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REVIEW OF APPLICATIONS NANOPARTICLES OF TiO_2 AND ZnO IN SUNSCREEN

Sulistyani

Department of Chemistry, State University of Yogyakarta, Karang Malang 55281, sulistyani@uny.ac.id

ABSTRACT

The use of sunscreen by the public, especially in Indonesia is quite popular. Health and beauty reasons underlying the popularity of the use of sunscreen products. This further fueled by increasing public awareness on the dangers of UV radiation of sunlight that the intensity at last decade more higher. It has been widely demonstrated that UV radiation of sunlight can cause sunburn (tanning effect to the skin), premature aging such as the appearance of dark spots and wrinkled skin, melanoma and non-melanoma skin, and cancer. Among the active particles are often used in sunscreen products as UV radiation filters are particles of TiO_2 and ZnO based nano size. Along with the development of nanotechnologies, sunscreen products are also diversified, often combined with cosmetics. This paper aims to disseminate to the public, especially in Indonesia about how the characteristics of nanoparticles TiO_2 and ZnO in sunscreens, the effectiveness of the particle as a barrier to UV radiation, and the dangers that can be caused by excessive use of the product.

Keywords: sunscreen, nanoparticle, TiO_2, ZnO, UV radiation.

A. Introduction

Nowadays, using of sunscreen by the public especially in Indonesia is quite popular. Most people use sunscreen products to maintain healthy skin and beauty. The presence of sunscreen on the skin layer is expected to anticipate the sun's heat so as not to burn the layer of skin, preventing skin cancer and premature aging (Steven-Wang, 2012). Initially, only a sunscreen cream that is used topically to the whole body, especially on body parts exposed to the sun. However, the development of technology gives diversified packaging of product sunscreen. In addition to the form of creams, sunscreens also exist in the form of a gel, lotion, mousse, spray, stick, and wipes. In fact, the development of nano technology allows the active ingredients of sunscreen combined with cosmetic so successful in the market. Based on data from the ongoing study, Friends of the Eart mention that the nanoparticles have been added in the individual care products such as deodorant, soap, toothpaste, shampoo, hair conditioner, anti wrinkle cream, moisturizer, foundation, powder, lipstick, blush on, eye shadow, nail polish, perfume and shaving lotion (Anuradha Patel *et al.* , 2011).

The dominant type of sunlight interacting with humans is ultraviolet light. Scientifically, ultraviolet light (UV) from the sun is divided into several types, i.e. UVA, UVB and UVC. The type of light is based on the UV wavelength region. UVA rays have a wavelength range of 320-400 nm, UVB rays have a wavelength range of 290-320 nm, and the UVC have a wavelength range of 100-290 nm. UVC is almost completely absorbed by the ozone layer (97-99%), whereas UVA and UVB rays partially able to reach the earth's surface and interact with human skin. During the day, the composition of the UV light is composed of 10% of UVB and 90%

UVA rays when the sun is perpendicular to the earth. When the sun inclines, the intensity of UVB rays will be reduced, while the intensity of UVA rays are relatively constant throughout the day (Nicholas *et al*., 1997).

From time to time, the intensity of the sun's UV rays that reach the earth's surface is constantly increasing. This phenomenon is attributed the depletion of the ozone layer and the greenhouse effect. Splendor of the use of ozone depleting substances (ODS) such as CFCs and HCFCs has led to radical particles are continuously decompose ozone into oxygen radicals and generate new particles (Fahey-Hegglin, 2010). CFCs and HCFCs are generally used to help power the spray on cosmetic appliances such as hair spray, mosquito spray, automotive maintenance equipment, house cleaners, spray paints, as well as air conditioning and refrigeration coolants. This condition is further aggravated by the greenhouse effect due to the high concentration of carbon dioxide in the earth. Increasing the amount of carbon dioxide in the lower atmosphere causing UV rays of the sun is trapped in the Earth's atmosphere so that the resulting radiation is also higher (IPCC, 2007).

