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Design and Test Performances of Respiratory Mask Prototype as Air Pollution Filter

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Abstract

According to the Republic of Indonesia Government Regulation Number 41 of 1999 [22], air pollution is the insertion of substances, energy, and other components into ambient air, so that the air quality drops to a certain level. Using a mask for breathing becomes an alternative way to get clean and comfortable air. The mask's effectiveness test was carried out by a method that refers to SNI 19-7117.11-2005 [1], and the test has been done at several places, such as LIPPI Biology Laboratory, Environmental Engineering Laboratory in Department of Civil and Environmental Engineering IPB, and Compost House. The effectiveness of the mask in filtering smoke, reducing odor intensity, filtering Total Suspended Particulate (TSP), and the effectiveness of the mask in filtering falling dust are some of the objectives in this research. This mask uses a non-woven material made from polypropylene or polyester. The masks have three main layers, namely the outer non-woven layer, the PM 2.5 filter layer, and the inner non-woven layer. The conclusion of this research is the average of mask effectiveness for air pollutant parameters is 90 %, with the range of effectiveness is between 80% and 99%.

Keywords: ambient air, dustfall, effectiveness, mask, pollutant

INTRODUCTION

The advancement of an area cannot be separated from the development of population, economics, industry, transportation, and the increase in the air pollution levels. Air pollution is a major environmental health problem in a densely populated urban area. According to the Republic of Indonesia Government Regulation No. 41 the Year 1999 concerning air pollution control, air pollution is the entry or insertion of substances, energy, and other components into ambient air by human activities so that the air quality drops to a certain level that causes the ambient air cannot fulfill its function [22]. The increase in the human population and the decrease of green open space have caused air pollution in ambient air. Besides, the increase in the number of industries, vehicle exhausts, and fossil fuels will produce air pollution and temperature growth from day to day [21]. Air pollution is composed of two kinds of outdoor air pollution and indoor air pollution. International Agency for Research on Cancer (IARC) has stated that outdoor air pollution is one of the factors of carcinogenesis with particulate matter (PM), the main causative component [18]. Air pollution has several sources, which are natural sources and sources caused by humans. The gas produced from the combustion of car fuel and industrial fuel is the major source of air pollution [4]. Within the air pollution phenomenon, the pollutant is a mixture of heterogeneous gas and particulate (PM) [11]. In the Constitutional Law No.32 Year 2009 concerning environmental protection and management explains that the physical form of substances that is causing air pollution can be either gas or particle. Examples of air pollutant particles are dust, smoke, fog, and TSP (total suspended particulate). Besides that, the odor is also one of the sources of air pollutants that should not be underestimated. Odor, which refers to unpleasant odors, is currently considered as an important air pollution problem because it has caused several deaths [40]. The health effects of environmental odor pollution vary from the source to the exposed population. Some environmental odors contain important exposures [30].

Urban areas or better known as cities, only have less than 5% of green open space and estimated producing 80% of CO_2 pollution [10]. Urban air pollution is a comprehensive problem with various sources of pollutants, which are mostly the result of the combustion process [23]. According to the World Health Organization, air pollution in urban areas is estimated to contribute to around 800,000 deaths per year [38]. Exposure in the long-term will result in various kinds of health problems, such as bronchitis, emphysema, and lung cancer [34]. Health impacts caused by air pollution vary among individuals. According to research in the United States, the group of the toddler has six times greater vulnerability compared to adults, breathing more air, and inhaling pollutants [33]. Odor pollution does not only create discomfort but also exposes the people to the disease [25]. Hazardous environmental odor can trigger the symptoms of various physiological mechanisms, stress-related illnesses, and possible phenomenal reactions [31].

In line with increasing public awareness on the importance of clean air, in various regions in Indonesia are often found the use of respiratory masks as a way to get clean and comfortable air for breathing. Recently, there is an increase in the interest of using respiratory masks to prevent illnesses caused by inhalation of biological organisms in the air. There are various types of masks which are used, ranging from the medical mask or surgical mask (usually have a light green color on the outer part and white color on the inside and also have a strap or rubber to be attached to the back of the head or ears) which is sold in the market to fabric mask with various attractive designs. The use of surgical masks is not entirely appropriate. A surgical mask is not designed to be used as a respirator particulate and does not provide much respiratory protection. A surgical mask protects a barrier against droplets, including large-sized breathing particles [24].

