Assessment of the Particle Filtration Efficiency of N95 Masks Protecting Quarry Workers in Erongo, Otjozondjupa, and Kunene Regions of Namibia

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Abstract

Background: Quarry workers use different types of N95 masks to protect themselves from occupational respirable dust. However, little is known about the filtration efficiency of N95 masks among Namibian quarry workers. Hence, this study measured the filtration efficiency of the different N95 masks used in quarry mines following respirable dust exposure.

Methodology: The study employed a quantitative experimental design in a controlled environment with a sample of seven (7) N95 masks labelled A, B, C, D, E, F, and G from seven (7) quarry mining sites, with one mask from each site. Samples were selected using purposive sampling, focusing on the availability of masks FFP1 and FFP2, which are considered standard respiratory protection masks used in quarry mines. Masks' particle filtration efficiency and effectiveness were assessed by an experiment that included gravimetric weighing, mask testing, and particle size analysis techniques.

Results: The seven N95 masks collected insignificant dust compared to the amount of dust that passed through them, through gravimetric weighing. Site G recorded the highest dust exposure at 0.015mg, above the technique's standard uncertainty of ±0.010mg. Sites A and B had lower filtered dust weights, whereas Sites C, D, F, and G had higher values. The mass on filters increased significantly with a 5-minute sample period. The particle size analyser method showed that Sites A, B, and C showed smaller particles with 100% of the PM10 range, while sample Site D showed the highest particle size, with at least 60% below the PM10 range.

Conclusions: The N95 mask efficiently filters respirable dust particles at the initial stages. However, their filtration efficiency diminishes following prolonged use. Accordingly, Efficacy decreases as respirable dust exposure increases.

Recommendations: Based on the study findings, all the N95 masks met the filtration efficiency standards that attain the ideal respiratory protection; therefore, quarry workers should just increase the frequency of changing the masks. Additionally, masks should be tested upon fitting, properly fitted when used, and frequently replaced to complement the desired filtration efficiency.

***Keywords**: Respiratory Protection, Particle Filtration Efficiency, Filters/Masks, and Quarry*

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Introduction

Employees working in quarry mines are commonly subjected to harmful dust. Unremitting harmful dust exposure bears recognised detrimental health effects ranging from mild to severe complications (various illnesses and conditions) of the respiratory system in most instances. In most instances, the normal function of the lungs is adversely affected, causing difficulties in breathing [1]. Commonly reported respiratory complications, among other problems reported among quarry workers, consist of pneumoconiosis, silicosis, lung cancer, and alveolitis. The respiratory complications among quarry workers are greatly controlled by the variance in Particulate Matter (PM) form, size, and solubility [2]. With ineffective administrative and engineering controls in place, most quarry workers rely on the last resort of Respiratory Protective Equipment (RPE), such as filters or masks, to protect themselves from dust inhalation [1]

Filters and masks aim to act as face coverings or barricades to restrict respirable dust from entering the user's respiratory system through the nasal passages [3]. Filters and masks are melt-blown by a method of injecting electrically charged ions into the filtration media (preferred material), framing a partially perpetual electro-field that retains the PM qualified by electrostatic energy. Filters and masks are then measured through a process called Particle Filtration Efficiency (PFE) [4]. The PFE assesses the number of airborne particles (filtrate) retained by the filtration media. Depending on the mining environment, the filtrate differs in particle magnitude, mass, and shape [5].

Quarry mines in Namibia utilise different filters for respiratory protection; however, the most commonly used are cloth, surgical, N95, and P100 filters. Cloth masks are simple and always available. The masks are made from intertwined fibrous materials like cotton and cloth. Cloth masks allow huge fibrous spaces between them [6]. Surgical masks are triple-layered, with the outer layer (spunbonded) repelling fluids while the mid-layer (melt-blown) is the filter membrane, and the inner layer (spun-bonded) takes in moisture [5]. N95 masks are oil-resistant with two main layers that are hydrophobic. The innermost part has acrylic, which gives the shape of the respirator, while the inner layer forms the prime filter membrane made from polypropylene, which traps airborne particles [6]. N95 respirators are designed to effectively filter out 95% of airborne particles; they may not be this effective if they do not fit properly [4]. P100 masks filter toxic air particles as it is strongly resistant to oil [7]. Given all the available masks/filters, the choice of a mask is affected by the type of tasks performed, so it is important to analyse the filtration efficiency.

