Assessment of a Food-Warming Cabinet for Heat and Humidity Decontamination of N95 Respirators

Stuart J. Williams
stuart.williams@louisville.edu
Department of Mechanical Engineering, University of Louisville

Abstract

During the COVID19 pandemic, various investigations have been conducted to determine if personal protective equipment, and specifically N95 masks, can be decontaminated for reuse when unused equipment is not available. One method under investigation that may be particularly adaptable in lower resource communities is the use of heat and humidity for the deactivation of SARS-CoV-2. Food-warming cabinets (a.k.a. holding cabinets) may reach applicable temperatures and thus the purpose of this study was to characterize the temperatures achieved in a typical food-warming cabinets that has been adapted for the deactivation of N95 masks. This manuscript provides a general description of how a food-warming cabinet operates and describes aspects that are important for heat deactivation including characterizing cyclical heating and temperature variations within the cabinet. The described experimental procedure could be used as a guide to characterize similar food-warming cabinets.

Background

Commercial food warming and holding equipment has been implemented in restaurants, cafeterias, caterers, and other food-handling businesses to improve food quality and service, keeping it fresh and warm until it is ready to serve. Holding food at elevated temperatures also improves food safety as pathogen growth is reduced at elevated temperatures, as such the FDA Food Code requires that the hot holding temperature be at least 135 °F (57 °C). Thus, the operating temperatures of food-warming cabinets is applicable towards ongoing efforts in implementing heat-and-humidity methods to deactivate the novel coronavirus (SARS-CoV-2) on personal protective equipment (PPE), particularly N95 respirators.

N95 filtering facepiece respirators (FFRs) are intended for one-time use operation, though the ongoing COVID19 pandemic has put a strain on the availability of such resources. Although new FFRs should be used if they are available, decontamination methods have been considered including hydrogen peroxide, UV light, and heat-and-humidity. The latter may be particularly attractive in lower resource settings if existing heating equipment can be adapted for the deactivation of FFRs. Research is ongoing with respect to the ideal heat and humidity levels that are applicable towards SARS-CoV-2 deactivation while not compromising the filtration efficiency of N95 masks. Thus, the reader is encouraged to seek the most recent findings as new studies are emerging (N95Decon 2020), findings from several recent results follow.

N95 FFRs are typically composed of multiple layers of nonwoven polypropylene and are subsequently charged through corona discharge and/or triboelectric charging, resulting in a filter that simultaneously has high efficiency and sufficient air permeability for breathing. SARS-CoV-2 is still detectable on plastic and stainless steel for 72 hours (van Doremalen et al. 2020), thus there is motivation to investigate more rapid decontamination methods on FFRs without compromising their efficiency. The performance of meltblown fabrics was not compromised after being treated with 85 °C, 30% relative humidity for 50 cycles or at 100 °C under dry conditions for 20 cycles (Liao et al. 2020). Other investigators demonstrated that several N95 FFRs can withstand five cycles of up to 75 - 85 °C with 60 - 90% relative humidity for 30 minutes (Anderegg et al. 2020, Massey et al. 2020). Significant deactivation of several viruses and bacteria were also achieved at 80 - 82 °C and moist humidity (62 - 66% relative humidity) (Wigginton et al. 2020). With respect to deactivation of SARS-CoV-2, 70 °C dry heat treatment of N95 fabric for 60 minutes was sufficient (3.3-log reduction), though it was not as effective for 30 minutes (1.9-log reduction) nor for stainless steel for 60 minutes (2.0-log reduction) (Fischer et al. 2020). There is an upper limit to the implementation of temperature levels for decontamination; for example, steam autoclave (121 °C) can sufficiently deactivate SARS-CoV-2 (Kumar et al. 2020), though some masks failed a fit test after one cycle (Viscusi et al. 2007, Bergman et al. 2010) and a significant reduction in filtration efficiency was observed after five cycles of heat treatment at 125 °C (Liao et al. 2020).