However, the use of mask today is still not supported by the knowledge on how to use mask effectively. As a result, there are still many inefficient uses of a mask; thus, it cannot function properly. Furthermore, there are still many different types of masks in the market that do not meet the standards to reduce the effect of air pollution. Therefore, further research is required to provide an alternative design of a mask that can meet the standards for reducing the effects of air pollution and also able to filter air pollutant particles. Moreover, the alternative design of this mask must be ergonomic and can be used daily by the people on a wide scale.

METHODOLOGY

The research "Design and Test Performances of Respiratory Mask Prototype as Air Pollution Filter" is conducted from July 2019 to February 2020. This research is carried out in several places, namely LIPPI Biology Laboratory, Environmental Engineering Laboratory in the Department of Civil Engineering and Environment of IPB, and Compost House. The procedures within this study are conducted in several stages, namely the design stage (including the stage of collecting tools and materials, the stage of making and assembling tools), testing stage, observing stage, and lastly analyzing stage. The mask designed in this research is a respiratory mask made from polypropylene, which is non-woven and consists of one sheet of filter material that has several layers. These layers consist of 3 main parts, a non-woven waterproof layer in the inner and outer parts. Then between the two layers in this mask, there is also a layer that serves as a filter to counteract other particles that come from outside or inside the mask.

According to (**Gunawan, 2016)**, the mask's effectiveness test is conducted using a mask test compartment. The smoke testing is conducted with a method that refers to SNI 19-7117.11-2005 [1]. The effectiveness test is carried out by using the designed mask in each compartment before and after, then the mask is weighed, and the dust and particle reduction is calculated. The mask's effectiveness test against smoke is measured by the opacity meter (OM) model AT-07-01, which is a device with a lens that has a black gradation scale. The source of the smoke is by burning used tire, then channeling it into the inlet pipe of the mask test compartment. The principle of this method is determined by comparing the smoke color that best suits the black scale color on the opacity meter lens. Then measuring the mask's effectiveness against falling dust is done by using a car as the source of falling dust and using two times measurement processes. The measurement of the mask's effectiveness on the odor intensity is using waste as the source of the odor channeled into the mask test compartment. Then, the test is conducted using an odor judge panel, namely the human nose. Odour characteristics are explained using odor descriptor, which is acceptable to the human sense of smell. In the smoke test, the smoke source is obtained by burning used tires, then channeling it into the inlet pipe of the mask test compartment. At the same time, the testing of the TSP is done by measuring the pore size of all layers of the mask and measuring the particle size before and after using a digital microscope. Moreover, compared to standard particles, which endanger health, namely PM 10 and PM 2.5. Pore measurement of the mask materials is conducted at the LIPPI Biology Laboratory. The modeling in this test is made to adjust the inspiratory capacity of an adult, which is around 3500 ml/min [27]. Whereas the mask's effectiveness is calculated using equation 1 [17].

$$\eta = \frac{X_a - X_b}{X_a} x\ 100\% \qquad \text{.. (1)}$$

Remark:

η = effectiveness (%)

