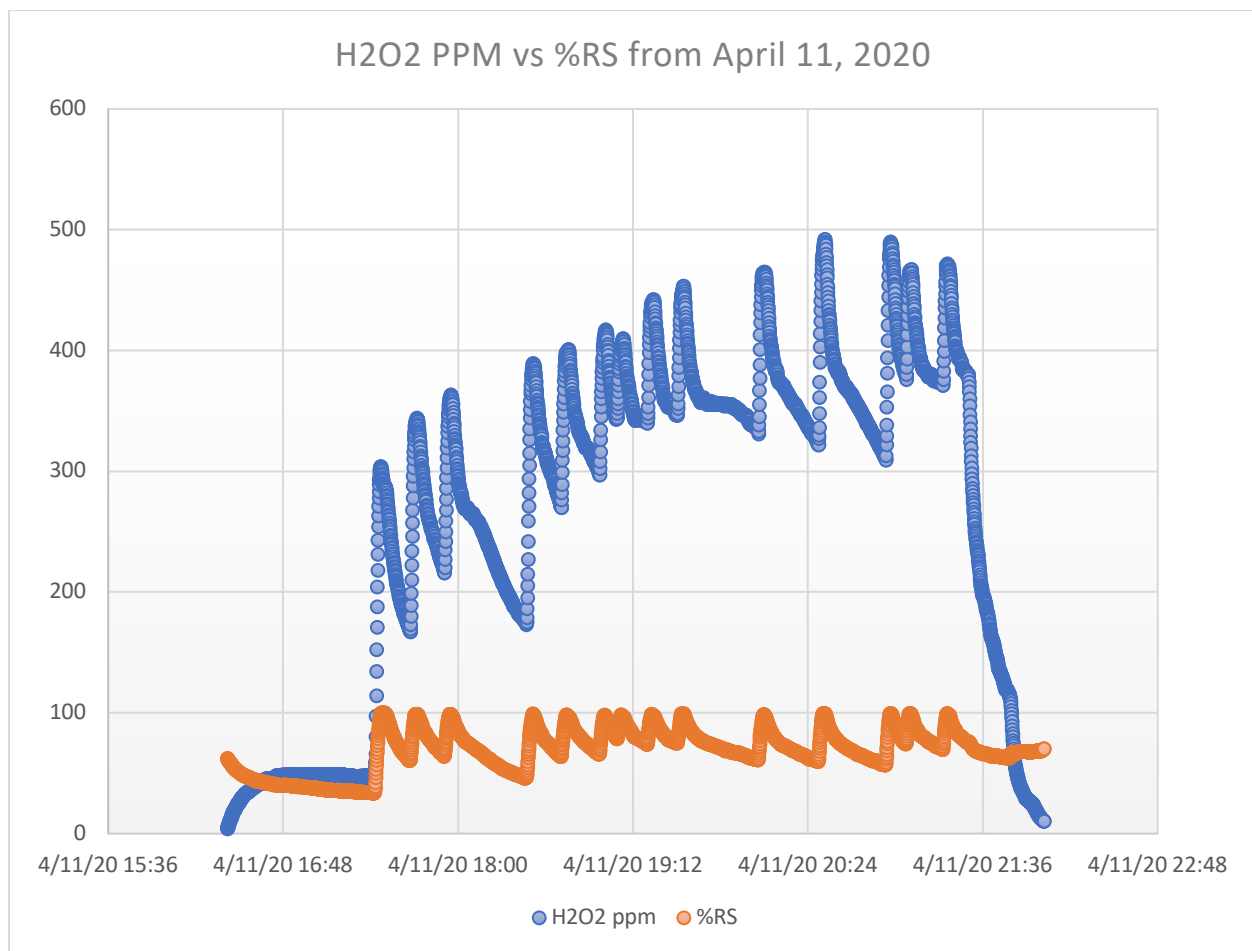


Overhead view of front top of the system.

After about an hour the relative saturation inside the box is lowered to below 30%. At this point we will energize the humidifier. After approximately 2 minutes the relative saturation will reach 95-99%. We unplug the humidifier at 95%. When using 35% hydrogen peroxide, the H2O2 ppm will be near 300ppm. Let the dehumidifier run for 10 minutes until the relative saturation goes back down to around 60%. The H2O2 ppm will also drop during this time to about 170-180 ppm. Plug the humidifier back in for 2 minutes to raise the H2O2 levels to about 320 ppm and 95% relative saturation. Repeat this 10 minute dehumidify and 2 minute humidify process until your ppm levels are at or around 400-500 ppm. After about 50 minutes at 300+ ppm the 3M chemical indicators will convert from blue to pink.



View from the right side of the system as its running.