Recently, the U.S. Food and Drug Administration issued an Emergency Use Authorization for decontaminating N95 for single-user reuse using a heat-based method of 65 °C for 30 minutes (F.D.A. 2020). Based on the previously-mentioned results and other studies (N95Decon 2020), the set target for this food cabinet study was to maintain temperatures > 70 °C and relative humidity > 50% for a period of at least 30 minutes after reaching the set temperature of the cabinet.

Materials and Methods

A food-warming cabinet (Vulcan, Model VHFA18 with two 1,000 watt heating elements and 16.7 amps total draw) was acquired for this study and its general operation is illustrated in Figure 1A. This particular model was chosen as a representative basic food-warming cabinet; of course advanced cabinet features are available that may significantly improve results or simplify the experimental procedure described herein. For this specific model the temperature controls are manual (digital options are possible), the walls are constructed of stainless steel and are not insulated (some cabinets are constructed from aluminum and walls may be insulated), there is a single door with a glass panel (some doors are metallic, insulated, and/or may be double-doored), there is no air ventilation (i.e. exhaust), and there is no humidity control. This model circulates air with an intake near the top of the cabinet where the air temperature is measured (some cabinets have air blowers and controls at the base of the cabinet). The air is then pushed through a rear duct that transports air towards the cabinet's base where the heating element is located. Heated air exits through vents at the perimeter of the base. The heating element is activated or deactivated based on the measured temperature of the air, thus there are inherent periodic temperature variations during heating. Eighteen wire shelves were available for accepting food trays.