Xa = the data result of the initial measurement

Xb = the data result of the final measurement

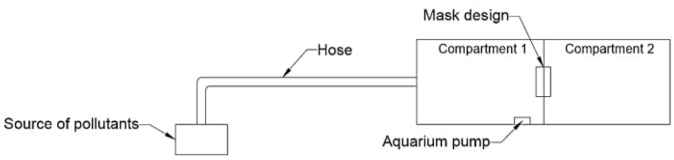

Figure 1. Experimental set up of the experiment

RESULT AND DISCUSSION

Respiratory Mask Design

Mask or respirator is personal protective equipment that is used on the face (including the nose and mouth) that serves to reduce the risk of danger of particles in the air, gas, and steam [26]. According to its function, masks are divided into air-purifying masks and air-supply masks. Air purifying masks filter particles and gases/vapors obtained due to influences in the work environment and due to air pollution [29]. The masks that were designed in this study are masks with disposable air-purifying masks (cannot be used repeatedly). The material used for designing this mask is a non-woven material. This material is produced from fibers or polymers made from polypropylene or polyester, which are mechanically processed with a high-tech machine, producing a good quality sheet that functions well as a filter [2]. The specific quality of this fabric, which is based mainly on very fine fibers, variable surface density, and high surface area, provides excellent filtration quality, heat insulation, and absorption [3]. The fiber has an unspecified length, is randomly oriented, and its diameter varies along its length. This material is characterized by a lower strength in stress and abrasion resistance. Materials produced with non-woven technology are suitable as filtration materials, industrial sorbents for oil, oil, hydro solution, air filtration, dust mask, medical mask, calendared absorbent, and absorbent cleaning materials [14].

This material's color is green and has 16 GSM values. This GSM value indicates the thickness of the material. The material used is a non-woven spun-bond material that has 16 grams per square meter thickness level. Besides that, this research also uses the PM 2.5 filter 200217YF25 type. This filter has five layers that consist of non-sticky fabric, fabric filter, and active carbon. This active carbon filter is considered efficient in isolating dust and smoke. Activated carbon is a porous solid containing 85% -95% carbon, which is produced from carbon-containing materials heated at high temperatures [36]. With a particular treatment that is the activation process, such as treatment with high pressure and temperature, activated carbon can be obtained, which has a large inner surface. In one gram of activated carbon, it generally has a surface area of 500-1500 m2, so it is very effective in capturing very fine particles [39]. Activated carbon is obtained by the activation process. The activation process is a process to remove impurities that line the surface of charcoal to increase the porosity of activated carbon. Commercial activated carbon applications can be used as a deodorizer and resin, distillation of raw materials, purification of wastewater, water purifier, and can be used as an adsorbent to adsorb materials derived from liquids or gas phases [8]. The design of this mask consists of non-woven material on the outer part and the inner part, as well as a 2.5 PM filter in between. On the outer part of the mask, there are two layers of the non-woven material, while on the inner part only uses one layer of non-woven material. Then, to frame the mask for protecting the mouth nose area from the source of pollution, thin cut and smoothed zinc are used as the mask frame. And Rubber straps are used to attach the mask to the ears; thus, the mask is comfortable to use. In detail, the design of the mask is presented in Figure 2 and Figure 3.

