Self-Disinfecting and Ergonomic N-95 Facial Mask

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1.0 Design Overview

The challenge of modifying an N95 mask to achieve better usability [1], safety, and comfort is changing elements of the mask while maintaining its N95 certification. The design must filter particles greater than 0.3 microns in size and maintain a tight seal on the user's face [2]. Additionally it must alleviate factors which would cause a disposable mask to deteriorate upon reuse such as moisture damage and mask deformation from a heat disinfection process [3]. To do so the design should:

- Maximize airflow
- Self-disinfect
- Minimize moisture
- Improve ergonomics

The design achieves the above objectives by modifying the mask structure, facial ergonomics, and airflow of the CuO Cupron Scientific N95 mask [4].

1.1 Mask Structure

The mask employs a four layer design. The outer and inner layers are made of spunbond polypropylene layers containing 2.2 wt% CuO. The second outermost layer is a meltblown polypropylene layer containing 2 wt% CuO. The second innermost layer is made of polyester to maintain mask shape [4].

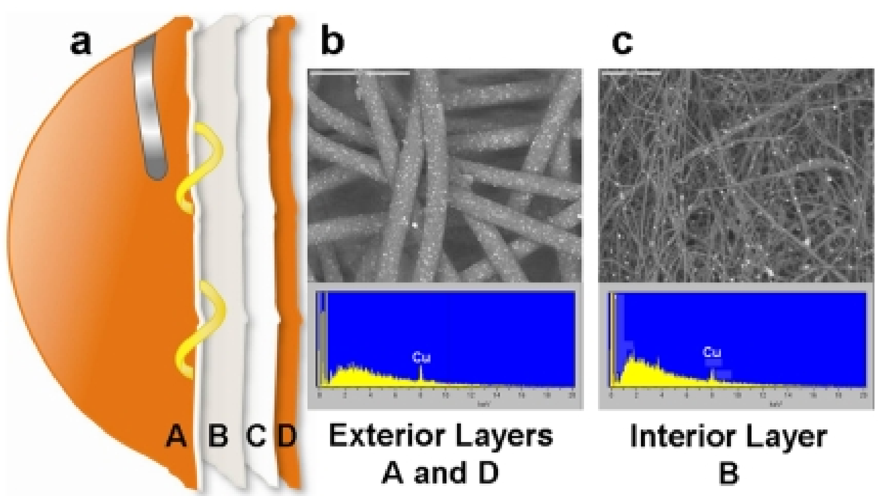

Fig 1.1.1: Layers A and D: made of spunbond polypropylene layers containing 2.2 wt% CuO. Layer B: meltblown polypropylene layer containing 2 wt% CuO. Layer C: plain polyester for mask shape [4]

To absorb excess moisture, a detachable, polypropylene fabric pouch containing 10g of Sodium Polyacrylate powder [5] will be added to the mask. Sodium Polyacrylate, a super-absorbent polymer, can absorb 300x its weight [6]. Since humans exhale approximately 110mL of water in 12 hours [7], the SAP powder will absorb moisture for at least 9 days before needing maintenance.

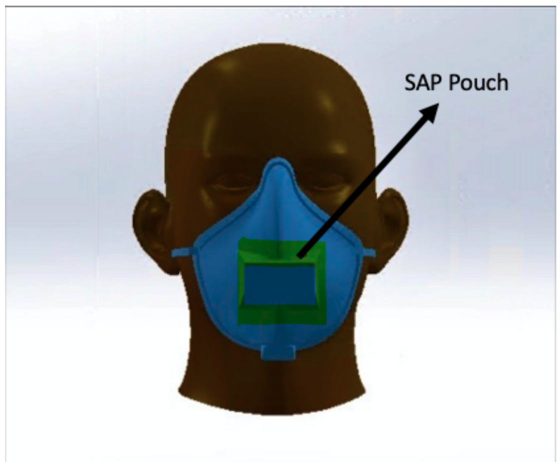

Fig. 1.1.2: CAD model of mask demonstrating the location of the SAP pouch

2.2 Facial Ergonomics

On average, COVID healthcare workers wear a medical mask for 8 hours. This often results in skin lacerations, bacterial/fungal infections, and decreased oxygen supply [8]. After interviewing 8 doctors [9] and from data, a level of discomfort was noted due to thermal stress, absolute humidity and breath resistance [10]. The average mask discomfort levels (Figure 1.2.1) [11] and guidelines by Ontario Health [1] was used to make the following improvements.