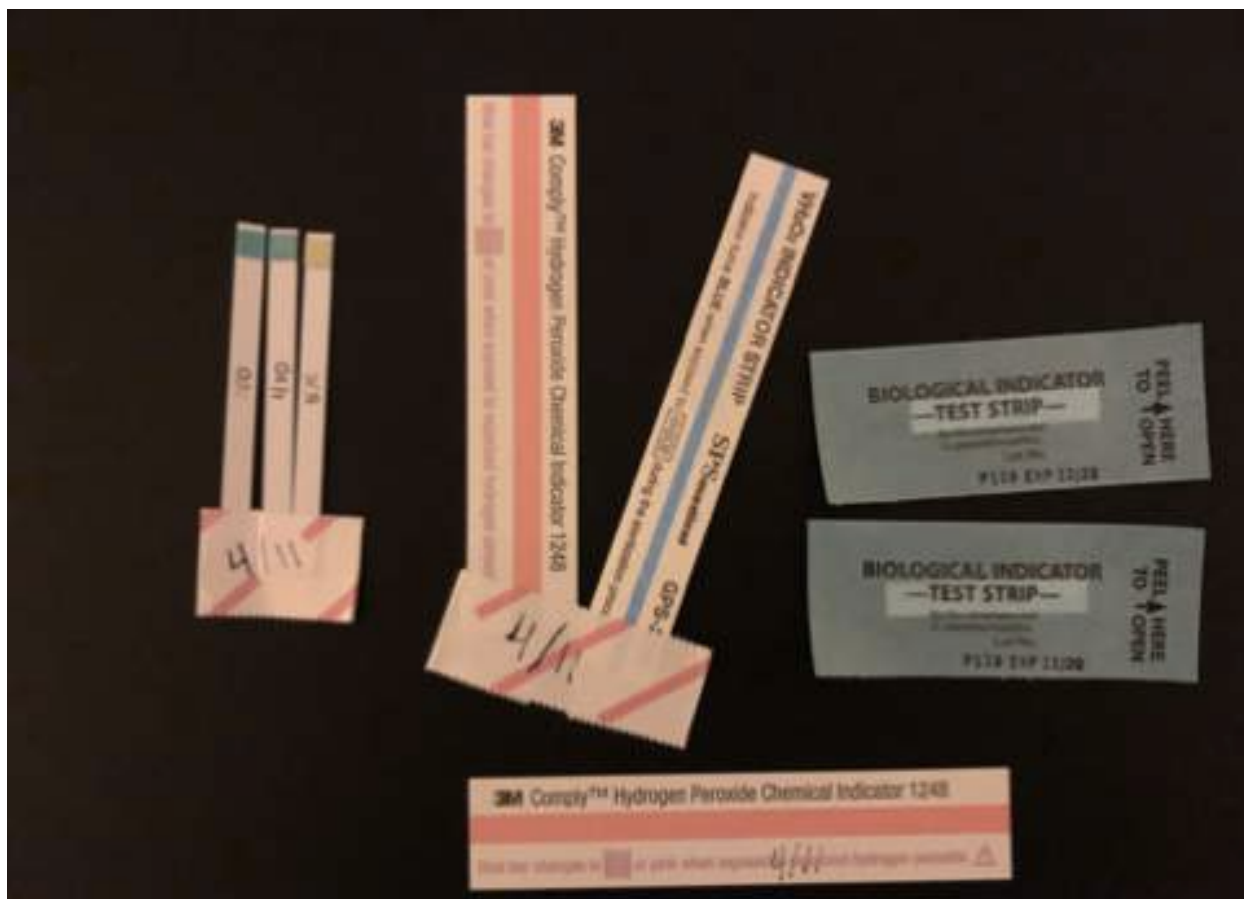
Experiment #9 April 11, 2020 Results

H2O2 338 ppm average at 245 minutes decontamination time.

After the decontamination process is completed the lid is removed. During the lid removal it's advisable to wear safety gear including nitrile gloves and a full face respirator. A venting system is recommended to remove the vapor from the container and exhaust it remotely. The box is aerated until the H2O2 ppm is 1 and the equipment and test indicators are then removed.

The masks are allowed to be exposed to air until they are below 1 ppm. We do not yet have testing for filter efficacy although similar processes with commercial equipment show that masks decontaminated with vaporized hydrogen peroxide are reusable. See FDA EUA for details. <https://www.fda.gov/emergency-preparedness-and-response/mcm-legal-regulatory-and-policy-framework/emergency-use-authorization#covidppe>

Experiment #9 on April 11, 2020 Chemical & Biological Indicator Results



Chemical & Biological Indicator (Proper Test ID: 2004210136) results.

Test Results:	PASS
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Dear OXYFOG MARINA,

The Proper microbiology lab has completed the analysis of your latest spore test. Your spore test dated 04/11/2020 is negative, your sterilizer has **passed** this indicator test.

A negative spore test signifies that your sterilizer is functioning properly and capable of inactivating the most difficult-to-kill species of bacteria under your current cycle settings.

3rd party testing confirmed 5 log (99.999%) kill of *Geobacillus stearothermophilus* and 6 log (99.9999%) kill of *Bacillus atrophaeus*.

Experiment Notes: The Vicks humidifier leaks when being moved so be very careful and make sure you have the appropriate protective gear when handling.

Top View of Experiment #10 on April 15, 2020

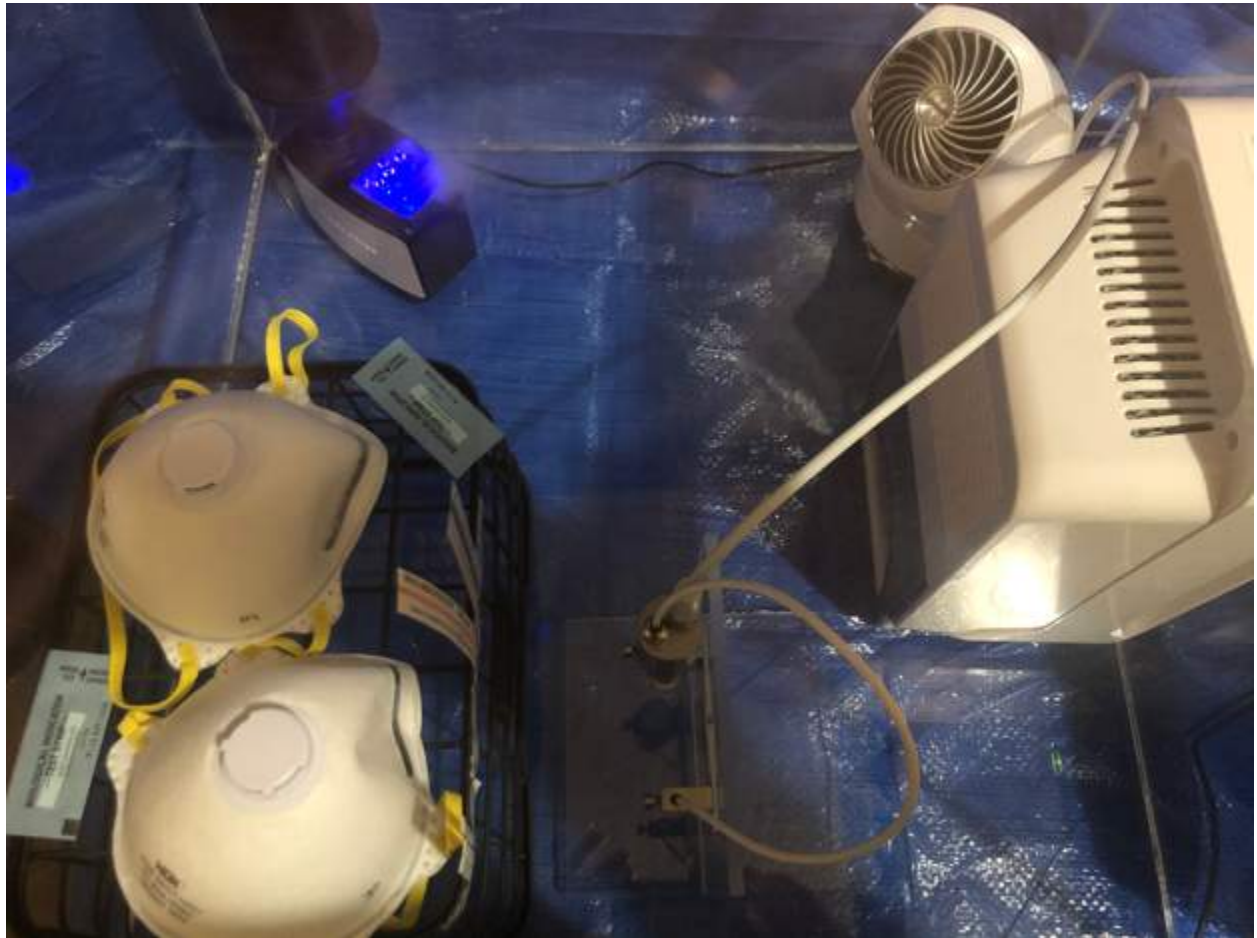
In this experiment we used the Elechomes mini humidifier with 35% H₂O₂ and Vornado Flippi fan set to the lowest setting. The Elechomes mini humidifier is smaller than the Vicks, produces similar results, and the liquid storage is easier to work with. The experiment started at 9:46PM and ended at 11:36PM.