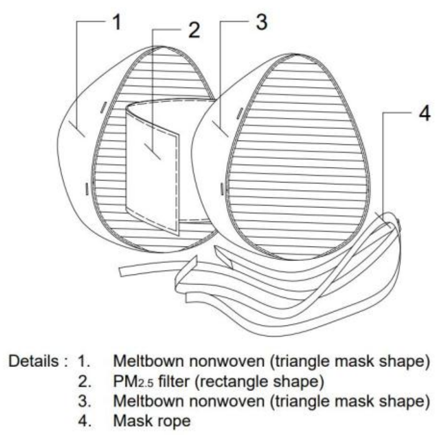

Figure 2. The components of the respiratory mask's design

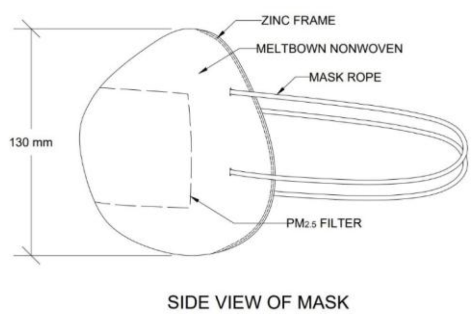

Figure 3. The side view of the respiratory mask's design

In this research, the mask produced should not only be effective in filtering pollutants but also needs to be ergonomic. Ergonomics is known as one of the knowledges relating to the relationship between humans and an object, especially the object used. Ergonomics is known as the study of human aspects in the work environment, which is reviewed in terms of anatomy, physiology, and human psychology as users as well as elements of engineering, management, and design [12]. In its application, ergonomics is specifically utilized to study human limitations and abilities in interacting with technology and product designs [6]. So that in its development, ergonomics can help humans in using the object's design properly and optimally. The ergonomic levels of the mask are determined, an assessment on the comfortability level is needed to be done, using the scale of comfortability. The scale of comfortability is presented in Table 1. This comfortability test is conducted with ten respondents consisting of five female respondents and five male respondents. The age range of respondents varies from 17 years to 39 years.

Table 1. The Scale of Comfortability Level

Level	Description
-2	Very uncomfortable
-1	Uncomfortable
0	Neutral
1	Comfortable
2	Very comfortable

Based on the comfortability test results, the respondents' responses are ranged from 1 to 2. The level of comfortability is presented in Figure 3. Based on the comfort level, number 2, which stands for very comfortable, is dominating by 70% of the result. While number 1, which stands for comfortable, receives 30% of the result.

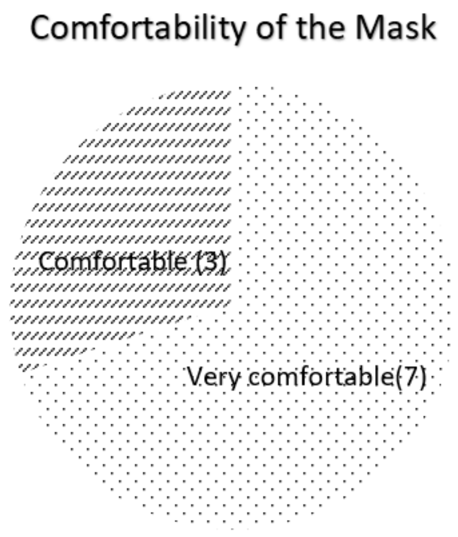

Figure 4. Mask's Comfortability Level

The Mask's Effectiveness in Filtering the Smoke

Smoke is a combination or mixture of carbon dioxide, water, substances diffused in the air, particulate matter, hydrocarbons, organic chemicals, nitrogen oxides, and minerals [13]. The level of smoke density and smoke composition depends on many actors, namely the type of material burned, humidity, fire temperature, and wind conditions [15]. The level of smoke density is called opacity. The content of dust particles and high opacity in ambient air is an important indicator that must be considered because it can disturb and disturb human health. According to Ministerial Decree of Environmental No.13/ 1995 concerning the emission opacity quality standard on immobile source for other activities, the standard quality level is 35%. The opacity measurement produced by the pollutant sources in each compartment varies greatly and resulting in the reduction of the mask's opacity, which is presented in Figure 5. The difference in opacity value, according to the research of **(Faisal et al, 2012)** depends on many factors, namely the type of material being burned, moisture, flame temperature, and wind condition.