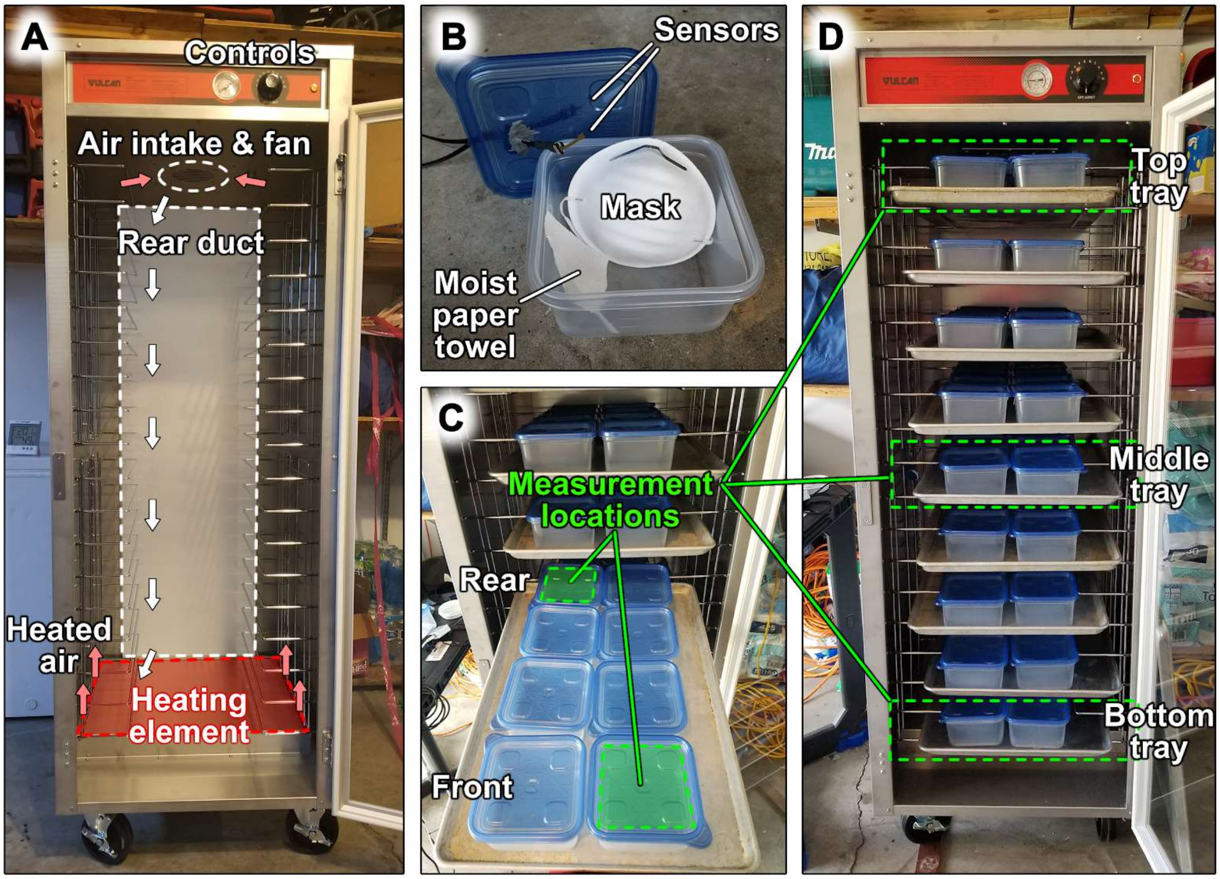

Figure 1. *(A) The food-warming cabinet is pictured with labels to demonstrate its general operation and air circulation. (B) Image of the measurement container with two dual temperature/humidity sensors (one inside of the container, one on its exterior), a drywall mask, and a moist paper towel with 300 μL of water. (C) Eight containers can fit on a single tray, two measurement locations are labeled. (D) Nine trays could fit into the cabinet and three were chosen for measurement locations.*

Several 1.25 quart hard walled polypropylene containers (Ziploc, medium square) were acquired after recent work demonstrated their use for heat deactivation of masks (Anderegg et al. 2020, Wigginton et al. 2020). There are several advantages of using these containers for heat deactivation, including mechanical protection from handling, preventing cross-contamination, enabling humidity control, and protecting from direct contact with hot surfaces. A dual temperature and humidity sensor (SHT31-DIS-B1E, Sensirion) was affixed to either the inside or the outside a container lid (Fig. 1B) using epoxy (J-B Weld 8281). The container contained one drywall mask in lieu of a N95 mask. It also contained one 7.5 cm x 7.5 cm paper towel with 300 μL of absorbed water to induce a humid environment inside of the container.

Nine food trays (26 in. x 18 in.) were placed on every other cabinet shelf (the height of the containers prevented the use of every shelf). Each tray held eight containers resulting in a cabinet capacity of 72. Each tray could hold twelve containers if unused shelving brackets were removed, thus increasing cabinet capacity to 108 (further optimization with custom shelving is possible). Every container was empty except for one or two containers containing the mask, moistened paper towel, and sensor. Measurements were conducted at six different cabinet locations based on two tray locations ('Front' and 'Rear', Fig. 1C) and three different cabinet locations ('Top', 'Middle', and 'Bottom', Fig. 1D).

Measurements were conducted as follows. First, an empty food cabinet was turned on and set to its highest temperature setting of "10" and allowed to reach steady state. Nine trays with 72 containers were prepared outside of the cabinet at room temperature (18 ºC - 22 ºC). For optimal operation, it was assumed that a user would prepare a load of masks, containers, and trays (at room temperature) while a second load was being heat-treated. Further, scheduled heat treatments would ensure consistency whereas intermittent opening and closing of cabinet doors would produce erratic and reduced heating. The measurement container was loaded with the mask and moist paper towel and it replaced an empty container at a particular location. The temperature sensors were connected to a SEK-SensorBridge and measurements were acquired every five seconds for the duration of the test. Next, the cabinet was opened and the load was placed inside; the cabinet door was closed and measurements were acquired for at least 90 minutes. This test was conducted at the six previously-describe measurement locations (i.e. Front-Top, Front-Middle, Front-Bottom, Rear-Top, Rear-Middle, and Rear-Bottom) and repeated at least thrice.