Front View of Experiment #10 on April 15, 2020



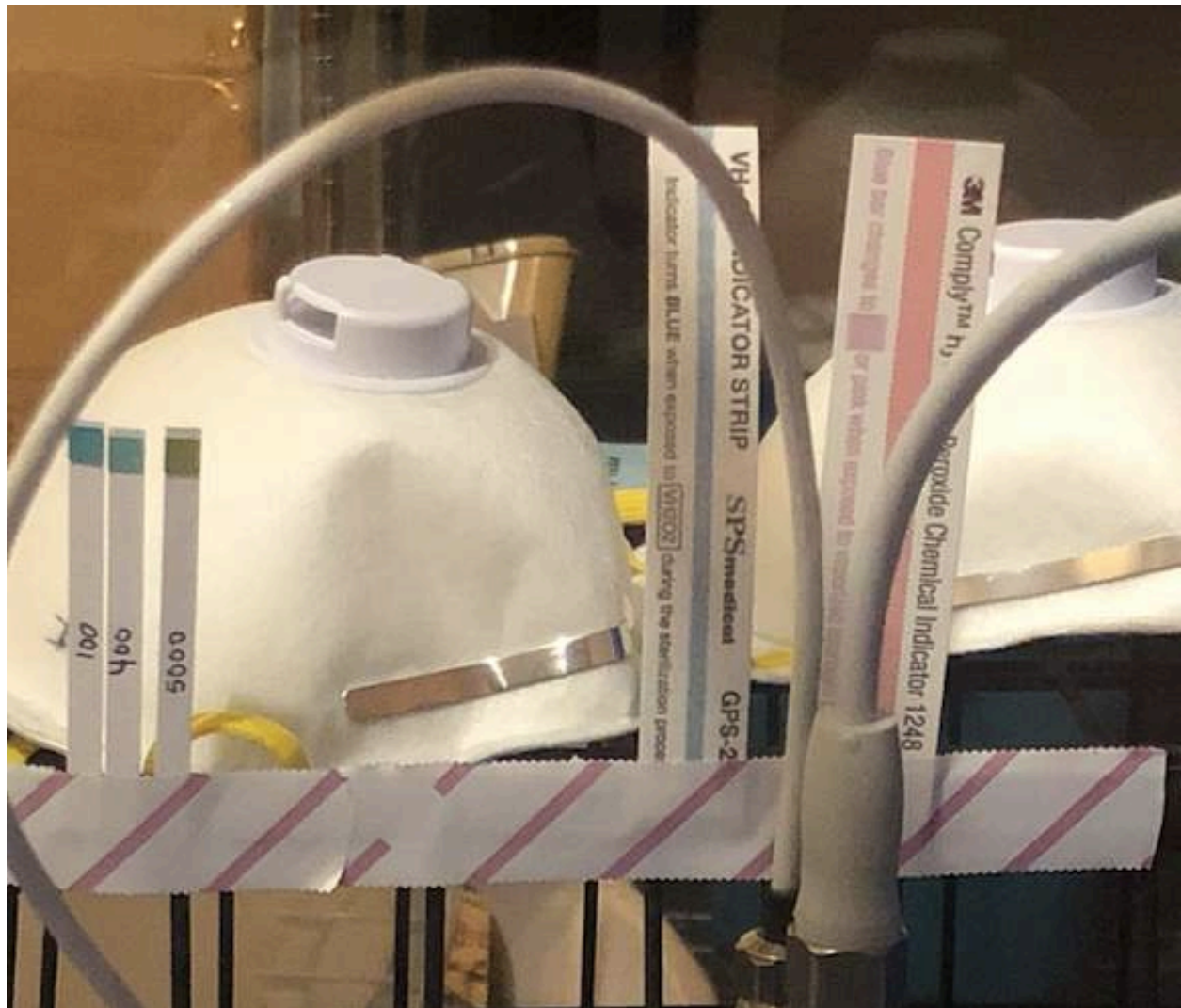
Front View with Humidifier Started at 10:11PM on April 15, 2020



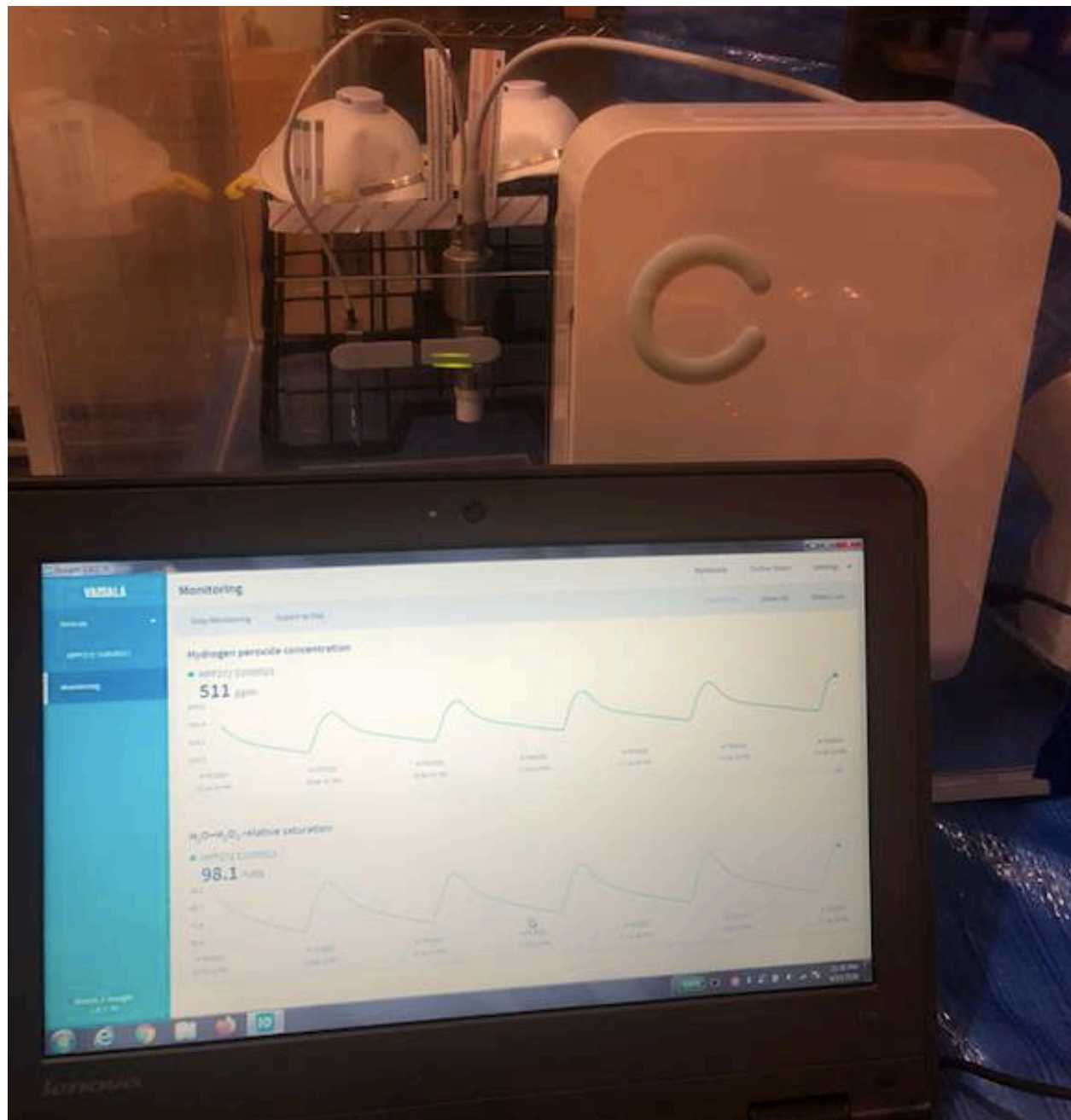
View of Chemical Indicators Partially Completed 10:37 PM on April 15, 2020