Increasing UV radiation on earth has raise public awareness and concern on the dangers of radiation. Nearly all cancers are either melanoma or nonmelanoma skin caused by excessive sun exposure (Armstrong-Kricker, 1993; Armstrong *et al*., 1997). The International Agency for Research on Cancer (IARC) has identified that high-intensity UVB radiation can damage DNA cells directly, whereas UVA radiation trigger skin cancer when absorbed in melanin. Both UVA and UVB radiation trigger the production of reactive oxygen species (ROS). UVA radiation of sunlight is responsible for more than 90% of skin cancer cases, whereas UVB radiation is responsible for skin pigment brownish to burn, known as erythema (Grist *et al*., 1993). Malignant melanoma and basal cell cancer (BCC) is associated with intermittent sun exposure is mainly experienced by children and adolescents. Squamous cell cancer (SCC) due to accumulated radiation exposure is associated mainly by solar UVA radiation, whereas lip cancer caused by sun exposure throughout life. An estimated 93% and 50% of skin cancer lip cancer caused by UV radiation from the sun (Gallagher *et al*., 2010; Balk, 2011). The highest melanoma cases occur in Quessland, Australia that there are 56 new cases per year per 100,000 men and 53 women (Leiter-Garbe, 2008). In addition, high exposure of UV radiation stimulates the appearance of cataracts, decreased body immunity, permanent eye damage in the form of retinal disorders 'Age macular degeneration' and premature aging.

Sunscreen active ingredient is always progressing, both made from natural and synthetic chemistry. Initially, the organic materials are used as the sole active ingredients in sunscreens. However, susceptible to degradation when exposed to sunlight, then develop inorganic particles as active ingredient of sunscreen. Among the inorganic particles often used in sunscreens are titanium dioxide (TiO_2) and zinc oxide (ZnO). At the microscale, particle leads a white coating on the surface of the skin, so the particle size is reduced to the nanosize (Wolf, 2001). At present time, sunscreen containing nanosized of TiO_2 and ZnO have been widely circulated in the community. Nevertheless most people including Indonesia society still doubt about the effectiveness and the safety of nanoparticle-based sunscreens. Therefore, this article will discuss about the characteristics, effectiveness, and health risks in the use of nanoparticle-based sunscreens, especially nanoparticles of ZnO and TiO_2.

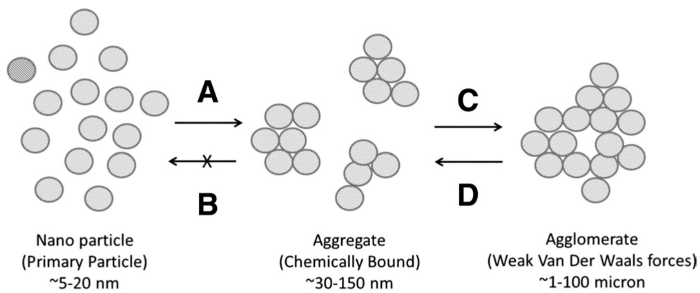
B. Discussion

Nanomaterial is a general term for both nanosize object in different shape and size (length, width or height). Nanotechnology is the manipulation of matter on a size between 1 to 100 nm, where one nanometer is equal to one millionth of a millimeter (National Nanotechnology Initiative, 2009). Changes of matter at the nanoscale is able to produce a much different material properties compared with larger particles. The nature of the changes include color, solubility, strength of materials, electrical conductivity, and magnetic behavior.

Nanoparticle materials have a larger surface area relative to volume. This makes the chemical nature of the substance to be more reactive than larger particles.

Physical Characteristics of Nanosized TiO_2 and ZnO

Sometimes, manufacturers do not put a label on the actual product nanoparticles using nanoparticle materials. That is because the characteristics of nanoparticles which easy to form clots. Based on its physical form, nanosized of TiO_2 and ZnO has three forms, namely primary particle, aggregate and agglomerate, as shown in Figure 1.



Source: Steven *et al*., 2011

Figure 1. Physical form of nanoparticle: primary particle, aggregate, and agglomerate.

The primary particle size of 5-20 nm is the smallest form of nano-crystalline particles. Primary particles tend to coalesce to form clumps (aggregates) due to the strong attractive force between the crystal particles. Size Aggregate particle is about 30-150 nm. Aggregates tend easily to form larger clumps and loose (agglomerate) by the effect of drying and heating during the production process. Agglomerate shape usually owned by TiO_2 and ZnO particles as a powder (Steven et al., 2011).

Potential Protection of Nanosized TiO_2 and ZnO in Sunscreen

Particles of TiO_2 and ZnO including inorganic active ingredients in sunscreens that have been developed to protect the skin of the harmful effects of UV rays. This is related to the characteristics and potential of those particles. Both minerals are not soluble in water and their performance are affected by particle size.