Temperature and relative humidity data was analyzed using a custom MATLAB program. One objective was to determine the amount of time it took for the measurement container to reach (i) the temperature goal of 70 ºC and (ii) the cabinet's set temperature after being loaded to capacity with room-temperature material consisting of trays and containers. A second objective was to determine the average temperature and relative humidity for each location for thirty minutes after the set temperature had been reached. Finally, the range of temperatures was measured at leach location to assess variability within the cabinet itself.

Results & Discussion

Figure 2 shows two experimental trials showing the time it took for the warming cabinet to reach its set temperature after the room-temperature load was applied. The labeled 'Rise time' was defined as the time it took for the internal container temperature measurement to reach its first peak in temperature, which occurs shortly after deactivation of the cabinet heating element. The average rise time from the trials was 42.8 minutes, ranging from approximately 40 minutes to 49 minutes with the longer time associated with lower room temperatures. Once the temperature was reached, the heating element would cycle on and off with a cycle period averaging 17.7 minutes. As expected, external temperature measurements were greater than inside of the measurement container though there was a greater difference between them for the Front locations compared to the Rear. The front of the cabinet was cooler due to air leakage near the door and the glass door itself was cooler than the other metallic walls of the cabinet. In addition, the elevated Rear temperatures also reduced the resulting container humidity.

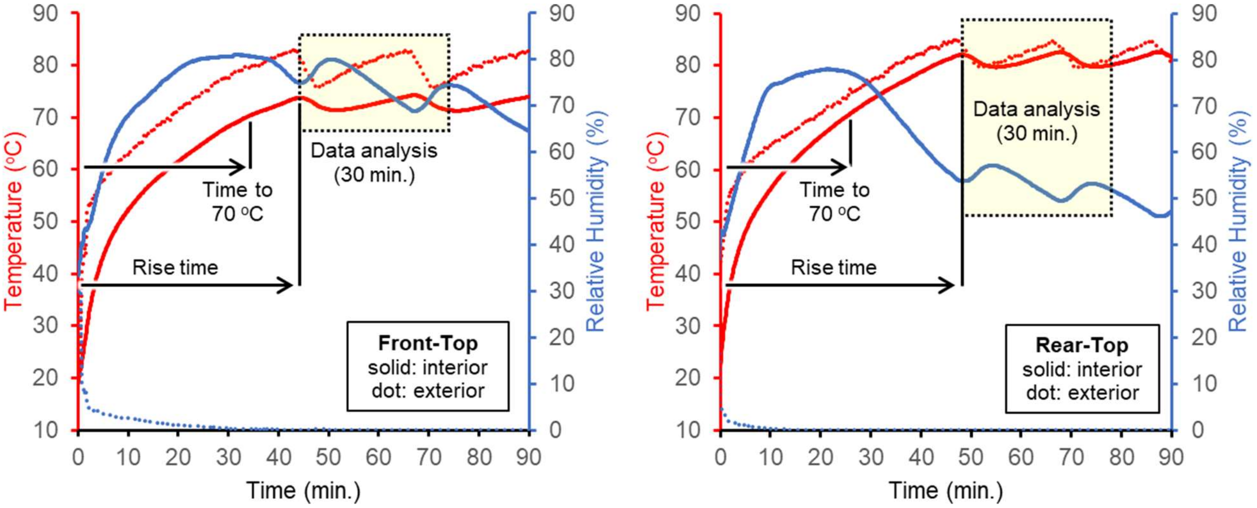

Figure 2. *A representative experimental trial showing the change in temperature (red) and humidity (blue) inside (solid line) and outside (dotted line) of the measurement container after the cabinet was filled to capacity with a room-temperature load. The (left) Front-Top and (right) Front-Rear locations are shown.*