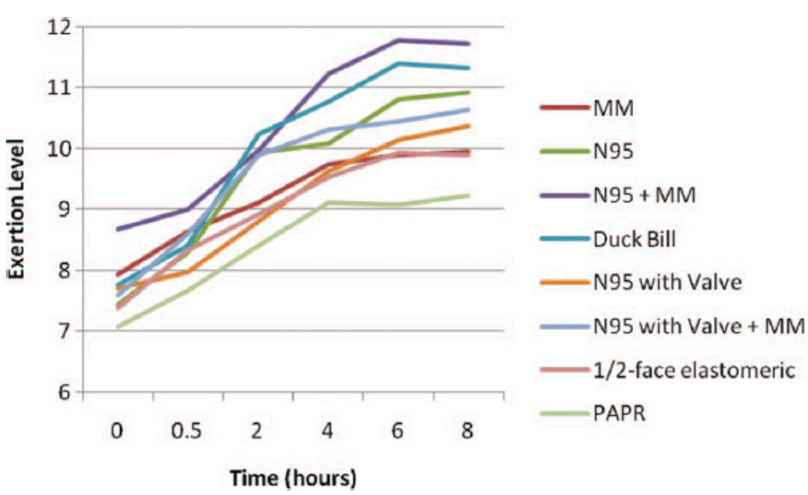

Fig. 1.2.1 : Exertion Level of different available masks for health care.[11]

To accommodate for the varied nose sizes for sealing a **Nose Adjustment Extension** would be provided. The following should be at a curvature of 0.014499 (Fig.1.4.1) modeled after an average head structure which would also accommodate for **safety glasses** and reduce fogging due to moisture release. The **metallic wire lining** helps adjust to varied facial structures while maintaining a proper seal. An **adjustable chin clip** is attached to the bottom lining to increase security. A rising problem is lacerations due to straps, it avoids this by using **elastic-straps** wrapping underneath the ear. Furthermore, adjustments can be made using an **adjustable cardboard scale** (fig.1.2.2)

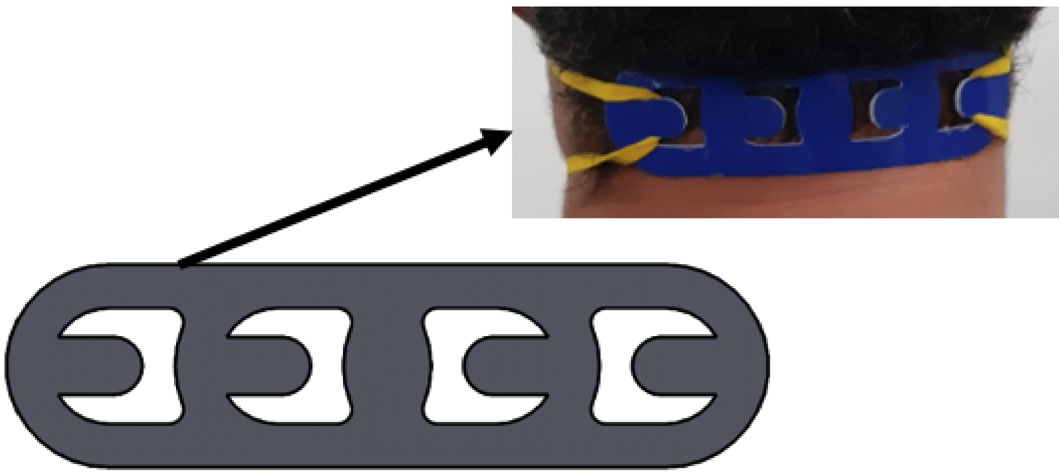

Fig. 1.2.2 : Adjustable scale 3D design and prototype.