View of Chemical Indicators Completed 11:28 PM on April 15, 2020

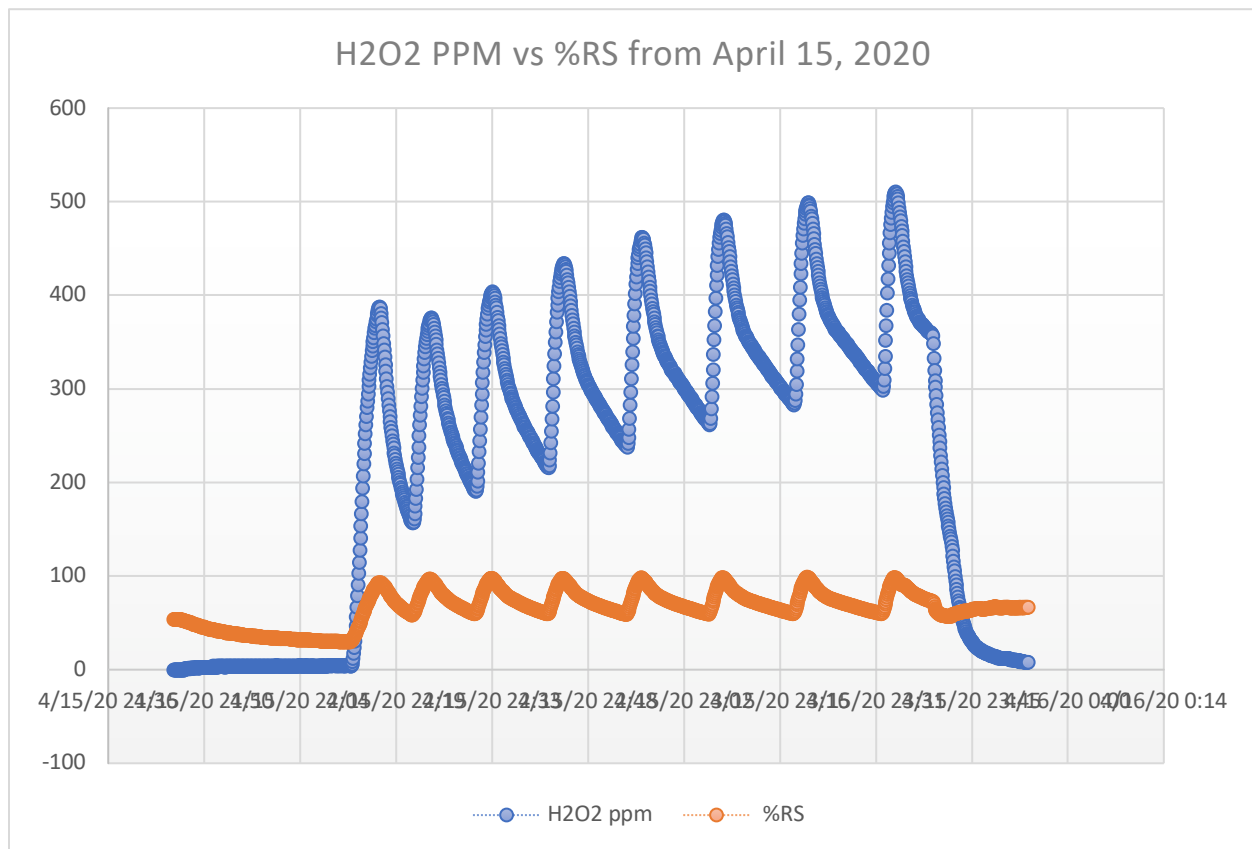


Side View of From Laptop Peak H₂O₂ PPM 11:34 PM on April 15, 2020

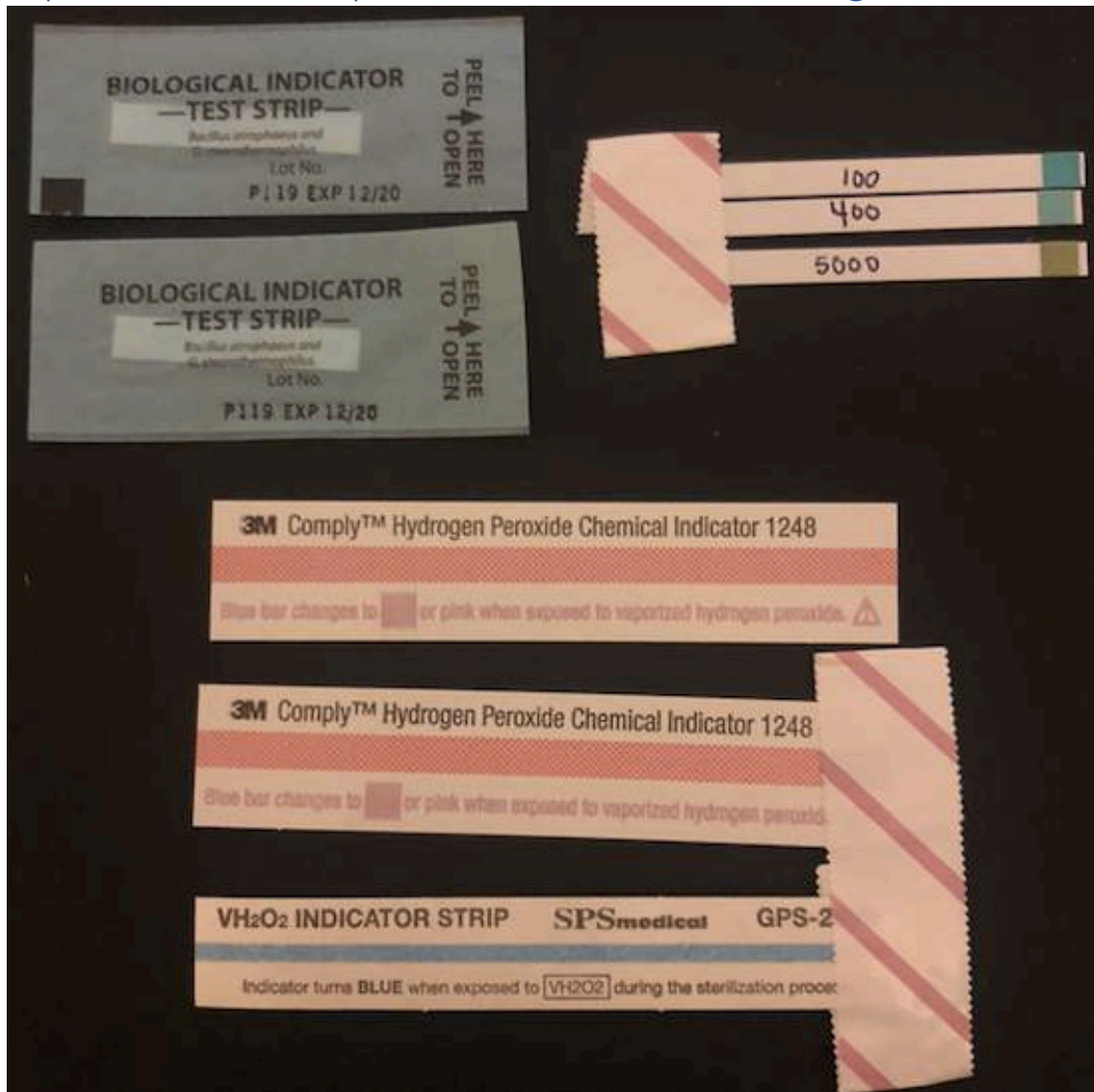


Experiment #10 on April 15, 2020 Results

H2O2 328 ppm average at 86 minutes decontamination time.