Namibia has mushrooming quarry mines, which are effectively contributing to the country's economic status; however, neglect in respiratory protection is evident in the absence of substantial legal frameworks and statutes in place [8]. Most quarry miners are artisanal, with the legal hand and government support being minimal [9]. Local studies have reported high Permissible Exposure Limit (PEL) values among quarry workers, which is exacerbated by the inability of quarry mine operators to provide employees with appropriate and adequate RPE (masks/filters) [2]. Consequently, most quarry workers opt to use N95 masks. Therefore, it becomes ideal to measure the PFE of the different N95 masks used in quarry mines. Namibia lacks evidence on the effectiveness of its common N95 masks utilised in the respiratory protection of quarry workers. The study measured the filtration efficiency of N95 masks used in Namibian quarry sites. Thus, this study evaluated various types of N95 masks commonly used in quarry mine settings to enhance the effectiveness of RPE.

Material and Methods

Particle filtration efficiency experiment of masks/filters

A quantitative experiment study was carried out to measure the effectiveness of the seven N95 masks used by quarry workers in three study regions, Erongo, Otjozondjupa, and Kunene, in Namibia (as shown in *Figure 1*). The seven N95 masks were selected using a purposive selection approach, with one mask chosen per quarry site to represent several different N95 masks used in the three study site regions. The N95 masks collected were properly sealed to avoid contamination and sent to the Air and Dust Laboratory Centre for Scientific and Industrial Research (CSIR), Pretoria, South Africa, for testing [10].

The study's inclusion and exclusion criteria for the N95 masks were based on availability, feasibility, and commonly used (FFP1 and FFP2) masks at the identified quarry sites. The comparability of the seven different masks at the sites in the three regions was that they all met the N95 standards of masks, but the masks varied in the way they were designed, the way they properly fit when worn, and the materials used for the masks. Thus, the mask performance at the various sites might be affected, especially considering differences in weather conditions and types of quarry work that might have different types of dust exposure to quarry workers.

