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DESIGN OF A PROTOTYPE PHOTOREACTOR UV-LEDS FOR RADIATION VULCANIZATION OF NATURAL RUBBER LATEX

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ABSTRACT

The land area and production of rubber on smallholder rubber plantations contribute to about 85% and 81% of national rubber production, respectively. Based on this, having technology to utilize vulcanized natural rubber latex (NRL) in a way that is simple, inexpensive, energy-saving, environmentally friendly, and according to the quality standards of the processing of NRL is important. The purpose of the current research is to design of a prototype photoreactor ultraviolet light-emitting diodes (UV-LEDs) for the vulcanization of NRL that is irradiated (VNRLI) to produce NRL-irradiated free carcinogens and protein allergens. The methodology used is the technological development of a prototype photoreactor with an UV-mercury irradiator that located in a vertical cylindrical glass column with the capacity of VNRLI about 249.2 tons/year. The development of technologies applied to increase the capacity of VNRLI by enlarging the area of thin NRL films to be irradiated with UV-A rays derived from UV-LED irradiators that are more energy-efficient, long-life, and environmentally friendly than UV-mercury irradiators. The results allowed for the design of a prototype photoreactor UV-LEDs to process feed NRL with the capacity VNRLI about 522 tons/year. The UV-LED photoreactor prototype design results show that the UV-LED photoreactor prototype is ready to test the VNRLI process function that can produce NRL- irradiated free carcinogen and protein allergens.

Keywords: Irradiator; Natural rubber latex; Photoreactor; UV-LEDs; Vulcanization

1. INTRODUCTION

Natural rubber latex is a milky colloidal system that consists of cis-1, 4-polyisoprene, proteins, carbohydrates, minerals, fatty acids, and a large amount of water. The dry rubber content of latex is approximately 28–40% (Wijesinghe et al., 2016).

Natural rubber latex is one of the most important industrial raw materials. Currently, over 12 million tons of natural rubber is produced annually, which is used in many industries to manufacture commercial products such as gloves, tires, condoms, balloons, rubber boots, mattresses, swim caps, catheters, and vial stoppers (Wu et al., 2016).

Natural rubber latex consists of a protein that is allergenic to the human body (Johns et.al., 2015). However, natural rubber latex contains 15 proven allergenic proteins (Hev b1 to Hev b15) that can elicit a hypersensitive immune response in the latex-responsive population,

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possibly leading to death if the condition becomes severe enough (anaphylaxis) (Wu et al., 2016).

Exposure to medical gloves that are high latex proteins should be a precaution for healthcare workers. Body sweat coming into contact with the latex gloves may make the latex proteins soluble, further allowing absorption through the skin, making the wearer become sensitized easily. The statistics indicate that 8–12% of healthcare workers and 1–6% of the general population have a latex allergy (Rasdi et al., 2015).

Vulcanization of natural rubber latex (VNRL) is a process of continued cross-linking between cis 1,4 polyisoprene molecules; this process is possible because of their vulcanizing agents, such as sulfur. Because of the vulcanization reaction, the sulfur will cross-connect and bond between the molecules of cis 1,4 polyisoprene (Harahap et al., 2015).

Vulcanization of natural rubber latex using a sulfur process requires five different kinds of materials: antioxidants, binders for polyisoprene sulfur cross-linking, accelerator materials such as carbamate compounds, activating materials, and stabilizing materials to prevent the early clotting of pre-coagulation.

Vulcanization at high temperatures can decrease the time, thus lowering production costs. However, vulcanization at high temperatures causes uncontrolled side reactions that result in lower product quality. At low temperatures, the quality and appearance of natural rubber products are better than high temperatures, but it takes a long vulcanization period, thereby increasing the cost of production The temperature of VNRL using the sulfur process ranges between 100–180^{o}C (Kinasih et al., 2015; Tambunan & Harahap, 2015).