Experiment #10 on April 15, 2020 Chemical & Biological Indicator Results



Test Results:

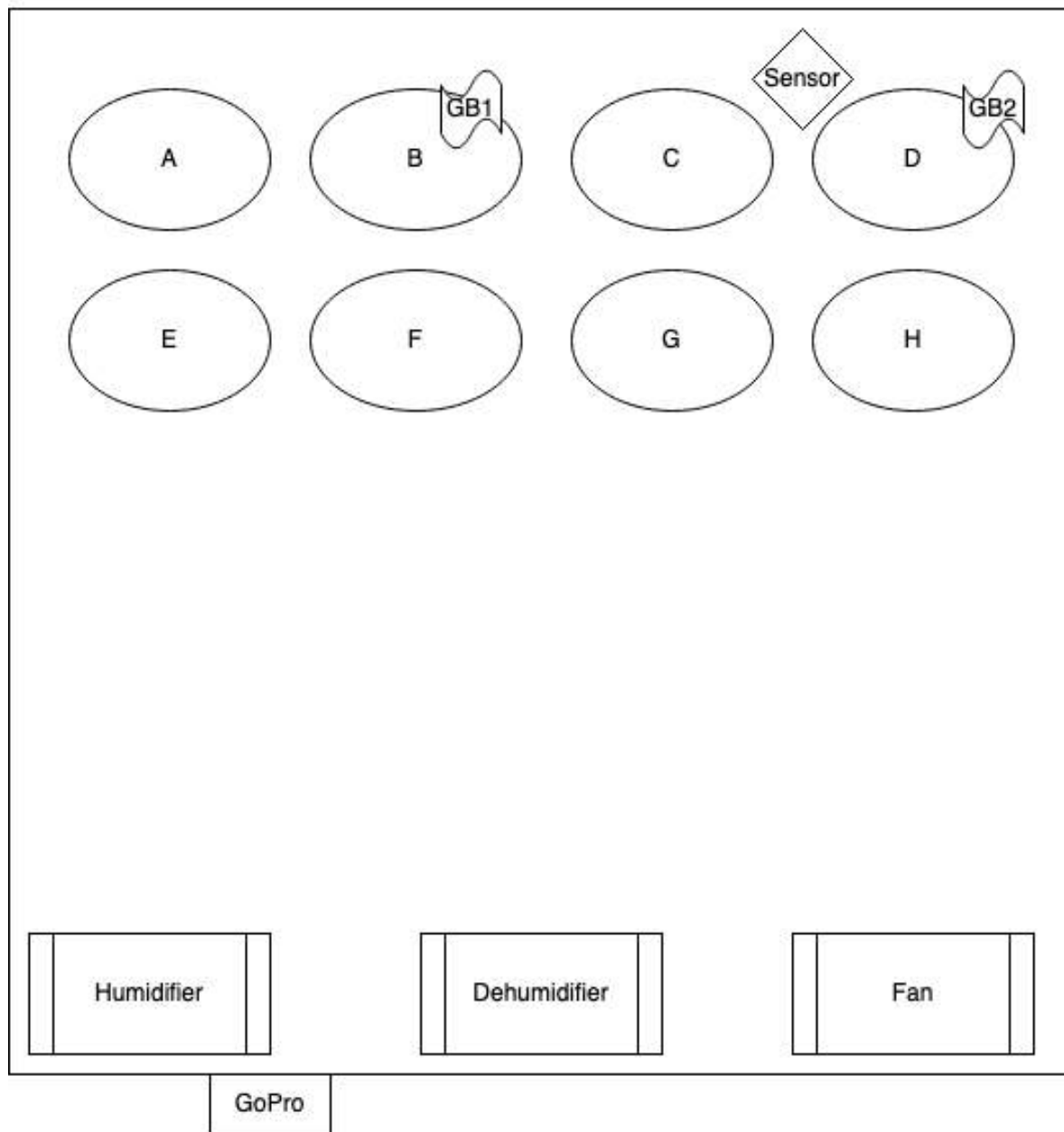
PASS

Dear OXYFOG MARINA,

The Proper microbiology lab has completed the analysis of your latest spore test. Your spore test dated 04/15/2020 is negative, your sterilizer has **passed** this indicator test.