Table 1 shows the averaged results from the multiple measurement trials. The Rear locations had greater temperatures and, thus, shorter times to reach 70 °C compared to Front locations (approximately 21 minutes compared to 35 minutes). For the Top and Middle racks there was approximately 8 °C difference in the Front and Rear temperature measurements. The Bottom rack had a difference of over 14 °C; however, upon closer inspection this tray is adjacent to the heating element which only covers the back two-thirds of the cabinet's base likely causing the greater temperature non-uniformity. All measured locations met the temperature goal of at least 70 °C with a range no greater than 3 °C, with the exception of the Rear-Bottom rack with a temperature variation of almost 5 °C. The relative greater temperature of the Rear-Bottom location led to a reduced relative humidity and was the only location that did not meet the goal of > 50% relative humidity for a 30 minute period after the cabinet first reached its set temperature.

Table 1. *Results of container measurements at different cabinet locations.*

	Time to	**Temperature (°C)**			**RH (%)**
Location	**70 °C (min.)**	**High**	**Mean***	**Low**	**Mean***
Front-Top	30.5	75.3	73.8	72.6	73.5
Front-Middle	38.5	72.3	71.6	71.1	82.2
Front-Bottom	35.0	75.2	73.8	72.9	75.4
Rear-Top	21.9	83.1	81.4	80.1	56.2
Rear-Middle	23.1	80.7	79.6	78.8	61.2
Rear-Bottom	18.9	90.9	88.2	86.2	45.5

*mean of 30 minutes of data after reaching set temperature

A tray of water was placed at the Bottom location of the cabinet to determine if significant and consistent humidity could be achieved in the cabinet, which would simplify sample preparation (i.e. eliminating the need for moist paper towels, though containers would need to be vented). After 80 minutes the relative humidity of the cabinet was approximately 30%, compared to typical dry heat levels of less than 1% (Fig. 2). One observation was that humidity levels would increase when the cabinet heating element was deactivated, thus warming cabinets with better insulation would likely produce greater levels of relative humidity using this method (i.e. the heating element would be activated less often).

The use of large metal trays significantly contribute towards the distribution of heat throughout the cabinet and their consistent use provides more repeatable heating for each load. Therefore, trays should be placed in the cabinet during the heat deactivation process, even if the trays themselves are not filled.

Concluding Remarks

Although unused N95 masks are ideal and are recommended if resources are available, deactivation methods may need to be implemented if the reuse of PPE equipment is considered. Results herein suggest that food-warming cabinets can be used for heat deactivation of SARS-CoV-2. Although there is inherent variability of temperature and humidity for this cabinet, more uniform levels may occur with models with more insulation. Literature suggests that a humid environment provides enhanced deactivation of SARS-CoV-2 compared to dry heat, though the precise relationship between heat and humidity is still not completely understood. Although there is inherent variability of heat and humidity using warming cabinets, the values presented (70 °C – 90 °C, > 45% RH) may be effective. Greater humidity levels can be achieved by saturating the paper towel with a greater volume of water (ex: 500 μL of water), though levels of 100% should be avoided as they may be less effective in deactivation (Casanova et al. 2010, Lin and Marr 2020). A more consistent humidity can be achieved using a paper towel with an absorbed saturated salt solution, though the impact of this method on N95 filtration efficiency and virus deactivation, to my knowledge, has not yet been studied.

Assuming a rise time of approximately 45 minutes and an additional treatment time of 30 minutes results in a total treatment time of 75 minutes, or approximately 19 cycles per day if operating continuously. If cabinet shelving was modified to accommodate 108 masks this would result in 2,052 mask treatments per day. Due to the availability of food-warming cabinets, this may be a cost-effective option for heat-and-humidity deactivation of N95 masks.

Acknowledgements

SJ Williams would like to acknowledge K Graven and others at the Vulcan Hart Corporation (Louisville, KY) for graciously donating the cabinet for this study. SJ Williams also acknowledges valuable conversations and feedback from L Anderegg (Harvard University), J Doyle (Harvard University), E Mazenc (Stanford University), and others from the N95Decon scientific consortium (n95decon.org).