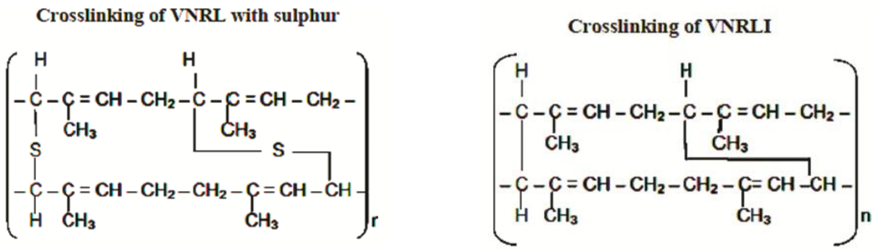
Data also show that the average prevalence of latex allergy worldwide remains at 9.7%, 7.2%, and 4.3% among healthcare workers, susceptible patients, and the general population, respectively (Wu et al., 2016). The prevalence of sensitivity to allergens because of use of rubber products for sex is 21.6% for females and 25.9% for males (Lin et al., 2015).

NRL proteins in products elicit high levels of IgE anti-HNR latex proteins that when inhaled or adsorbed, cause the release of vasoactive mediators from mast cells and basophils. Clinical evidence shows that an individual can become “sensitized” with upper airway rhinitis and lower airway asthma. Following airborne or direct contact exposure to NR latex allergens, some individuals who are highly sensitized to NRL proteins experience life-threatening allergic symptoms involving anaphylaxis (Cornish et al., 2015).

Natural rubber latex is vucannised with sulphur form carcinogenic compounds such as N-nitrosomorpholine, 4-nitrosomorphine, and dimethylnitrosamine, in which the number of parts per billion (ppb) alone can cause cancer (Radford et al., 2013).

Natural rubber latex is known to cause type I and type IV allergic reactions, as well as irritant contact dermatitis. Natural rubber latex, an extract from the sap of hevea brasiliensis trees, contains 200–256 proteins, including 11 potential allergens. At least 13 distinct proteins have been identified and associated with latex sensitivities in healthcare workers, spina bifida in patients and children or adults within the general population (Kokollari et al., 2015; Nanti et al., 2014).

The cross-linking compound generated by VNRLI is much stronger than that produced by VNRL with sulphur. This is because the VNRLI cross-linking occurs between the carbon atoms directly without going through the sulphur atoms (C-C bond energy = 58.6 kcal/mol and C-S = 27.5 kcal/mol), as shown in Figure 1 (Marsongko, 2013).



(a) (b)

Figure 1 Cross-linking of VNRL with sulphur (a) and VNRLI (b)

2. LITERATURE REVIEW

2.1. Successful Commissioning of the Pilot Plant VNRLI with the UV-A/B of UV Mercury Lamp Irradiators

The process of VNRLI can be carried out using a photoreactor with the UV-A/B of UV-mercury lamps. Research of VNRLI using ultraviolet irradiation of UV-mercury lamps has also been successfully carried out jointly by the Faculty of Engineering, Kasetsart University, Bangkok, Thailand and the National Metal and Materials Technology Center (MTEC) and Thailand Science Park (TSP) (Hansupalak et al., 2016).

The research team from the Polymer Competence Center Roseggerstraße, Leoben, Austria has managed to make a NRL vulcanization pilot plant for the manufacturing of non-allergenic surgical gloves using a photoreactor with the UV-A/B of UV-mercury lamps in the wavelength range of 240–420 nm. The photoreactor is a vertical glass column with a diameter of 13.5 cm and a length of about 1 m, with the source of the UV-A/B radiation emitted from one UV-mercury lamp type T8 TL with a length of 1 ft, power of 3000 W, and irradiance of 1.1 W/cm^2. This lamp is located in the middle of the glass column, as shown in Figure 2 (Schlögl et al., 2010; Schlögl et al., 2012; Schlögl et al., 2014).