Multiple Mask Decontamination - Experiment #18 on May 8, 2020

05/08/2020



We tested bulk decontamination of 13 HDX N95's and 20 Generic KN95's masks. The masks were chained together by their straps. The top mask was hung from a 3M command hook attached to the top of the container. 3M chemical indicators were placed in the top mask for every set (A1, B1, C1, D1, E1, F1, G1, H1). 3M chemical indicators were also placed in the middle and bottom of full stacks (D3, D7, G3, G7). Biological indicators were placed in B1 and D7. In the 24" top to bottom we can fit 7 masks. The masks require approximately 6" of space

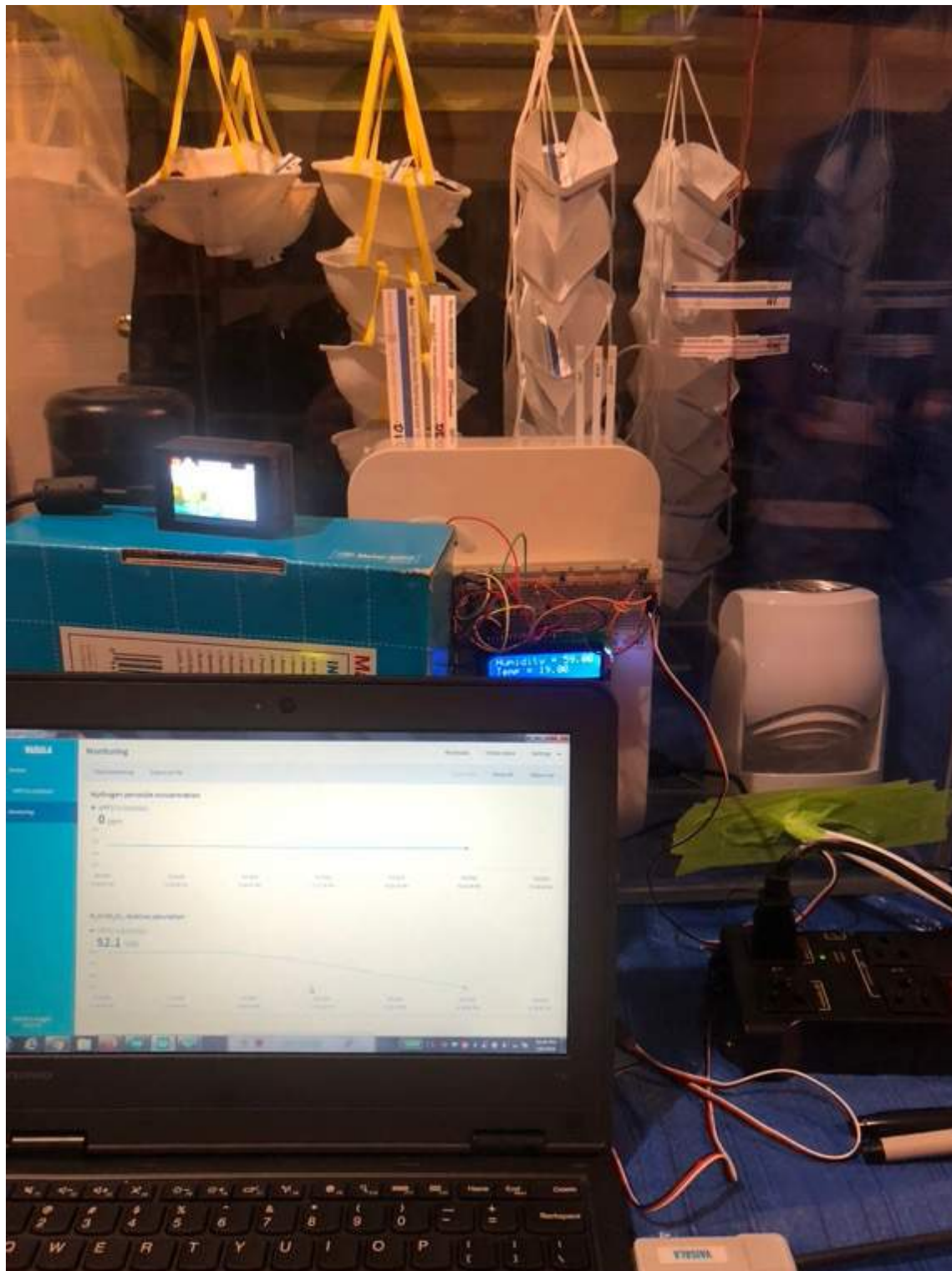
in both directions to not interfere with their neighbor. Chemical indicators were also placed on the dehumidifier for visual verification. An Arduino controller was devised with a relay to allow automated on/off function of the humidifier. The DHT11 humidity sensor was found to be not as accurate as the Vaisala and the code was adjusted to turn the humidifier on below 89% and off at above 94%. This correlated to the Vaisala measurement around 58% and 84%. The DHT11 was not very good and we will be switching to the BME280 probe going forward. After the experiment biological indicators were packaged up and sent for processing.