References

- Anderegg, L., C. Meisenhelder, C. O. Ngooi, L. Liao, W. Xiao, S. Chu, Y. Cui and J. M. Doyle (2020). "A Scalable Method of Applying Heat and Humidity for Decontamination of N95 Respirators During the COVID-19 Crisis." medRxiv.
- Bergman, M. S., D. J. Viscusi, B. K. Heimbuch, J. D. Wander, A. R. Sambol and R. E. Shaffer (2010). "Evaluation of Multiple (3-Cycle) Decontamination Processing for Filtering Facepiece Respirators." Journal of Engineered Fibers and Fabrics **5**(4): 155892501000500405.
- Casanova, L. M., S. Jeon, W. A. Rutala, D. J. Weber and M. D. Sobsey (2010). "Effects of Air Temperature and Relative Humidity on Coronavirus Survival on Surfaces." Applied and Environmental Microbiology **76**(9): 2712.
- F.D.A., U. S. (2020). STERIS STEAM Decon Cycle in AMSCO Medium Steam Sterilizers. U. S. F. a. D. Administration. Coronavirus Disease 2019 (COVID-19) Emergency Use Authorizations for Medican Devices.
- Fischer, R., D. H. Morris, N. van Doremalen, S. Sarchette, J. Matson, T. Bushmaker, C. K. Yinda, S. Seifert, A. Gamble, B. Williamson, S. Judson, E. de Wit, J. Lloyd-Smith and V. Munster (2020). "Assessment of N95 respirator decontamination and re-use for SARS-CoV-2." medRxiv.
- Kumar, A., S. B. Kasloff, A. Leung, T. Cutts, J. E. Strong, K. Hills, G. Vazquez-Grande, B. Rush, S. Lother, R. Zarychanski and J. Krishnan (2020). "N95 Mask Decontamination using Standard Hospital Sterilization Technologies." medRxiv: 2020.2004.2005.20049346.
- Liao, L., W. Xiao, M. Zhao, X. Yu, H. Wang, Q. Wang, S. Chu and Y. Cui (2020). "Can N95 Respirators Be Reused after Disinfection? How Many Times?" ACS Nano.
- Lin, K. and L. C. Marr (2020). "Humidity-Dependent Decay of Viruses, but Not Bacteria, in Aerosols and Droplets Follows Disinfection Kinetics." Environmental Science & Technology **54**(2): 1024-1032.
- Massey, T., M. Borucki, S. Paik, K. Fuhrer, M. Bora, S. Kane, R. Haque and S. H. BAXAMUSA (2020). "Quantitative form and fit of N95 filtering facepiece respirators are retained and coronavirus surrogate is inactivated after heat treatments." medRxiv.
- N95Decon (2020). Technical report for heat-humidity-based N95 reuse risk management. n95decon.org.
- van Doremalen, N., T. Bushmaker, D. H. Morris, M. G. Holbrook, A. Gamble, B. N. Williamson, A. Tamin, J. L. Harcourt, N. J. Thornburg, S. I. Gerber, J. O. Lloyd-Smith, E. de Wit and V. J. Munster (2020). "Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1." New England Journal of Medicine **382**(16): 1564-1567.
- Viscusi, D. J., W. P. King and R. E. Shaffer (2007). "Effect of decontamination on the filtration efficiency of two filtering facepiece respirator models." Journal of the International Society for Respiratory Protection **24**: 93-107.
- Wigginton, K. R., P. J. Arts, H. Clack, W. J. Fitzsimmons, M. Gamba, K. R. Harrison, W. LeBar, A. S. Lauring, L. Li, W. W. Roberts, N. Rockey, J. Torreblanca, C. Young, L. C. Anderegg, A. Cohn, J. M. Doyle, C. O. Meisenhelder, L. Raskin, N. G. Love and K. S. Kaye (2020). "Validation of N95 filtering facepiece respirator decontamination methods available at a large university hospital." medRxiv.