EDUCACIÓN | TECNOLÓGICO NACIONAL DE MÉXICO | IPSUMTEC
ISSN: 2594 - 2905

REENGINEERING OF ALTERNATIVE FACE MASKS TO THE K-N95 COVER MASK

REENGINEERING OF ALTERNATIVE MASKS TO THE K-N95 MOUTH COVER

[1]Vasquez Martínez Marcelo, [2]Bartolo Alemán Martha Hilaria, [3]Robledo Taboada Luis Humberto, [4]Martínez López Moisés, [5]Morales Castillo Vicente

[1] Industrial Engineering Intern, [2] Master in Administration, [3] Master in Science, ([4]Mechatronics Engineer, [5] Industrial Production Engineer.
[1]l13160776@oaxaca.tecnm.mx ,(2)martha.bartolo@itoaxaca.edu.mx(,) (3)luis.rt@itoaxaca.edu.mx(,) (4)moises.ml@itoaxaca.edu.mx(,)
(5)vicente.morales@itoaxaca.edu.mx.

[1 (2) (3) 4 5] Tecnológico Nacional de México / Instituto Tecnológico de Oaxaca, [1 (2) (3) 4) 5] Departamento de Ingeniería Industrial, Avenida Ing. Víctor Bravo Ahuja No. 125 Esquina Calzada Tecnológico, (951)5015016 C.P. 68030, Oaxaca de Juárez, Oaxaca.

Abstract -- Different types of materials and components were synthesized to assemble respirator type masks as an alternative (sustainable and durable) to a KN-95 mouthpiece. 3D injection type printers were used to manufacture the components, where the thickness, injection height, printing time, fastening and filling density were varied. The morphological analysis tests (surface and transversal) were performed with Scanning Electron Microscopy. The filtration degree of the filters and the mask was performed with a physical test that simulated a human sneeze. Biological characterization was performed in situ using culture media and observing the growth of pathogenic organisms. The results show that the effectiveness of the mask is similar to the KN-95 in both biological and physical aspects, in addition to being more durable and environmentally friendly.

Keywords**:** 3D printing, mask, covid-19.

Abstract -- Different types of materials and components were synthesized to assemble respirator-type masks as an alternative (sustainable and durable) to a KN-95 face mask. Injection-type 3D printers were used to manufacture the components, where the thickness and injection height were varied, printing time, clamping method and fill density. Morphological analysis tests (superficial and transversal) were performed with Scanning Electron Microscopy. The degree of filtration of the filters and the mask was made with a physical test that simulated a human sneeze. Biological characterization was carried out in situ by using culture media and observing the growth of pathogenic organisms. The results show an effectiveness of the mask similar to KN-95 both in the biological and physical aspects, in addition to having greater durability and being ecological.

Key words: 3D printing, mask, covid-19.

INTRODUCTION

After the outbreak of the SARS-COV-2 disease (COVID-19) [1], the collapse of the different clinical resources in the region was due to the fact that the necessary infrastructure and resources were not sufficient to meet the demand due to the growing number of infections [2]. The shortage of masks, gloves, disinfectant liquids and face shields led to the appearance of different types of devices and masks to deal with the pandemic worldwide [3-11].

Currently working with various alternatives to curb the spread SARS-COV-2, Instituto Tecnológico de Oaxaca chose to reengineer a respirator type mask that could be universal according to the facial characteristics of the various users, in addition to providing the opportunity to obtain a product with greater durability than the existing masks found in the market.

In this research, an optimal configuration of the 3D printing process, design and ideal material was found to high security to the user against the possible infection of the SARS-COV-2 virus. Through the use of 3D printers equipped with fused deposition modeling (FDM) technology [12-14], we sought to address a global pandemic of

Date Received: September 2020 | Date of Acceptance: December 2020

ISSN: 2594 - 2905

reliable and environmentally friendly way using the current resources of the Industrial Engineering laboratory of the Instituto Tecnológico de Oaxaca.

DEVELOPMENT

In the manufacturing process of the masks, a Rostock Maxv4 Dual Extruder 3D printer was used, has a printing area of 30x30x40 mm, and a 3DWox1 printer with a printing area of 25x25x14 cm, both with fused deposition modeling (FDM) technology; these printers use thermoplastic materials for the manufacture of various parts (Fig. 1).