In sunscreen, there are three mechanisms of UV radiation attenuation, i.e. the absorption, scattering, and reflection. However, in general there are two ways of electromagnetic radiation interacts with matter, i.e. absorption and scattering. Comparison between scattered to radiation light absorbed depends on the particle size. The larger the particle size, the ratio between scattering and absorption greater. Conversely, the smaller the particle size the ratio between scattering and absorption are getting smaller. Therefore, in the case of nanosized ZnO and TiO_2 process uv rays absorption is more dominant occurs (Henry-Zoe, 2009).

Nanosized particle also affects the properties of the conductor material. The smaller the particle size causes the energy gap between the valence band and conductor band further away. It means that the nanoparticles are more semiconductor or even changed insulator. Thus, absorption of UV radiation required to raise an electron from the valence band to the conduction band requires a larger energy. Nanosized TiO_2 has the potential to protect the skin from the effects of UVA radiation, while nanosized TiO_2 has the potential to protect the skin from the effects of UVB radiation. So, the combination of sunscreen active ingredients consisting of nanosized TiO_2 and ZnO will provide protection to a broader spectrum (Nicholas *et al*., 1997).

In terms of stability, nanosized ZnO are much more stable than TiO_2 particles when exposed to sunlight. ZnO particles are not photoreactive so it does not generate harmful free radicals. While TiO_2 is more photocatalytic by releasing electrons or particles radicals when exposed to the radiation light. Therefore, the particle surface is usually wrapped inert material such as aluminum oxide or silicon oil. This coating is important because the photocatalytic properties of nanosized titanium dioxide harmful to skin fibroblasts, nucleic acids and cell-cell carcinoma of the human small intestine. In addition, it is also useful to improve the dispersion of nanoparticles in sunscreen formulas (Anuradha Patel *et al*., 2011).

Initially, microsize (powder) TiO_2 and ZnO particles used as a sunscreen active ingredient. Unfortunately, these microparticles have a shortage, i.e. less effective at absorbing UV light and lead to white residue on the skin surface. Furthermore, microsize (agglomerate) is reduced into nanosize (aggregate). Changes in particle size into the nano turns out to be transparent so that the white layer on the surface skin invisible either in the form of aggregate or agglomerate. In addition, nanosized particles make the surface become wider thereby increasing the absorption of the particles against UV radiation. Thus, smaller particle size higher the Sun Protection Factor (SPF) value significantly. SPF value indicates duration of sunscreen to protect the skin before burning. SPF can be defined as the rasio between the minimal dose that produces perceptible erythema on the skin (i.e., minimal erythema dose) /MED) in the presence or absence of 2 mg/cm^2 of sunscreen, using solar simulated radiation as a light source (United State Food and Drug Administration, 1999). The scientists recommend the use of sunscreen products that have SPF value of at least 15. Actually, SPF value of sunscreen only indicates protection against UVB radiation.

To obtain a wider absorbtion area (filter UVA and UVB), the composition of the formula should use a combination of nanoparticles with different sizes (Steven *et al*., 2011). Indicator of sunscreen protection against UVA radiation can be seen from the value of the critical wavelength (CW). CW is a wavelength region where the absorption of the UV light reaches at least 90%. The greater ability of sunscreen protection against UVA radiation, the greater the CW value. The label "broad spectrum" of sunscreen products are only allowed for products that CW value is larger than 370 nm (FDA, 2011). This is consistent with the results of research conducted by Costello *et al.* (2012) that broad spectrum sunscreens can reduce the damage of the dermal molecules so that preventing skin damage caused by the UV radiation.

Based on the characteristics of nanosized TiO_2 and ZnO which easy to agglomerate, sunscreen manufacturers must maintain the optimum particle size until the end of the production process. One way to do this is by adding a dispersing agent so that the components can be mixed in sunscreen evenly. The presence of dispersing agent in sunscreen formula was able to enhance the SPF value up to 5 times (Steven et al, 2011). Sunscreen usually also contain film-forming additives (such as acrylate, acrylamides, and copolymers) so that when sunscreen is applied to the skin will feel supple, uniform, and thoroughly wrap (Schwarzenbach-Huber, 2003; Hunter-Trevino, 2004).

Aggregate of nanosized TiO_2 and ZnO in sunscreen can be designed as a hollow sphere. It can improve the performance of the sunscreen products i.e. enhance the SPF value, reducing the potential for irritation of the skin, resulting in a softer texture, and more transparent when applied to the skin surface thereby increasing its aesthetic value (Jones, 2002; Miki Uematsu *et al.,*undate). Modified particle can also be done by doping TiO_2 crystal with manganese (Mn). Manganese ions in the crystal are placed in and on the surface of TiO_2 particles. This modified aim to overcome the reactivity of TiO_2 particles. The crystal modified successfully prevent the formation of free radicals, therefore TiO_2 coating is not necessary. Material doped Mn-TiO_2 particle improves retention percentage of organic ingredients and vitamins to make them more stable. Vitamins function as an anti-aging active ingredients, thus indirectly TiO_2 provide advantages in anti-aging skin products as effectively as its role as protector of UV light (Wakefield *et al*., 2006; Hewitt *et al*., 2008).