1.3 Optimizing air flow

Prolonged usage of masks can lead to reduced air exchange and mask deoxygenation. A rectangular nose exhalation valve (Fig1.4.1) is used to increase air flow and user comfort (Fig1.4.1) . The rectangular shape was chosen due to its ease of manufacture compared to a circular valve. It also reduces the chance of mask deoxygenation. A valve also decreases the rate of change of cheek skin and internal body temperatures [12]. Along with a large surface area for air breathability it would also accommodate the SAP pouch to maintain comfortable moisture levels while maintaining an N95 certification.

1.4 Design Renderings

Size: Standard 4.5 inches (11.4 cm) - Outer edge category [13]

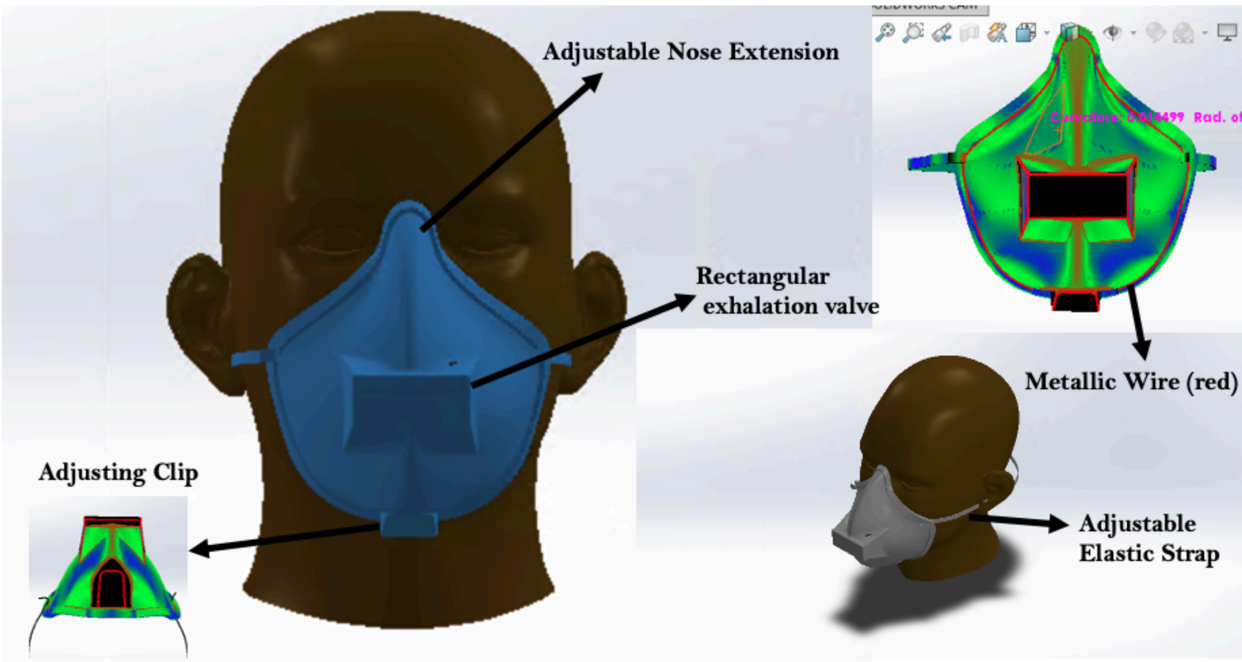

Figure 1.4.1: CAD Diagrammatic representation of mask.