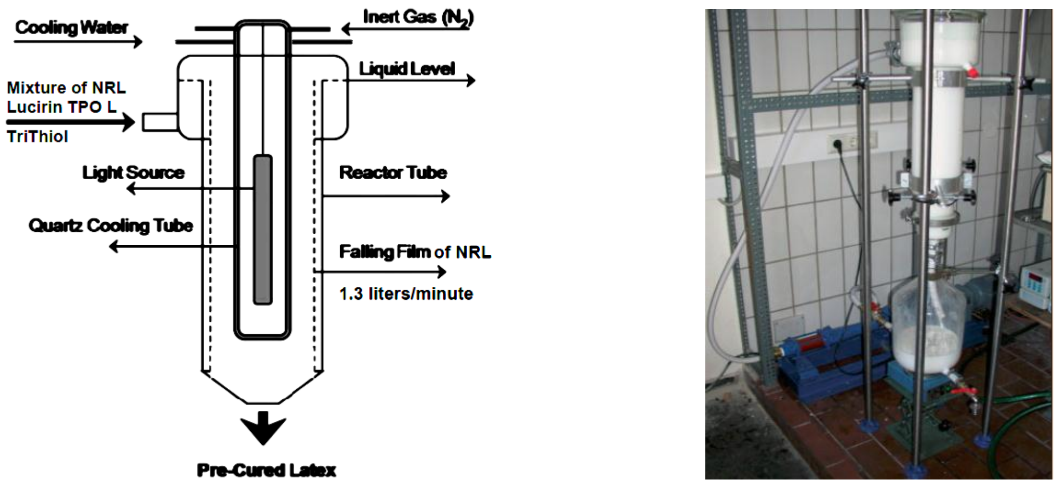


Figure 2 Photoreactor prototype of UV-mercury irradiators for VNRLI

The VNRLI process is carried out as follows: A thin layer (film) NRL is passed through the photoreactor wall using gravity at a flow rate of 1.3 liters/minute and then irradiated with a beam of UV-A/B photons derived from the UV-mercury lamp irradiators. The UV-A/B photon beam will cause heat radiation. Heat accumulation of the film of NRL can cause the temperature rise. To avoid the accumulation of heat radiation, which can cause degradation in the NRL film, the necessary cooling systems using water at a temperature of 12–16°C in the pipe annulus of quartz glass with a long arc in a circle of 25 cm is used so that the pre-cured NRL can come out at a temperature of 38^{o}C.

The light transmissivity is low, so only a thin layer of natural rubber latex can be homogeneously irradiated with UV-A/B. To ensure a sufficient irradiation dose for vulcanizing the NRL, the process is carried out in a flow photoreactor with a thin layer (film) of NRL falling from the force of gravity. This technology is well known and commonly used in water purification and sterilization, as well as in organic chemical and photochemical processes on an industrial scale. Besides easy handling and regulations, the concept of thin layer falls has allowed for the provision of the continuous illumination (irradiation with UV-A/B light) of natural rubber latex in a thin layer.

The new technique of vulcanizing NRL with UV-A/B radiation has an advantage: it does not use a sensitizer, accelerator material such as dithiocarbamate and 2-mercapt-benzothiazole which are a high risk of cytotoxicity and tissue irritancies, or activators, so it is worth considering for further development in the manufacturing of surgical gloves (Schlögl et al., 2010; Schlögl et al., 2012; Schlögl et al., 2014).

Mechanical tests on surgical gloves made of pre-cured NRL of VNRLI show the tensile strength and cross-link density, as shown in Figure 3a. Mechanical tests on the surgical gloves made of pre-cured NRL of VNRLI after the aging process, again expressed by tensile strength, are shown in Figure 3b (Schlögl et al., 2010).