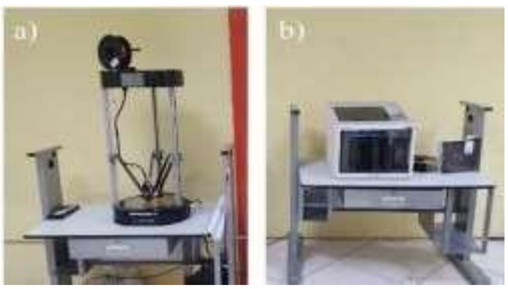


Figure 1. a) Rostock 3D printer and b) 3DWox1 printer.

Mask redesign

In recent years, the use of various masks based on the polymer 3D printing process has been investigated [3,7,15-17], one of the most recent being proposed by the factory research group [3].

The design of the mask proposed by the Industrial Engineering research group of the Instituto Tecnológico de Oaxaca is based on a respirator type mask that consists of several components assembled together, this design was made in SolidWorks software (Figure 2), in addition to this, the base material to be used and its efficiency against the filtration of pathogenic organisms were determined through different tests and characterization techniques.

Figure 2. Design in Solid Works.

Three dimensions of the mask were defined, based on the physiognomy of Oaxacan people (see table 1).

Table 1. Mask dimensions

Mask	Height	External width	Internal width
Girl	55 mm	81 mm	80 mm
Median	55 mm	84 mm	83 mm
Grande	55 mm	87 mm	85 mm

In addition, elastic attachment holes were added from 1.5mm x 3mm to 2mm x 6mm.

Material selection

Some of the materials that can currently be used in 3D printing are the following: PLA (Poly Lactic Acid), ABS (Acrylonitrile Butadiene Styrene), PETG (Polyester Glycol), TPU (Thermoplastic Polyurethane), etc. [18]. PLA is a bio-polyester, so this material is 100% biodegradable, its main characteristics are: printing temperature of 195 - 220°C, a printing speed between 40 - 100 mm/s, modulus of elasticity up to 2,960 MPa (Mega Pascals), due to these properties and its easy accessibility it was chosen as the base material for the masks.

3D printing parameters

Table 2 shows the parameters that were varied in the 3D printing process in order to optimize its physical and mechanical properties such as porosity reduction, higher strength and high durability.

Table 2. 3D printing parameters

Método de sujeción	Densidad de relleno (%)	Tiempo (minutos)	Altura de Capa(mm)	Grosor de pared (mm)
Balsa	20	35	0.25	0.80
Skirt	20	70	0.25	.80
Skirt	20	24	0.25	.70
Skirt	20	24	0.30	.80
Skirt	20	28	0.25	.90
Skirt	25	23	0.25	.90

Selection of hermetic seal

For a proper airtight seal [19], a D-profile shaped ethylene propylene diene rubber was selected (Fig. 3), in order to ensure a uniform seal around the mask and prevent possible leakage or ingress of unwanted biological particles.

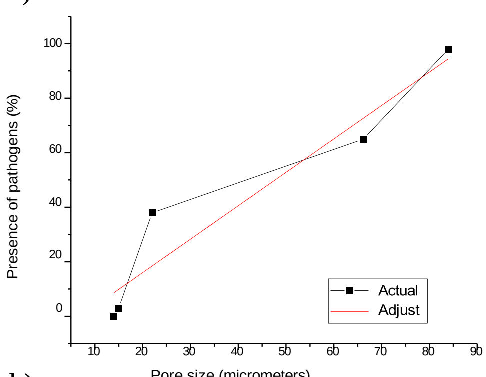
ISSN: 2594 - 2905

Figu

Filter selection

The selection of filters was based on several options of filters based on cotton and activated carbon, this selection was made by testing two characterization , on the one hand the characterization of pore size and thickness of the layers using Scanning Electron Microscopy (SEM) and on the other hand the growth of pathogens, with the objective of testing the effectiveness of the filters, The graphs in Figure 4 were obtained, where it can be seen that from a pore size of 15 micrometers the presence of microorganisms is minimal, in addition to this, the thickness of the layers plays an important role in the filtration system because as seen in the graphs, thick layers (more than 2 mm) have less presence of pathogens.

a)



b)

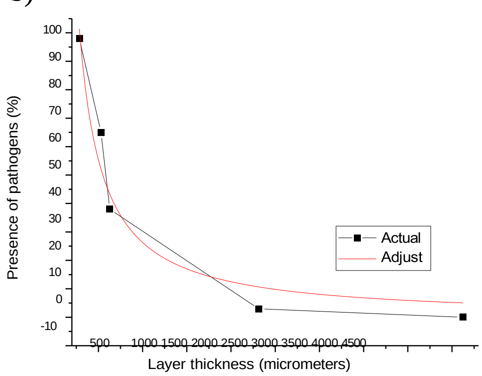


Figure 4. a) Pore size vs. pathogen presence plot and b) Layer thickness vs. pathogen presence plot.