Potential Toxic Properties of Nanosized TiO_2 and ZnO in Sunscreen

The main issues of application of nanosized TiO_2 and ZnO as active ingredients in sunscreen is the potential toxic properties. The toxic properties associated with the ability of nanosized TiO_2 and ZnO to generate free radicals and reactive oxygen species (ROS) during exposure to UV radiation. Widely surfaces of particle at the nanosized will increase the reactivity of substances, particularly the formation of oxygen radicals. This is especially feared because of reactive oxygen species can damage DNA, can cause mutations, can damage proteins and fats causing permanent injury to cells and tissues. In fact, the widespread damage by ROS can cause changes in the genetic code of the entire body tissues. Although the body has a natural antioxidant defenses against ROS, but the system would be overwhelmed if the body's endogenous receive excessively oxidative substances.

Some things that need to be understood by the consumer sunscreen products including the following. First, nanoparticles of TiO_2 and ZnO in its application covered by a protective layer on its surface. The protective layer serves to protect the nanoparticles of contact with other materials including oxygen. Thus, nanoparticles are inert and the risk of free radical formation can be prevented. Components can be used as the protective layer such as silicon dioxide, stearic acid, and aluminum stearate (Lademann et al., 2000). Second, the skin has its own antioxidant mechanism consisting of molecules of enzyme and non-enzyme, to cope with ROS (Steven *et al*., 2011). Thus, ROS generated by nanosized TiO_2 and ZnO during UV exposure can be neutralized by the body's natural defense mechanism. Furthermore, modified TiO_2 crystals have been proved could stabilize the photocatalytic properties of TiO_2 particles (Wakefield *et al*., 2004).

In terms of solubility, ZnO particles are easily soluble form zinc ions compared to TiO_2 particles. Zinc ion is one of the minerals that the body needs to intake of about 10-15 mg/day (Henry-Zoe, 2009). It means that if there is zinc ions are absorbed into the body will be processed by the body. Thus the use of ZnO as active substance in sunscreen is relatively safe. Another important thing to be consider related the safety of use nanosized TiO_2 and ZnO are both nanoparticles have been widely used in various products for decades. TiO_2 is often used in various products such as toothpaste, lotions, skim milk, and cheese boxes, while the ZnO commonly used in baby powder, anti-dandruff shampoo, and various creams. However, the photocatalytic activity of nanoparticles must be continuously monitored so as not to damage the composite product system. Therefore it is necessary supervision and testing, especially when the merger of the matrix polymer with nano particles (Anuradha Patel, 2011).

Potential Penetration of Nanosized TiO_2 and ZnO into the Skin

The anxiety by the harmful effects of very small particle size (nano size) also appears. It happens because there are fears that nanoparticles will penetrate into the skin layers to the internal organs. Research on this subject have been carried out either by government, industry, and academia. The results showed that TiO_2 and ZnO relatively little penetrates the skin and is not visible to penetrate the stratum corneum in healthy human skin or wounded (Zvyagin, 2008; Sadrieh *et al*., 2010; Hallmans, *et al*., 1985; Agren, 1990; Agren *et al*., 1991). Analysis of possible penetration of nanoparticles on the burn skin due to exposure to radiation have been conducted (NA Monteiro-Riviere *et al*., 2011). The results showed that up to 48 hours of exposure no penetration ZnO occurs, while the TiO_2 penetration only occurs in the stratum corneum layer with the depth twice of the normal skin, but still tolerable, whereas the layer transdermal absorption does not occur. In general, the penetration of nanoparticles into the skin layer is minimal category.

When the nanoparticles are added to the cream or lotion, the primary particles tend to coalesce to form aggregates due to strong attractive forces between molecules. Aggregates formed in a lotion or cream is too large to cross the blood-skin barrier. Although some of the nanoparticles found in the pilosebaceous open and shallow part of the follicle, the possibility of nanoparticles enter the body tissues through of transfollicular route can be ignored. It is because the hair growth tends to push the particles to the surface of the skin. However, there is the possibility of nanoparticles accumulated in the stratum corneum, but the skin renewal process by the epidermis will prevent long-term accumulation and nanoparticle penetration into skin tissue sections (Steven *et al*., 2011).