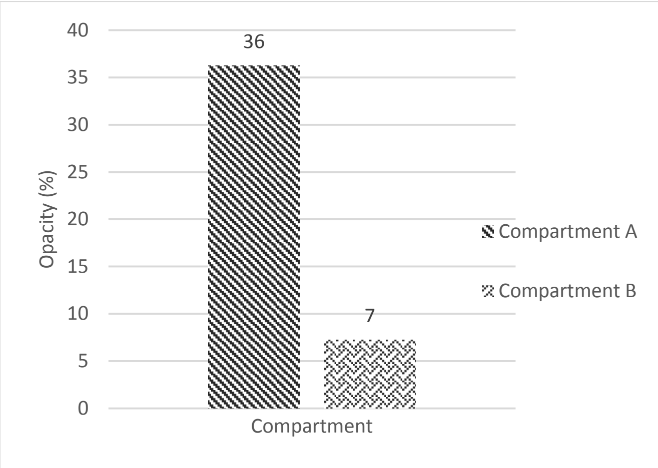

Figure 5. Opacity before and after passing through the mask

In compartment A, the compartment before attaching the mask, the opacity value ranged from 20% to 60% with an average of 36%. The average opacity value before attaching the mask indicates a value that exceeds the quality standard. While in compartment B, the compartment, after attaching the mask, obtains an opacity value range from 0% to 10%, with the average opacity value reaching 7%. This value has reached the safety level or under the quality standards which has been set. The mask's effectiveness test result from reduced opacity value before and after attaching the mask reaches 80%. The high content of dust and opacity particles in the ambient air can affect human health. According to **(Syahputra, 2016)**, The impact of smoke can cause health disorders such as acute respiratory infections (ISPA), bronchial asthma, bronchitis, pneumonia (pneumonia), eye and skin irritation.

The Mask's Effectiveness in Filtering *Total Suspended Particulate (TSP)*

Total Suspended Particulate (TSP) is small airborne particles such as dust, smoke, and steam with a diameter of fewer than 100 micrometers. TSP can be derived from several sources, including power plants, incinerators, vehicles, and construction activities [37]. According to **(Sivaramasundaram, 2010)**, high exposure due to particulates poses a high risk of lung cancer as well. PM (particulate matter) or particulate is a term for solid and liquid particles in the air. Testing the mask's effectiveness in filtering the TSP has quite significant results and is presented in Figure 6. The average particle size located in compartment A which is the compartment before mask attachment is 47 µm. While in compartment B, which is the compartment after mask attachment, it is 1 µm. From this value, it is obtained that the mask's effectiveness in filtering the TSP is quite high, i.e. 98.71%. According to **(Gunawan, 2016)**, in a study, the effectiveness of disposable respirator masks to the TSP shows the results of efficacy between 24% -73%. When compared with previous studies,s the effectiveness of masks in this research showed better results because it has a higher effectiveness value of 99%.

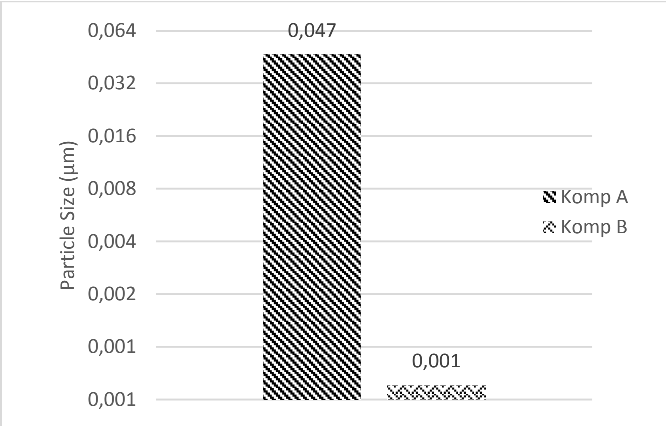

Figure 6. Average Particle Size

The Mask Effectiveness in Filtering Dust

Particle/dust materials are complex and mixed materials consisting of carbon, dust, and aerosol base particles. The amount of dust in the air greatly affects its diversity in the air. The smaller the diameter of the dust, the longer its presence in the air or the wider distribution [5]. This research also measures dust or particle concentration contained in each compartment, where compartment A is the compartment before attaching the mask, and compartment B is the compartment after attaching the mask. From the tests, the concentration of falling dust generated by each compartment is resulting in a significant reduction value. It is presented in Figure 7. From the testing compartment before the mask's attachment, obtains of 153.83 gr/m^2/month and 141.74 gr/m2/month for each measurement. On the other hand, the compartment that has been attached by mask obtains 20.74 gr/m^2/month and 13.82 gr/m^2/month for each measurement. The concentration values above are not able to fulfill the quality standards, which is 10 gr/m^2/month as regulated in Government Regulation No. 41 the year 1999 concerning the control of air pollution and ambient air quality standard.