By analyzing the above graphs, the equation for the behavior of the presence of pathogens with respect to the pore diameter was determined:

$$y = 1.22601x \qquad \text{Eq. (1)}$$

This equation indicates that the smaller the average pore size in the filters, the lower the presence of external pathogenic organisms, thus it is estimated that the presence of pathogens will tend to be 0 if the pore diameter is less than 15 micrometers.

With equation 2 it was determined that the thicker the filter layer, the lower the percentage of microorganisms, so that the equation shows that with layers of more than 2400 micrometers the presence of harmful microorganisms is very low.

$$y = 44163.60635x^{-1.07502} \qquad \text{Eq. (2)}$$

Thus, a filter composed of 3 layers (cotton, activated carbon and cotton) was selected to form a system 4.5 millimeters thick and whose efficiency is quite optimal.

Final assembly of the mask manufactured piece by piece by 3D printing.

Once the parts of the mask body were printed and the filters, the hermetic rubber and the elastic band were selected, all the components were assembled (Figure 5) to form the final prototype.

Components of the prototype a) fabricated body, b) filters, c) hermetic band and d) assembled mask.

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Characterization tests and techniques

During the development of the model proposed by the industrial engineering research team, 3 characterization techniques were carried out to determine the efficiency of the mask and its filters; the results are presented below.

Physical characterization of filters against commercial mouthpieces

The proposed filters are based on layers, the first layer is activated carbon and cotton fiber, the second layer is activated carbon and the final layer is activated carbon and cotton fiber. The first test was performed using an aerosol that simulates a human sneeze and the use of a dark surface that shows the particles filtered through the pores of each type of mask.

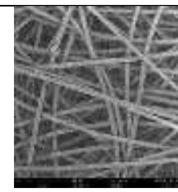
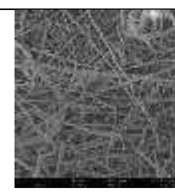
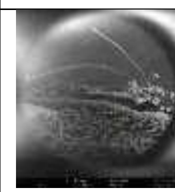
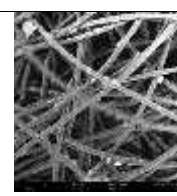
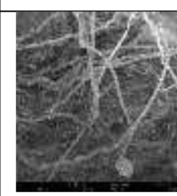
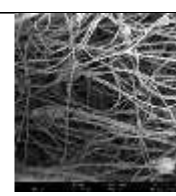
Table 3. Physical test of the different types of masks vs. filters of the proposed masks.

Type of mouthpiece	Test performance	Result
Commercial blue		
White laboratory Y White-Blue laboratory		
Fabric - homemade		
N-95		
Industrial Engineering Proposal Filters		

Scanning Electron Microscopy of the proposed prototype against commercial coverslips.

The morphological analysis (surface and cross-sectional) at the microscopic level was performed using Scanning Electron Microscopy (SEM) with a SEM Pure microscope. Different magnifications are shown, in order to observe and analyze the structures and layers of each mask with respect to proposed masks.

Scanning Electron Microscope () analysis at normal and cross-sectional incidence.

Type of mouthpiece	Morphology at Normal incidence	90° cut morphology
Commercial blue		
Fabric - home made		
Blue white - laboratory		
N -95		
Proposed Filters		
Cotton - activated carbon		

100% activated carbon	 	 

Microbiological Analysis

The culture media or human respiration (with the different types of coverslips) were exposed for a period of 5 minutes, this was done twice for each coverslip to show reproducibility (Fig. 5), the results are shown in Table 5.

Figure 6. In situ biological filtration test of the proposed mask.

Table 5. In situ tests of biological pathogen leaks in each type of mouthpiece and in the proposed masks.