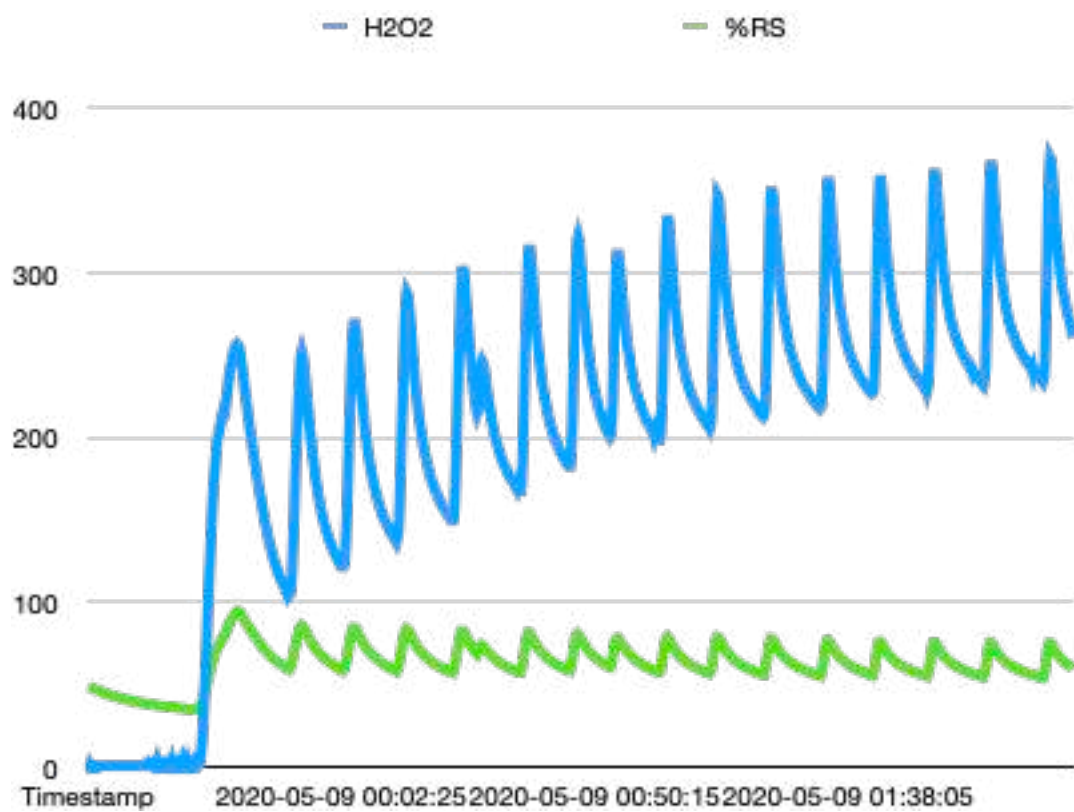
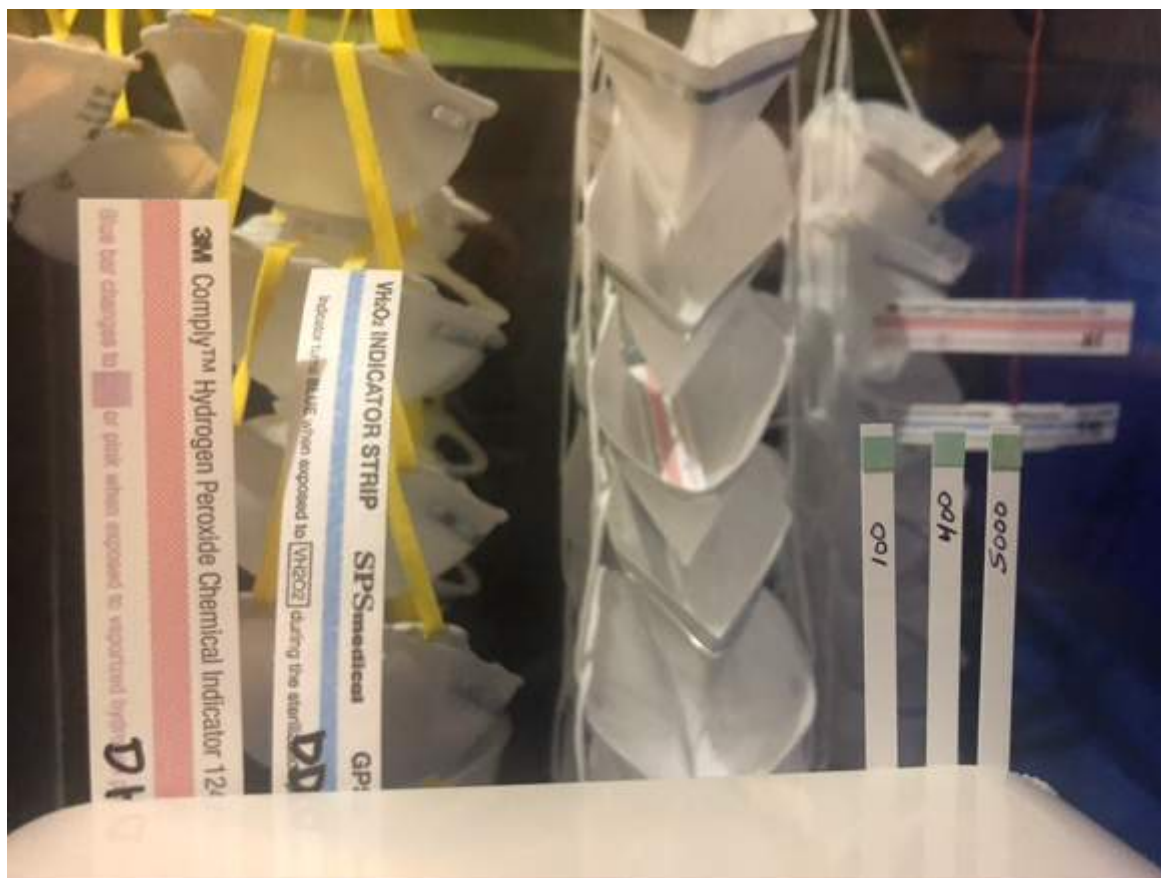
Decontamination was run for 160 minutes from 23:40 to 02:20
Average PPM was 234

Top View



Side View







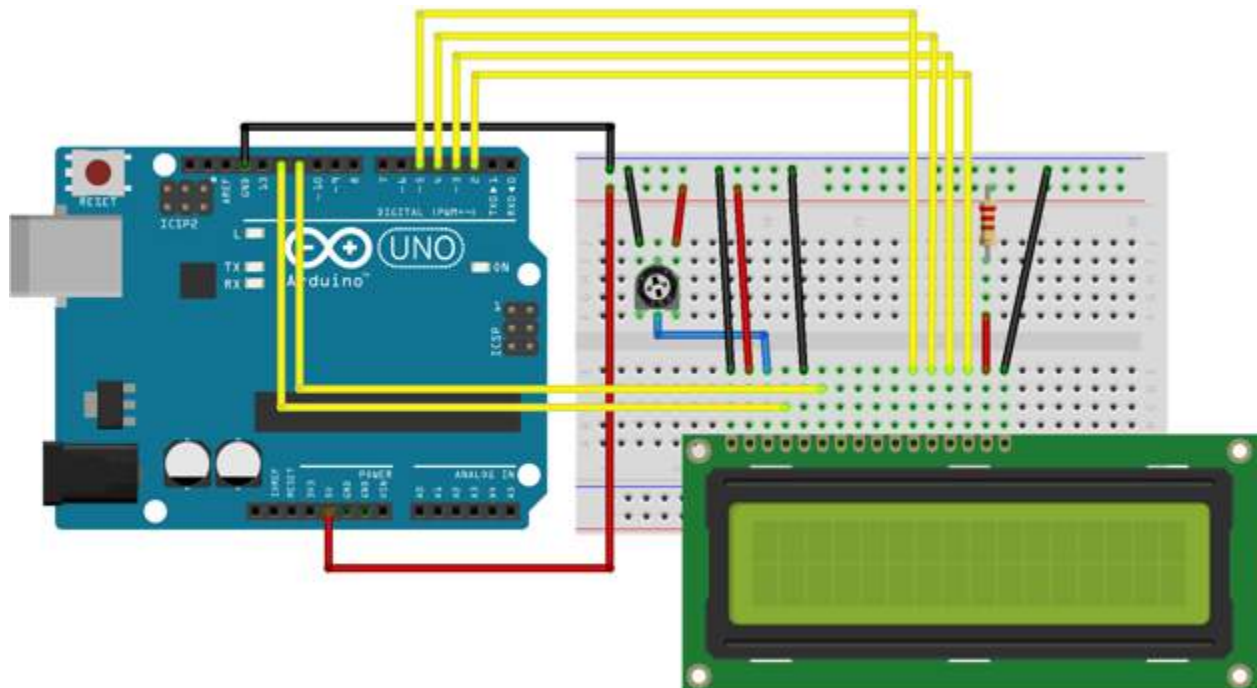
May 8, 2019 All chemical indicators were activated