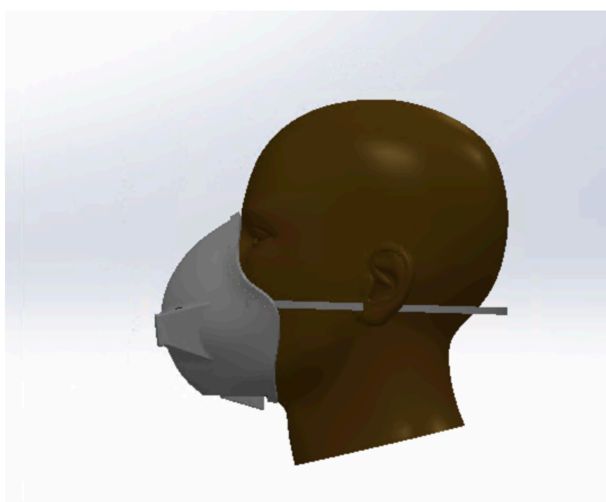

Figure 1.4.2: Sideways view of the mask

2.0 Potential drawbacks

- Mask will be more expensive than the regular N95 with the addition of copper-oxide layer and SAP pouch.
- While the mask will be mostly self-disinfecting, hospital staff will need to eventually sterilize it as the straps/other parts not covered with copper oxide may become contaminated.
- SAP pouch will need to be maintained properly to evaporate water and/or replaced to ensure good moisture absorption and reduce weight on the mask.
- Mask will eventually be disposed (due to wearing of the polypropylene material) after around 5 years at most. [14] Disposable mask will pose environmental problems such as filling up landfills and possible biohazards if disposal is improper. [15]

3.0 Implementation

With all stages considered it is estimated to take around 2-3 weeks to implement this design.

3.1 Testing

A prototype of the design will be benchmarked against a 3M Health Care Particulate Respirator and Surgical Mask 8210. It will be tested upon production, and then 1 week after re-use, then 2 weeks, etc. for a month to measure how well the mask satisfies the objectives whilst being reusable for a month.

Breathability:

- Differential pressure test in accordance with ASTM F2100 [16]
- An acceptable value for a mask would be lower than 5.0 (mm of H20/cm^2)
    - A high pressure differential would indicate that the mask has too tight of a seal, limiting breathability [17].

Filtration:

- In accordance with ASTM F2100 [16]
- The particle filtration objective will be tested with a Particle Filtration Efficiency test such as the Nelson Labs “Latex Particle Challenge” [17]
- The biological filtration efficiency can be measured by the BFE101(Bacterial Filtration Efficiency) and VFE110 (Virus FIltration Efficiency) tests. [18]

Ergonomics:

- User Seal Check
    - Pass/Fail qualitative user tests
    - Positive Pressure Test:
        - The mask is secured to a proper fit. The user exhales. If a slight positive pressure builds in the mask without leakage the seal is satisfactory.
    - Negative Pressure Test:

        - The mask is secured to a proper fit. The user inhales and holds their breath for 10 seconds. If the mask slightly collapses in on itself without leakage, the seal is satisfactory [19].
- Interior Mask Temperature
    - The interior mask temperature will be measured using the Hydrochron iButton® DS1923 [20]
    - As a control for the thermometer,
    - Mean interior mask temperature should be ≤29.1 ºC [21]

Moisture absorption:

- The relative humidity of the inside the mask will be measured using the Hydrochron iButton® DS1923 [20] and benchmarked against the 3M 8210 N95 Respirator.

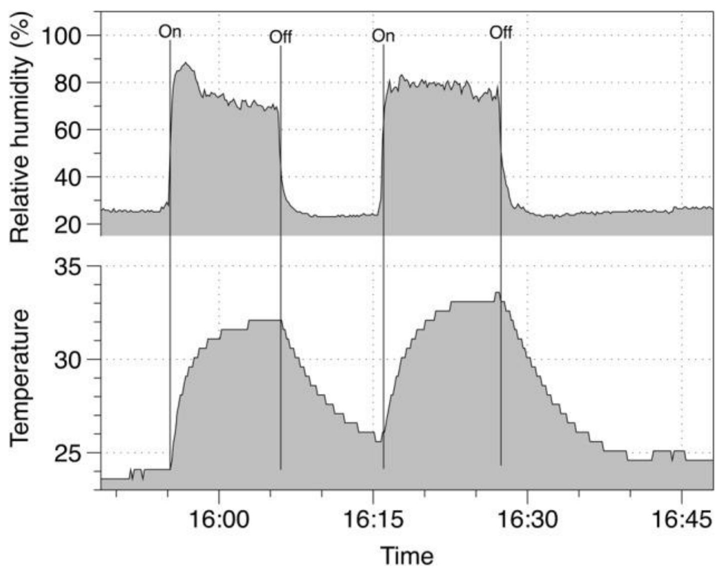

Figure 3.1.1: Sample temperature and relative humidity profile of an N95 respirator [21]

Self Disinfection:

- Measure biological material density relative to the 3M 8210 N95 respirator using qRT-PCR [22].