The effectiveness resulting from the reduction value in filtering falling dust has reached 88%. In the study conducted

(Gunawan, 2016) previously obtained effectiveness against dust fall; masks have a value of 11% -36%. Based on previous research, the results of the effectiveness of masks in mask design research has a higher yield and can reduce the dust feel better. The mechanism of entry of acutely fallen dust particles causes bronchial irritation, increased lung reactivity, and suppresses local immunity. According to **(Samet *et al*, 2000)**, potential effects on health cause shortness of breath, recurring asthma, airway infections, and chronic bronchitis.

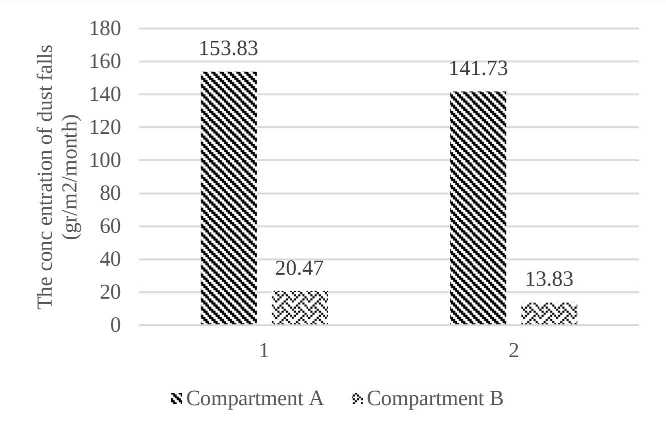

Figure 7. Falling dust concentration before and after filtered by the mask

The Mask's Effectiveness in Reducing Odour Intensity

The odor is undesirable odor levels and specific time that can disrupt human health. One of the purposes of using a mask is to reduce discomfort caused by odor. Odor pollution is pollution caused by pollutants in the air resulting from the process of decomposition of a material or the event of the release of a chemical compound that has accumulated in a room [20]. The source of odor is called odorant, which is a single oxygenated substance or a mixture of compounds that cause odor stimulation in certain circumstances [16]. Naturally, odors can only be captured by the human sense of smell, but in the categorization of odors can use odor descriptors that indicate the odor level of a concentration of substances in the air. Besides, the assessment of odor is quite different for each person. In testing the mask's ability to reduce the description of the odor, it is indicating diverse value on each source of the odor. The results of this test are presented in the scale of hedonism, as in Figure 8. This testing uses three sources of odor, namely, 3-days household waste, 1-day household waste, and used diapers.

In compartment A, the compartment before the mask's attachment, the scale value range of hedonism is from -4 to -1. It can be defined that the odor that is smelled in compartment A is between much disliked and slightly disliked. On the other hand, in compartment B, which is the compartment after the mask's attachment, the scale value range of hedonism is from -1 to 0. It is defined that in compartment B, the odor that is smelled is between slightly disliked to neutral. The mask's effectiveness in reducing the intensity of the odor shows 93%.

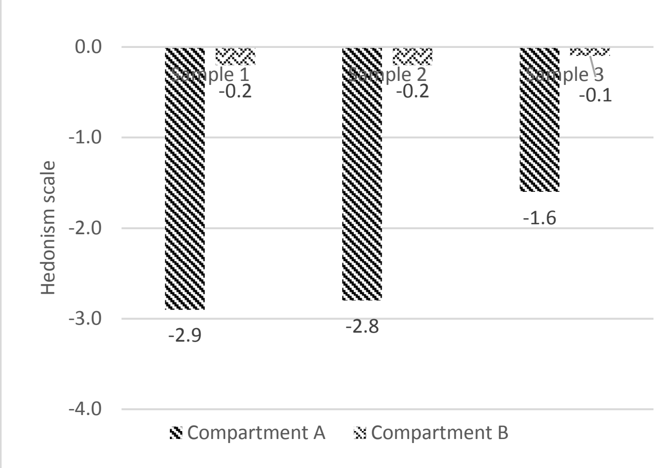

Figure 8. Hedonism scale of odor in mask testing

The Pore Size on Each Mask's Layer

The mask designed in this research has three main layers, namely, the non-woven outer part, the PM 2.5 filter layer, and the non-woven inner part. In the filter part, there are several layers inside, which generally consist of two main materials, white filter fabric, and black active carbon layer. In the big figure, inside the mask's design, three materials have different pore sizes. In each material, there is also a variety of pore sizes. The average pore size in each material is shown in Figure 9.