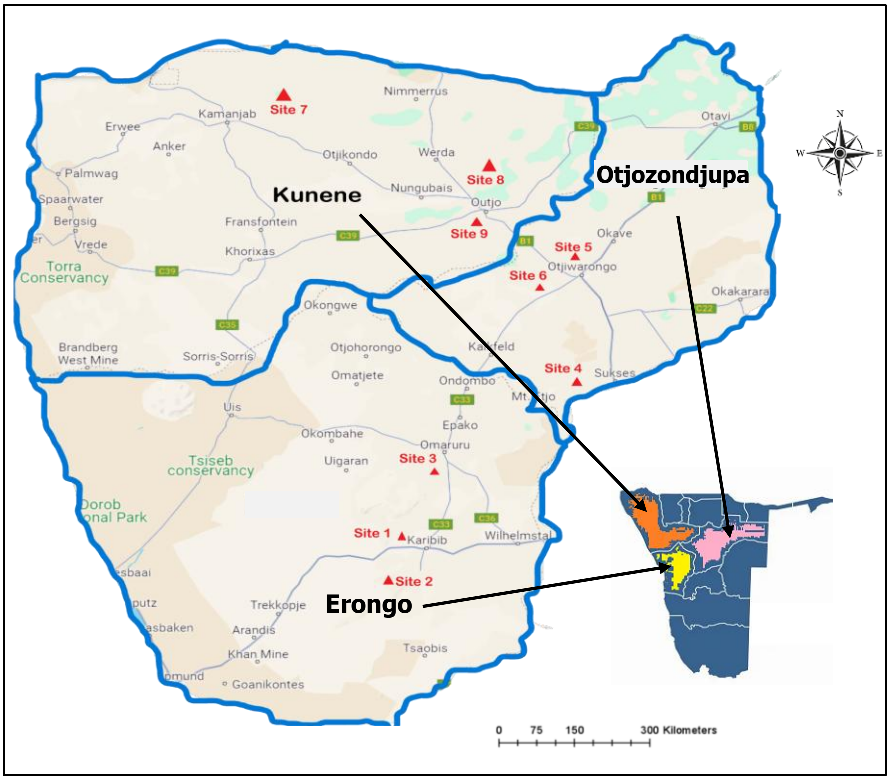


Figure 1:
A Map of Namibia that Shows the three Study Sites

Figure 2:
N95 Dust Masks

The PFE test assessed the viable retention capability of dust particles subjected to a filtration membrane (filters and masks), utilising the method of dry sampling at the sub-micron level. A total of seven (7) N95 dust masks collected from different sites (labelled as samples A, B, C, D, E, F, and G) were collected and submitted to the laboratory in sealed bags. Masks designed as RPE are intended to attain close contact with the face when fitted to achieve the greatest filtration efficiency of airborne particles. In so doing, the mask edges are tailored to maintain an air-tight seal surrounding the nasal passage (nose and mouth). The submission of filters and masks in sealed bags intends to support the enclosed nasal passages, as would have been the filters or masks worn. The laboratory opted for the method of dry sampling to moderately incorporate the technique used in silica dust sampling, which leverages calibrated samples for silica analysis procedures. The masks (samples) seen in Figure 2 were inserted into a dust-generating glass compartment, with laboratory filters being used to quantify the amount of dust passing through them (*see Figure 3*). The masks were subjected to the aforementioned process for optimum periods of varied times, at 1 minute and 5 minutes individually.

The following methods were implemented.

Gravimetric weighing (pre and post)

The gravimetric method measures dust particles sampled and retained by the filtration membrane of the masks. Initially, the technique involved pre-weighing the 7 samples using the gravimetric microbalance according to the Methods for the Determination of Hazardous Substances (MDHS) 14/4 international procedure within an environment with controlled humidity and temperature [11]. Subsequently, the masks were pre-cured for about 12 hours using 3 reference unfilled filters to account for potential weight discrepancies arising from the procedural conditions. The post-run samples were weighed after sampling, along with the reference blanks.

Sampling (mask testing)

The filtration efficiency of the dust masks was conducted using the MDHS 101/2 international procedure with a flow rate of ± 2.2 L/min [12].

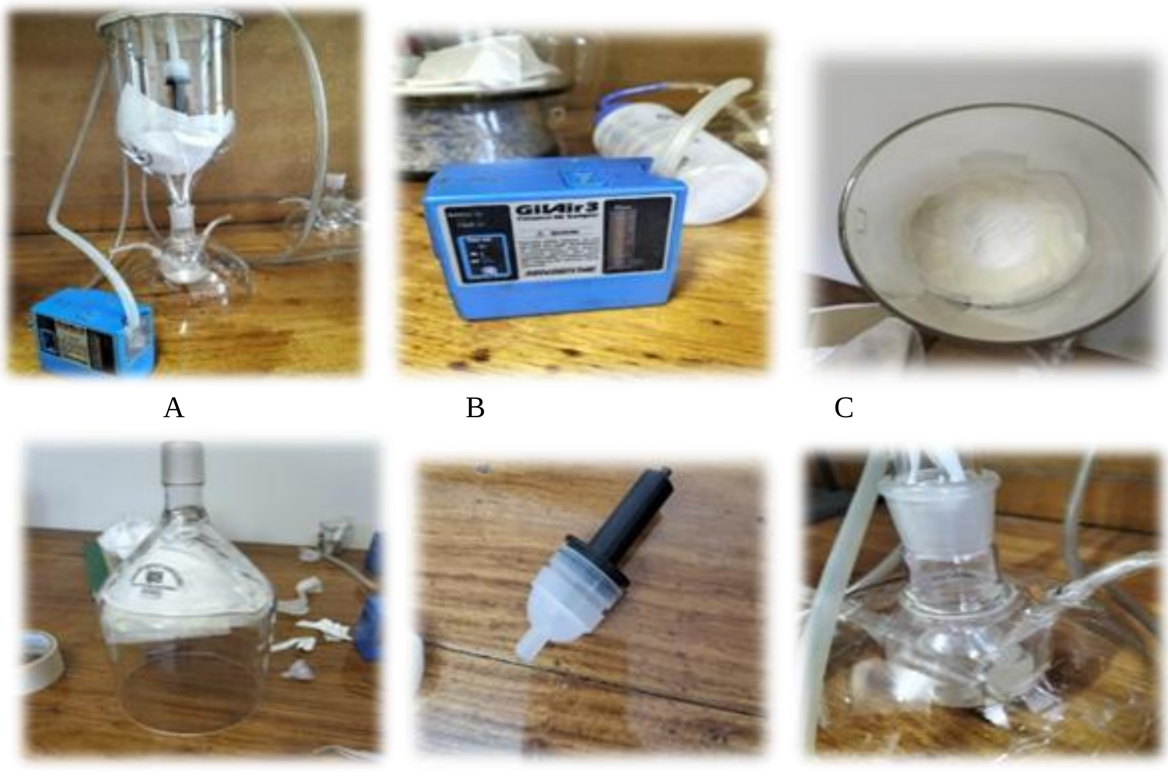
Figure 3:
Dust masks combined in a dust-generating glass chamber