3.2 Manufacturing

Enlist local manufacturers in Ontario such as Windsor Manufacturer, Ellipse Automation, etc to produce and distribute masks [23][24].

Timeline:

- Send design to manufacturers.
- Manufacturers may invest in capital such as copper oxide and accompanying processors, etc.
- Arrange for sodium polyacrylate (SAP) from other suppliers.

- Assemble at the manufacturers' using premade molds.
- Masks with SAP pouches distributed to hospitals, with maintenance instructions.

3.3 Mask Maintenance

The copper oxide layers provide copper ions that can kill pathogens that are trapped in the layer fibres by destroying their cell membranes [25][4]. The CuO takes 1-4 hours to disinfect the mask surface [4] unlike traditional N95 masks that can become easily contaminated [27]. Moreover, even after multiple uses, the copper ions still aid electrostatic filtration whereas this ability is impaired in the N95 filters due to the air humidity [3]. The combination of disinfection and electrostatic activity make these modified masks reusable for a longer period before needing maintenance. The SAP pouch can absorb moisture up to nearly a month (12 hour shifts), but should be replaced after 9 days.

4.0 Economic Feasibility

The costs for this design were estimated using the prices of off the shelf components and an estimation of manufacturing costs based on similar designs. However, this is likely an **overestimate** as both manufacturing and materials costs decrease per unit with increased production volume.

Table 4.1: Estimation of material and manufacturing costs per mask

No.	Layer/Material	Cost/...	Amount used in one mask	Total cost
1	Copper oxide-woven fibre	$11.8 per piece	1 piece	$11.8
2	SAP pouch	$1.36-$2.45 per kg [28]	0.01kg	$0.0245
3	Filtration medium for N95 and Mask Polymer	$35.78 per kg [29]	0.0099 kg[30]	$0.354
5	Manufacturing Cost	*Varies based on manufacturer	*Varies based on manufacturer	*Varies based on manufacturer
6	Elastic/Attaching Material	$6.11	1 piece	$6.11
			Total Cost of Mask:	***$18.29***

For comparison a 3M 8210 N95 mask cost approximately $1.36 per mask at MSRP [31], around one eleventh the cost of the mask. The cost would also be covered by government funding(around $50 million) which would further subsidise individual cost and bring down the cost to around $15.99 [32]. Although CuO masks are more expensive, they potentially provide lifespan of up to **5 years of use.** Using a CuO infused mask reduces the contaminated surface area of the front of the mask. This reduces the likelihood of an outbreak of COVID-19 among healthcare professionals, 2029 of which have been infected in long-term care facilities alone [33].

5.0 References

[1]Public Health Ontario, "Personal Protective Equipment (PPE) use during the COVID-19 Pandemic," May 30, 2020. [Online]. Available: https://www.oha.com/Bulletins/Personal%20Protective%20Equipment%20use-COVID-19_Released_March_30_2020.pdf

[2]L. Brosseau and R. B. Ann, "N95 Respirators and Surgical Masks." [Online]. Available: https://blogs.cdc.gov/niosh-science-blog/2009/10/14/n95/. [Accessed: 14-Jun-2020].

[3]"N95-electrocharged filtration principle based face mask design using common materials," OIST Groups, 18-Apr-2020. [Online]. Available: https://groups.oist.jp/nnp/diy-face-mask. [Accessed: 14-Jun-2020].

[4]G. Borkow, S. S. Zhou, T. Page, and J. Gabbay, "A Novel Anti-Influenza Copper Oxide Containing Respiratory Face Mask," PLoS ONE, vol. 5, no. 6, 2010.