Diversification Sunscreen Packaging

Packaging sunscreen products had been developed. In the beginning, most of the sunscreen packaging is cream. Neverthelesss the cream packaging is less favored because hands dirty and takes more time. This constraint is an important issue because majority of consumers products are children and adolescents. Then, sunscreen product packaging has varied into spray form. Currently, sunscreen in spray packaging have been widely sold in the market, either single phase oil-based (emulsion sprays) or single phase alcohol-based (aerosol sprays). Sunscreen in spray packaging is often expressed as "continuous spray sunscreen" or "no-rub sunscreen" because it can be applied in a sustainable manner and without the need to scrub by hand. The concept is very fine particles and the polymer added to the solvent phase to assist the formation of a layer (film) on the surface skin. This product is preferred because the results are very satisfactory, i.e. invisible on the skin, not grained, and does not feel greasy on the skin (Tadros *et al*., 2003).

Sunscreen in the wipe packaging is also available in the market. In this formula, a thin liquid emulsion containing active sunscreen ingredients impregnated into the wipe. This packaging is intended for use on small children to avoid the risk of spills or inhaled. In addition there is also a stick packaging for sunscreen. Stick packaging of sunscreen is generally used for the lips and face to be easily applied and avoid greasy effect on the hand (Henry-Zoe, 2009).

At present, the popular phenomenon is active ingredients of sunscreen combined in cosmetics. In terms of effectiveness, protection ability of sunscreen agents in cosmetic products may not be as effective as pure sunscreen. Nevertheless, the presence of multiple layers of sunscreen substances on the skin's surface will extend the performance of the sunscreen protection. In general, color cosmetic products are divided into several groups, i.e. facial foundation, facial powders, facial moisturizer, cosmetic eyelid, and lipstick. The presence of a number of pigment in the product formula will determine the level of product protection. For example, facial foundations that contain only small amounts of TiO_2 has an SPF value of about 2 because the radiation is still reach to the skin. Generally, facial foundation has an SPF value of about 6 which allows the product still produce invisibility effect (translucent). Moreover, the presence of organic UVA and UVB filter allows increased SPF value of the product to 15 (Floyd *et al*., 1997; Angelinetta *et al*., 1995).

In addition to enhancing the protection of the skin from UV radiation, the formulas of inorganic particles also increase the aesthetic value. For example, transparent white layer by nanosized TiO_2 and ZnO makes skin look brighter and feels smoother. In addition, the doped Mn-TiO_2 particles produce a light brown color (beige) in order to obtain natural color cosmetics such as skin color. Emulsion nanoparticles is also commonly used in products conditioner or lotion. Nano emulsion combined with traditional cosmetic ingredients such as water, oil, and surfactant, in a two-phase system which the size droplet about 50-100 nm dispersed in an external phase (aqueous). Tiny droplets that produce a transparent nano emulsion and smooth effect (Sonneville, 2004).

C. Conclusion and Suggestion

Application of nanoparticles of TiO_2 and ZnO as inorganic sunscreen active ingredient provides many advantages, of which raises no skin irritation, allergies, inert to the other constituent materials sunscreen, minimal penetration into the skin and has a broad spectrum of protection. In the production process of the sunscreen active ingredients, besides determine the optimum particle size is also important to keep the particle size until the end of the production process. This is related to the nature of the particles easily form aggregates or agglomerates. Advances in nanotechnology accompanied the development of nanoparticles of TiO_2 and ZnO as the active ingredient of sunscreen allows the creation of cosmetic products to be more effective and elegant. In addition to concentrating on the determination of the type and concentration of the active ingredient UV filter, it should be considered is compatible other ingredient in sunscreen formulas, such as dispersing agents, moisturizers, thickeners, stabilizers, and perfume. A suitable combination of such material will increase the performance of both the potential for protection from UV radiation and increased aesthetic value. However, the convenience and safety of the consumers becomes a major factor in calculating the efficacy of sunscreen ingredients.

The important thing people need to realize that sunscreen is only one attempt to overcome the harmful effects of solar radiation. Society should also anticipate the hazards of radiation in other ways that do not involve the use of chemicals continuously, for example by using protective clothing, a hat, or umbrella when exposed to sunlight. Thus, sunscreen especially made from nanoparticles of TiO_2 and ZnO are not used excessively and continuously so that the skin is able to regenerate and neutralize the toxic nature or the possibility of penetration into the skin and even blood vessels.

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