The following apparatus includes the sampling pumps, the flow meter for calibrating the pumps, a 25 ml cassette fitted with a cyclone for the collection of dust, Arizona National Institute of Standards and Technology (NIST) dust with a certified median size of 31.8µm, and a dust cloud generator made of glass [13]. The lid of the chamber consists of symmetrical holes through which a cyclone sampler can be suspended.

Figure 4 shows images A to F, which illustrate the sampling setup during the testing of the masks. Images A to D depict the dust glass chamber, personnel pump, and how the mask was fitted onto the glass. Figure E features the 25mm cassette used for capturing the dust, fitted with the cyclone; the cassette contains a polyvinyl chloride (PVC) filter inside. Image F displays the Arizona dust generated to pass through the mask for measuring its effectiveness. A small quantity (approximately 1-5 g) of Arizona NIST dust was placed in the chamber bowl. A sampling pump was connected to the sampler, and the volumetric flow rates were set at ± 2.2 L/min, with samples fixed on cyclones placed on the compartment's lid, which closed at the top. A jet stream of pressured air was directed at the bowl's lateral arms for a duration of 30 to 60 seconds to allow the settling of the agglomerates from the precipitated dust cloud. Evaluation of each filter and mask filtration efficiency was conducted intermittently at 1-minute and 5-minute intervals following sample dust exposure. The reweighing of samples was performed to ascertain the load, as shown in Figure 4.

Particle size analyser

The particle size analyser technique was employed using the American Society for Testing and Materials (ASTM) C1070 (2020) [11]. A standard to measure dust particles that had passed through the filtration membrane. A blend of water and isopropanol isolated the dust that had adhered to the filtration membrane of the mask.



A B C

D E F

***Figure 4*:**
Mask testing procedure

A stream of light penetrated the blend, which contained scattering particles (utilising the laser light scattering principle). As the stream of light passes through, a portion of the light is dispersed, while the remainder is absorbed. The diffused light, directed onto the detector, is composed and processed for calculation. Median values are defined as values where half the population resides above this point and half below, while PM 10 represents a percentage of small particles below 10µm.

Using reference standards/protocols, namely MDHS 14/4; MDHS 101/2, and ASTM C1070, ensured accurate and consistent results. The laboratory experiment validated the testing methods by minimizing confounders through controlled laboratory testing conditions, which increased the reliability of the study's results. Particle and flow counting instruments were calibrated according to the manufacturer's guidelines, with appropriate documentation certifying the calibration frequency. Additionally, the laboratory performed quality control checks with certified reference material before and after analysis to verify the particulate instruments used in the experiment.

Ethical considerations

Ethical clearance was obtained from the Research Ethics Committee of the Namibia University of Science and Technology (FHAS: 19/2021) and the Ministry of Health and Social Services (Ref. 22/4/2/3) in Namibia.

Results

Pre- and post-gravimetric weighing outcome

Table 1 presents the mask filter results for pre- and post-weighing. Filters were weighed before and after use to evaluate the amount of dust trapped in them. No weight adjustment factor was used during this weighing. The mask filter for Site C (row 5) shows a negative net dust amount, which can be attributed to the ambient conditions in the weighing room. Procedural factors may have caused Site C to record negative post-weighing results, as the masks/filters could have lost some fibres/particles before post-weighing. The mask filter dust value of -0.006 for Site C indicates that it collected relatively little dust, which was insignificant compared to the filtration efficiency standard of at least 95% for PM 10, PM 2,5, and smaller dust particles. The net dust quantities are displayed in Table 1, with sites E and G recording the highest amounts of dust particles that passed through the mask/filter compared to the other sites.