[5]www.fibre2fashion.com, "The SAP Market," Fibre2Fashion. [Online]. Available: https://www.fibre2fashion.com/industry-article/7712/the-sap-market. [Accessed: 14-Jun-2020].

[6] J. Zohuriaan and K. Kabiri, "Superabsorbent Polymer Materials: A Review," Iranian Polymer Journal, Jun. 2008.

[7]Z. J. P. J; "[How Much Water Is Lost During Breathing?]," Pneumonologia i alergologia polska, 2012. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/22714078/. [Accessed: 14-Jun-2020].

[8]S. Writer, "5 Side Effects Of Wearing Face Masks," Taarifa Rwanda, 21-May-2020. [Online]. Available: https://taarifa.rw/5-side-effects-of-wearing-face-masks/. [Accessed: 14-Jun-2020].

[9]S.A.I.M.S COVID Doctors,Online interview, 10 June, 2020

[10]Y. Li, H. Tokura, Y. P. Guo, A. S. W. Wong, T. Wong, J. Chung, and E. Newton, "Effects of wearing N95 and surgical facemasks on heart rate, thermal stress and subjective sensations," International archives of occupational and environmental health, Jul-2005. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7087880/. [Accessed: 14-Jun-2020].

[11]B. V. Shenal, L. J. Radonovich, J. Cheng, M. Hodgson, and B. S. Bender, "Discomfort and Exertion Associated with Prolonged Wear of Respiratory Protection in a Health Care Setting," Journal of Occupational and Environmental Hygiene, vol. 9, no. 1, pp. 59–64, Jan. 2012.

[12]"The effects of two kinds of mask (with or without exhaust valve) on clothing microclimates inside the mask in participants wearing protective clothing for spraying pesticides," ResearchGate. [Online]. Available: https://www.researchgate.net/publication/10582068_The_effects_of_two_kinds_of_mask_with_or_without_exhaust_valve_on_clothing_microclimates_inside_the_mask_in_participants_wearing_protective_clothing_for_spraying_pesticides. [Accessed: 14-Jun-2020].

[13]"Training Mask Size Chart," Training Mask. [Online]. Available: https://www.trainingmask.com/training-mask-size-chart/#:~:text=choosing the correct mask size&text=LARGE - 5 inches (12.7 cm,10.2 cm) 100lbs to 145. [Accessed: 14-Jun-2020]

[14]R. Ruibag, RUIBAG, 2020. [Online]. Available: https://www.ruibagfactory.com/what-is-non-woven-polypropylene-fabric/. [Accessed: 14-Jun-2020].

[15]S. C. M. P. Editorial, "The disposal of face masks and medical waste is a crisis in the making," South China Morning Post, 08-Mar-2020. [Online]. Available: https://www.scmp.com/comment/opinion/article/3074162/disposal-face-masks-and-medical-waste-crisis-making. [Accessed: 14-Jun-2020].

[16]Standard Specification for
Performance of Materials Used in Medical Face Masks, ASTM F2100, April, 2020. Available: https://compass-astm-org.myaccess.library.utoronto.ca/download/F2100.35461.pdf

[17]“Surgical Face and General-Use Masks Tests,” 08-Aug-2019. [Online]. Available: https://www.nelsonlabs.com/testing/surgical-face-masks-and-general-use-masks-astm-f2100/. [Accessed: 14-Jun-2020].

[18]“Bacterial & Viral Filtration Efficiency Tests,” 04-Feb-2020. [Online]. Available: https://www.nelsonlabs.com/testing/bacterial-viral-filtration-efficiency-bfe-vfe/. [Accessed: 14-Jun-2020].

[19]American Dental Association, " Conducting Respirator Fit Tests and Seal Checks," May 12, 2020. Available: https://success.ada.org/~/media/CPS/Files/COVID/Conducting_Respirator_Fit_Tests_And_Seal_Checks.pdf

[20]“DS1923 iButton Hygrochron Temperature/Humidity Logger with 8KB Data-Log Memory - Maxim Integrated.” [Online]. Available: https://www.maximintegrated.com/en/products/ibutton-one-wire/data-loggers/DS1923.html. [Accessed: 14-Jun-2020].