Type of mouthguards and explanation	Result
Control from reference (without mouth covers): This test is conducted by speaking in front of media cultivation y the lighter without el use of no mouth covers, with the objective of see the growth of the native bacteria from human breath.	 High presence of pathogenic microorganisms
White laboratory Y White-Blue laboratory: Se used a mouth cover blue from laboratory to observe its efficiency from filtration from microorganisms.	 Average or 50% presence of pathogenic microorganisms
Fabric - homemade: Se carried out the same test The same test as above was performed with the homemade mouthpiece.	 High presence of microorganisms pathogens
KN-95: In the case of this mouth covers to put special attention at at proof because it is the competence direct from mouthguards designed by engineer industrial.	 Almost no presence of pathogenic organisms
Mask Proposal by Engineering Industrial: In this case, the performed the test at on	

Test after 3 months

In order to guarantee the effectiveness and durability of the protective equipment (filters and mask), it was tested after 3 months of continuous use, it should be noted that the mask and filters were superficially cleaned every day (every 8 hours) using an atomizer with a disinfectant solution rich in alcohol; in addition, every third day (24 hours of use) the filters were removed and immersed in a solution rich in alcohol to prevent contamination by pathogenic organisms. Figure 7 shows the result of the biological test performed on mask after having been used for 3 months (480 hours), showing no colony formation, which demonstrates the effectiveness of the protective equipment after a period of 3 months.

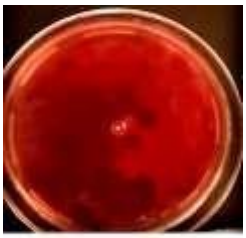


Figure 7. Petri dish resulting from the exposure of the culture medium of a person's breath for 5 minutes using the mask (after 3 months of daily use).

DISCUSSION AND ANALYSIS OF RESULTS

After analyzing the microscopic morphologies of the aforementioned coverslips, it is possible to understand in a more precise way their performance and efficiency [20]. It is observed that the coverslips that did not pass the sneeze simulation test have fewer layers [21-23], therefore the total system of layers has a much smaller thickness, added to what has already been mentioned, the fibers of the homemade and commercial blue coversare very separated forming pores of between 30.4 to 87 micrometers, in these cases there is a greater probability that various pathogens can pass through the protection system [23-26], depending on the pressure with which they dissipate (normal breathing or sneezing) and the size of the droplets.

It is important to highlight that the KN-95 mouthpiece cover and the proposed mask are effective due to the number of layers they have [22-24], their thickness (greater than 2400 micrometers) and the porosity formed (10 to 15 micrometers) by the fibers [21-26], it should be noted that both the KN-95 mouthpiece cover and the filters of the proposed mask have a thick layer in the center and compact activated carbon, which favors the filtration of biological organisms.

The growth of pathogenic organisms (bacteria, viruses and fungi) in the control culture media (initial experimental reference) and fabric is very high, therefore the filtration of a fabric cover slip is very deficient; on the other hand, in the samples of the blue cover slip (laboratory) there is an intermediate presence of these organisms, so its filtration is regular but not efficient, In the case of the KN-95 and the proposal designed by Industrial Engineering, there is no or very low presence of pathogenic organisms, so it is considered that both have a high air filtration efficiency.

CONCLUSIONS

The proposed filter system is made up of 3 stages (two cotton fiber and one intermediate activated carbon), it is effective due to the number of internal layers that each stage has, that is, layers within the same layers and their composition (cotton - activated carbon, activated carbon and one more stage of cotton - carbon), the dispersion of its fibers, the size of pores produced and the total thickness of the system, In addition to this, the base material was injected efficiently after several tests until reaching a solid model with minimum porosity and high density of area. In the case of the biological tests, a null presence of pathogens was observed in the culture medium corresponding to the proposed masks, which shows a high effectiveness of the masks, making their use recommendable.

The Industrial Engineering laboratory has the technological equipment (3D printers and plastic injector) but not the material and molds to carry out the chain production of these products. Once these inputs are obtained, the Industrial Engineering laboratory of the Tecnológico de Oaxaca would be prepared for the mass creation of these masks, which low cost and good pathogen filtration effectiveness. It is important to mention that each mask must be cleaned daily after each use with an alcohol-based sanitizer, in order to guarantee its functional efficiency and pathogen elimination.

In order to demonstrate the effectiveness of the masks, a final biological test was added, where it is important to mention that after 3 months of use, no pathogenic organisms were detected, however, it is highly relevant to mention the following recommendations for use:

-Daily disinfection of the mask and filters superficially.

-Extraction and sanitization of the filters every third day, immersing them for 5 minutes in a solution rich in 98% alcohol.
- It is considered 3 months as test life, however with proper care, ideal use and little wear and tear the filters can last even longer.
- For greater prevention, it is recommended that the user change the filters after 4 months of use.

In addition to everything described above, research will continue on better materials and designs to obtain more efficient and economical prototypes and thus contribute in solidarity with a key product to the Oaxacan and Mexican society in this COVID 19 contingency.

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