The gravimetric analysis of dust retention in masks revealed that the masks' performance varied, especially after prolonged use. For the experiment, the masks were immersed in quarry dust for 5 minutes and then for 10 minutes, simulating the conditions encountered at mining sites.

Table 1:

Gravimetric Analysis of Dust Particles at Sampling Sites

Sample	Description	Pre-Weight (g)	Post weight (g)	Post Difference (g)
Site A	PIONEER SAFETY EP005 ENISO9001:2008 EN149:2001 FFP2 CE0194	8.159	8.163	0.004
Site B	PIONEER SAFETY EP005 ENISO9001:2008 EN149:2001 FFP2 CE0194	7.818	7.823	0.005
Site C	WURTH 0899 1211 102 CE 2849 EN149:2001+A1:2009 FFP2 NR	11.748	11.742	-0.006
Site D	WURTH 0899 1211 102 2849 EN149:2001+A1:2009 FFP2 NR	10.281	10.284	0.003
Site E	QSA 2010 FFP1 NR A2/2006/21	7.227	7.283	0.056
Site F	QSA 2010 FFP1 NR A2/2006/21	6.935	6.941	0.006
Site G	QSA 2010 FFP1 NR A2/2006/21	6.880	6.891	0.011

The N95 masks maintained the most amount of dust throughout the test period. Over time, the retention rate increased significantly. After 5 minutes of exposure, the N95 masks maintained an average retention rate of 0.010mg of dust. Although the masks were able to capture larger particles during short periods of exposure, they lost their effectiveness after prolonged use, as this can be the result of clogged filter material.

Mask testing results

Table 2 delineates weight determination findings aligned to captured respirable dust particles within periods of 1 minute and 5 minutes. The second column indicates the mask weight following 1 minute of sampling, and the third column shows the weight after 5 minutes. The study findings show that masks exposed for a short period bear little dust passing through them. Sample Site G had the highest exposure to dust at 0.015mg, which is above the technical standard uncertainty of ±0.010mg. The mass on filters increased significantly with a 5-minute sample period; Sites A and B had lower filtered dust weights, whereas Sites C, D, F, and G had higher values. The latter once again produced a lot of dust.

Particle size analyser

Table 3 shows that in all samples, smaller dust particles infiltrated the masks with a median size below 10µm. Sites A, B, and C showed smaller particles with 100 % of the PM10 range, while sample Site D showed the highest particle size, with at least 60% below the PM10 range.

Discussions

This study assessed the PFE of different N95 masks used in the respiratory protection of Namibian quarry workers in the 3 main mining regions, namely Erongo, Otjozondjupa, and Kunene. This quantitative laboratory experimental study was conducted under laboratory conditions. The results indicated that the N95 masks meet the regulatory standard for filters of at least 95% of PM10, PM2.5, and other small particles up to 0.3 microns.

Table 2:
Gravimetric Analysis of Dust Particles Relative to Times

Sample ID	Description	1 min Weight (mg)	5 min Weight (mg)
Site A	PIONEER SAFETY EP005 ENISO9001:2008 EN149:2001 FFP2 CE0194	0.000	0.017
Site B	PIONEER SAFETY EP005 ENISO9001:2008 EN149:2001 FFP2 CE0194	0.008	0.038
Site C	WURTH 0899 1211 102 CE 2849 EN149:2001+A1:2009 FFP2 NR	0.000	0.290
Site D	WURTH 0899 1211 102 2849 EN149:2001+A1:2009 FFP2 NR	0.002	0.218
Site E	QSA 2010 FFP1 NR A2/2006/21	0.005	0.057
Site F	QSA 2010 FFP1 NR A2/2006/21	0.007	0.368
Site G	QSA 2010 FFP1 NR A2/2006/21	0.015	0.437