[21]J. W. Cherrie, S. Wang, W. Mueller, C. Wendelboe-Nelson, and M. Loh, “In-mask temperature and humidity can validate respirator wear-time and indicate lung health status,” *Journal of Exposure Science & Environmental Epidemiology*, vol. 29, no. 4, pp. 578–583, 2018.

[22]Julian, T. R., Tamayo, F. J., Leckie, J. O., & Boehm, A. B. (2011). Comparison of Surface Sampling Methods for Virus Recovery from Fomites. Applied and Environmental Microbiology, 77(19), 6918-6925. Retrieved June 14, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3187074/

[23]C. Ensing, “Windsor manufacturer says producing thousands of N95 masks possible, but materials unavailable | CBC News,” CBCnews, 17-Apr-2020. [Online]. Available: https://www.cbc.ca/news/canada/windsor/laval-international-n95-mask-material-issues-1.5535512. [Accessed: 14-Jun-2020].

[24]M. Automation, “Eclipse Automation to facilitate N95 mask production in Ontario with new system,” Manufacturing AUTOMATION, 22-Apr-2020. [Online]. Available: https://www.automationmag.com/eclipse-automation-to-install-system-to-help-with-n95-mask-production-in-ontario/. [Accessed: 14-Jun-2020].

[25]A. Matteo, “Copper Metal Kills Viruses on Contact,” VOA, 01-Feb-2016. [Online]. Available: https://learningenglish.voanews.com/a/copper-kills-viruses-on-contact/3147962.html. [Accessed: 14-Jun-2020].

[26]N. V. Doremalen, T. Bushmaker, D. Morris, M. Holbrook, A. Gamble, B. Williamson, A. Tamin, J. Harcourt, N. Thornburg, S. Gerber, J. Lloyd-Smith, E. D. Wit, and V. Munster, “Aerosol and surface stability of HCoV-19 (SARS-CoV-2) compared to SARS-CoV-1,” 2020.

[27]G. Borkow, S. S. Zhou, T. Page, and J. Gabbay, “A Novel Anti-Influenza Copper Oxide Containing Respiratory Face Mask,” PLoS ONE, vol. 5, no. 6, 2010.

[28]“Msds Super Absorbent Polymer Sap Powder - Buy Msds Super Absorbent Polymer,Msds Sap,Super Absorbent Polymer Powder Product on Alibaba.com.” [Online]. Available:

https://www.alibaba.com/product-detail/MSDS-SUPER-ABSORBENT-POLYMER-SAP-POWDER_829577314.html?spm=a2700.7724857.normalList.2.6cc74ebb7HTW2E. [Accessed: 14-Jun-2020].
[29]"Meltblown Non Woven Fabric." [Online]. Available: https://www.indiamart.com/proddetail/meltblown-non-woven-fabric-22375492962.html. [Accessed: 14-Jun-2020].
[30]"3M™ Particulate Respirator 8210, N95 Technical Specification Sheet." [Online]. Available: https://multimedia.3m.com/mws/media/1425070O/3m-particulate-respirator-8210-n95-technical-specifications.pdf. [Accessed: 14-Jun-2020].
[31]"3M™ 8210 N95 Particulate Respirator (Box of 20)." [Online]. Available: https://www.envirosafetyproducts.com/3m-8210-respirator.html. [Accessed: 14-Jun-2020].
[32]"Ontario Helps Manufacturers Ramp Up Production of Personal Protective Equipment," *news.ontario.ca*. [Online]. Available: https://news.ontario.ca/opo/en/2020/06/ontario-helps-manufacturers-ramp-up-production-of-personal-protective-equipment.html. [Accessed: 15-Jun-2020].
[33]"How Ontario is responding to COVID-19," *ontario.ca*. [Online]. Available: https://www.ontario.ca/page/how-ontario-is-responding-covid-19. [Accessed: 14-Jun-2020].