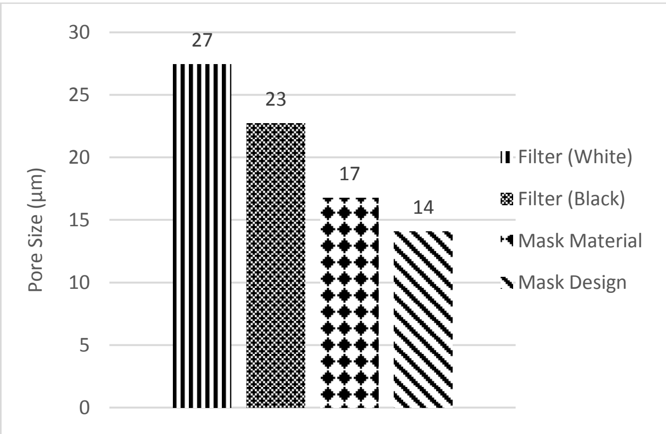

Figure 9. The average pore size of the materials

Inside the filter, the white filter layer has a pore size range from 7 µm to 54 µm, with an average of 27 µm. Then in the next filter layer, the black active carbon layer has a pore size range from 2 µm to 58 µm and has an average of 23 µm. As for the non-woven mask material, the pore size ranges from 6 µm to 34 µm, with an average of 17 µm. I assumed every layer of material is stacked with the same shaft, the average of pore size in the mask is 14 within the scale ranging from 2 µm to 30 µm. The pore size of each material and the mask's design is above 2.5 µm; thus the harmful particles smaller than 2.5 µm can still go through. Nevertheless, after testing the TSP of the mask's design, it shows that the average particle is below 2.5 µm; this can occur when the material's pore on each layer is stacked, resulting in smaller pore size.

The active carbon inside the filter can also reduce air pollutants. **(Masitoh and Sianita-B, 2013)**, active carbon can absorb anion, cation, and molecule in the form of organic compounds, both liquid, and gas, and has a very selective absorption, which prefers non-polar material compared to polar material. Based on several air pollutant parameters, the mask's effectiveness is presented in Figure 10. Based on the mask's effectiveness measurement, the average mask's effectiveness against pollutants is 90%.

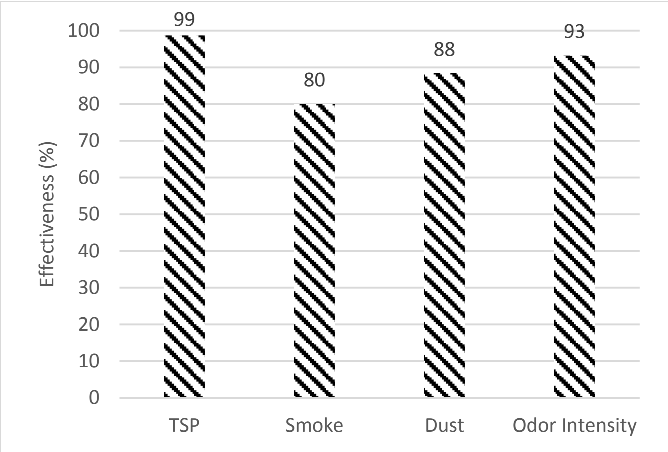

Figure 10. The mask's effectiveness recap based on air pollutants parameter

CONCLUSION

The conclusion that can be drawn from the research are as follows:

1. The average mask's effectiveness for the air pollutants parameter is 90.82% on a scale of 80.00% to 98.711%. The effectiveness value shows that the mask's design in this research is effective in reducing air pollutants. On the contrary, the mask's design in this research still cannot reduce the concentration of falling dust above the standard value.
2. The mask is also considered ergonomic. This is demonstrated by how the mask's comfortability level ranges between 1 and 2 that described as comfortable and very comfortable.

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