Table 3:
Analysis of Different Particle Sizes at Sampling Sites

Sample ID	Description	Median (µg)	PM10
Site A	PIONEER SAFETY EP005 ENISO9001:2008	2.572	99%
Site B	EN149:2001 FFP2 CE0194	2.423	100%
Site C	PIONEER SAFETY EP005 ENISO9001:2008	4.596	86%
Site D	EN149:2001 FFP2 CE0194	7.006	60%
Site E	WURTH 0899 1211 102 CE 2849	3.172	100%
Site F	EN149:2001+A1:2009 FFP2 NR	5.281	64%
Site G	WURTH 0899 1211 102 2849	3.821	82%

It is thus important for quarry workers to understand which mask will protect against their exposure. Compared to the amount of dust that was carried through the masks, the minimal amount collected by the filters was insignificant. The net dust levels exhibited indicate that the masks did not contain a lot of dust. The results revealed that masks were relatively dust-free when exposed to varying levels of dust for a brief period. For instance, in Site G, the exposure to dust was at 0.015mg, which exceeded the technique's standard uncertainty of 0.010mg. The study showed that N95 masks bear the highest or favourable efficiency of filtration during the initial phases of usage; however, with prolonged usage, the filtration efficiency recedes proportionately to increasing dust particles admittance through the filtration membrane [12]

The failure to use PPE/C by most quarry workers is associated with multiple reasons, which include uncomfortable PPE, inconvenience, interference with work, and hot weather conditions [9]. Quarry workers were more likely to wear respirators than construction workers 39.1% and 32.5%, respectively), and charcoal workers were 3.5 times less likely to wear respiratory protection than any other category [10]. Therefore, the continued dust exposure by the quarry and allied workers emphasises the importance of filtering facepiece respirators (FFRs) in dusty environments.

The dust particle analysis found that small particles that were less than 10 microns in size were able to filter through the masks. In all the samples, except for Site D, the smallest particles had a PM10 value of 100%. The results of the study revealed that the masks functioned well at first, until they were subjected to prolonged use. Contradictory trends were noted in the previous study, where the dust penetrating particle size was measured around 40 nm in a laboratory experiment that used polydisperse aerosol. The average dust particles that penetrated the N95 masks of 40 nm size were found to surpass 5% for the two N95 masks that were being compared [7]. Also contrasting with the current findings are dust particles of 36.5 nm in size at blasting and concrete grinding sites [6]. The difference in N95 masks and dust properties triggers changes in the electrostatic charges of dust particles trapped on the filtration membrane of the masks [8].

Limitations of the Study

The dust cloud for sampling was generated manually due to the lack of an available, consistent dust generator, resulting in human-related errors. The interpretation of gravimetric weighing as part of the methodology used was a limiting factor because of the absence of automation. Employing the purposive sampling technique may introduce sampling bias since the selection of research sites might not adequately represent the general population. Additionally, sampling only seven masks from seven sites in the three regions complicates the generalizability of the findings to the entire Namibian quarry mining sector.

Conclusion

This study assessed the PFE of protective masks worn by quarry workers by comparing the exposure time to the amount of respirable dust collected by the filtration membrane (mask) from 7 sites after 1-minute and 5-minute intervals. It can be concluded that masks are efficient in filtering respirable dust particles in the initial stages, but with prolonged use, the PFE decreases inversely proportional to the increasing respirable dust in the workplace environment.

The study infers that quarry workers' repeated use of the same N95 mask over prolonged periods decreases the level of respiratory protection. As evidenced by the PSA results, prolonged inhalation of PM10 by quarry workers, coupled with diminished respiratory protection from the overused N95 masks, increases the risk of developing respiratory diseases or conditions over time.

Recommendations

Based on the study results, quarry sites should implement fit testing to ensure the appropriate sealing of N95 masks for all quarry workers. Additionally, the study recommends that quarry workers with facial hair, such as beards, be informed that open spaces around the mask reduce dust particles' filtration efficiency and respiratory protection, thus suggesting the use of tight-fitting N95 masks to enhance respiratory safety. The different mask brands used at each quarry site in the study increased the variability of the masks, making comparisons difficult. Therefore, the results showing declining filtration efficiency at the quarry sites require future studies to confirm the varying work conditions.

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