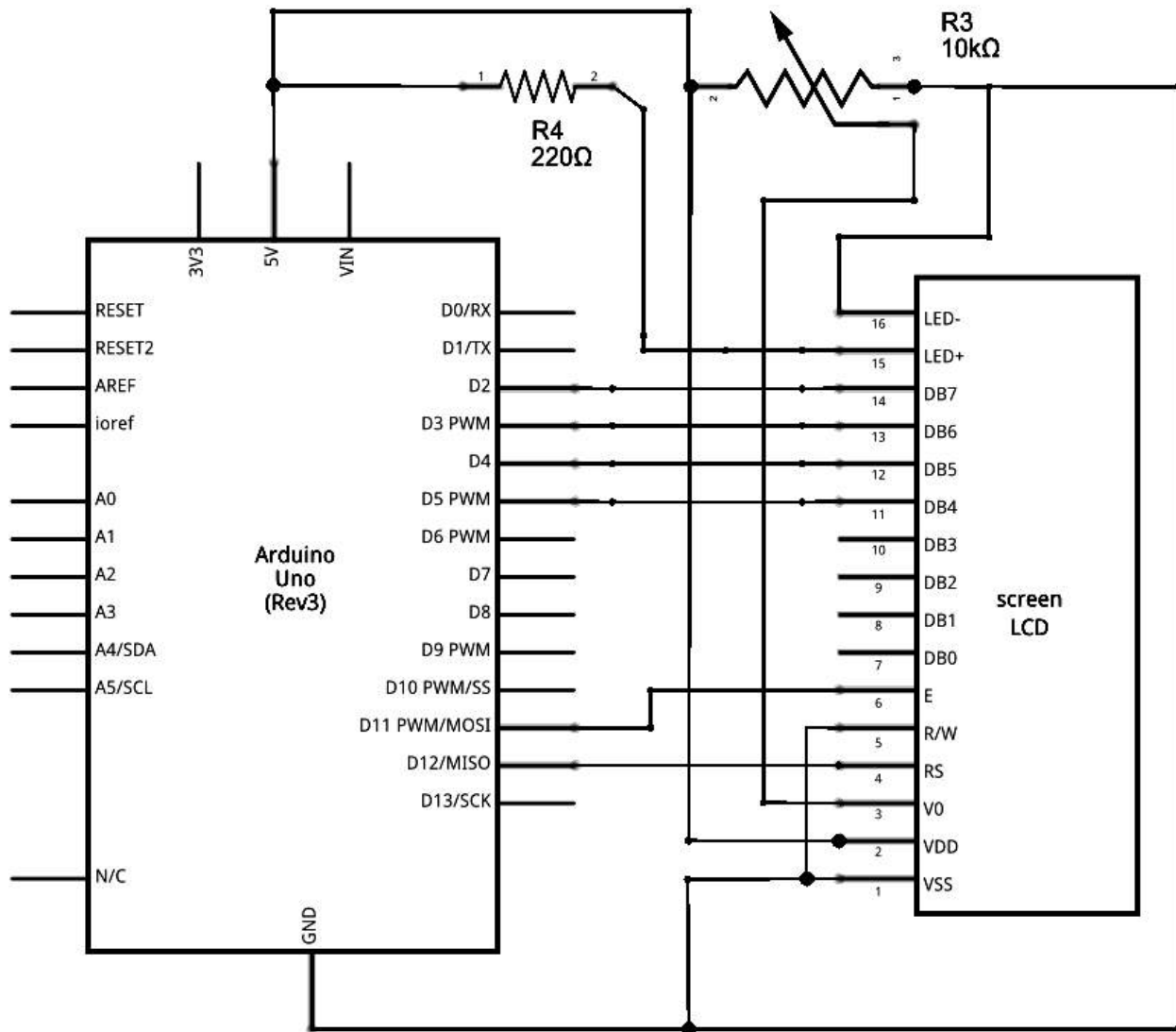
OXYFOG Controller v1.1

Parts List

- Arduino or Genuino Board
- LCD Screen (compatible with Hitachi HD44780 driver)
- pin headers to solder to the LCD display pins
- 10k ohm potentiometer
- 220 ohm resistor
- hook-up wires
- breadboard
- DHT11 or similar humidity sensor
- Relay: Digital Loggers IoT relay or similar

LCD wiring:





Wire up the LCD first since it's the most complicated. Then add the connections for the humidity sensor and relay.

We hookup the 3 pin DHT11 Center/Signal wire to port A0. Negative and Positive to the breadboard Negative and Positive top rails. Positive side of relay connects to digital port 8. Negative side of relay connects to ground rail. We plug the humidifier into the normally off plug of the IoT relay. The dehumidifier and fan go into a regular always on plug. The humidity sensor is placed inside of the container to be decontaminated with an extension to the controller outside of the box.

Do add library for LiquidCrystal.h and dht.h

Source Code for OXFYOG-Controller-1.0 (89%-94%)

```
#include <LiquidCrystal.h>
#include <dht.h>

LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
int greenPin = A0;
dht sensor;

//variables
int check;
float H1; //Stores humidity value
float T1; //Stores temperature value

void setup()
{
  lcd.begin(16,2); //16 by 2 character display
  pinMode(8,OUTPUT);
  digitalWrite(8,HIGH);
}

void loop()
{
  delay(2000); //wait a sec (recommended for DHT11)
  sensor.read11(greenPin);
  lcd.clear();
  lcd.setCursor(0,0);
  lcd.print("Humidity = ");
  lcd.print(sensor.humidity);
  H1 = (sensor.humidity);
  lcd.setCursor(0,1);
  lcd.print("Temp = ");
  lcd.print(sensor.temperature);
  T1 = (sensor.temperature);

  if (H1 < 89){
    {
      digitalWrite(8,HIGH); //high means on. When the humidity is below 89, the relay will turn on.
      delay(2000);
    }
  }
  else if (H1 > 94){
    digitalWrite(8,LOW); //low means off. When the humidity is above 94, the relay will turn off.
    delay(2000); //Delay 2 sec.
  }
}
```

Closing Notes

The process for decontamination using vaporized hydrogen peroxide is achievable with off the shelf equipment. For healthcare facilities that don't have extensive budgets, time to wait for commercial solutions, and need a rapid way to decontaminate equipment, we believe we have created a practicable option.

References

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Ref "CDC guidance Decontamination and Reuse of Filtering Facepiece Respirators"

<https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-strategy/decontamination-reuse-respirators.html>

Ref "Decontamination and Reuse of N95 Respirators with Hydrogen Peroxide Vapor to Address Worldwide Personal Protective Equipment Shortages During the SARS-CoV-2 (COVID-19)

Pandemic" https://www.safety.duke.edu/sites/default/files/N-95_VHP-Decon-Re-Use.pdf