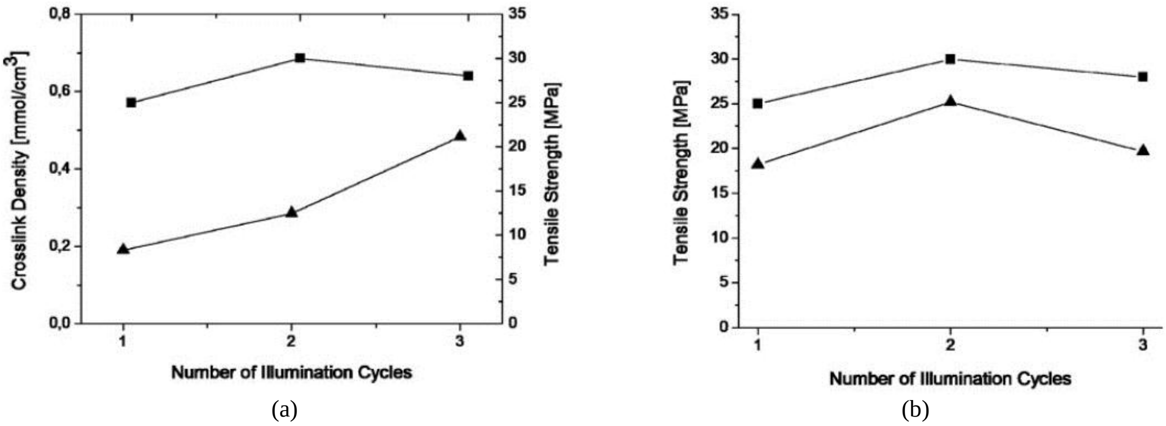


Figure 3 Test of mechanical surgical gloves made of pre-cured NRL of VNRLI

Figure 3a shows that a two times illumination provides the best mechanical test results with a tensile strength of 30 MPa. However, with a one times illumination, the tensile strength is 25 MPa, which is already above the standard requirements of EN-455 2 (2000), which requires a tensile strength 24 MPa. Figure 3b indicates that the process of aging the NRL results from VNRLI at room temperature for 7 days showed a tensile strength of 23 MPa (with one times illumination) and 28 MPa (with two times illumination), already above the standard requirements of ASTM D 3577, which requires a tensile strength of 18 MPa, as shown in Table 1 (Schlögl et al., 2010).

At the initiation stage, the presence of a photoinitiator in the latex materials is excited by the UV-A/B, followed by the termination of the bond to generate free radicals. This moves their thiol hydrogen from thiol to generate the free radical photoinitiator radical form thiyl (RS). Once formed, the radical thiyl will be able to react with the C = C double bonds in the poly-isoprene in the NRL to generate thioeter and a carbon radical center. Furthermore, the radical thiyl form binds with hydrogen from another thiol with a carbon radical center.

Table 1 Comparison of the physical properties of international standards to sterile surgical gloves made of VNRLI by irradiation with UV-A/B from mercury lamps

Physical Properties	Sterile Surgical Gloves			
	ASTM D 3577		UV Pre-cured NR Latex Film	
	Before Aging	After Aging	Before Aging	After Aging
Tensile Strength (MPa)	24	18	25–32	23–28
Ultimate Elongation (%)	750	560	770–870	680–720
Force at Break (N)	12	9	12.5–15	11.5–14

The terminated reaction involves combining a radical push toward disulfide, thioeter, and covalent carbon-carbon bond (Schlögl et al., 2010).

The NRL vulcanization stage is followed by a conventional coagulant dipping process. The surgical gloves are made on a series of dyeing machines in the porcelain hand formers on which the latex films were shaped were connected to both sides of the chain. Surgical gloves made of VNRLI show perfect physical properties and good age stability. The physical properties of surgical gloves conforms with the skin good, which has been proven by studies of acute skin irritation in rabbits (methods and research in accordance with ISO 10993-10: 2002) and studying skin sensitivity (Schlögl et al., 2010).

Some technical data on the manufacture of pilot plant experiments creating VNRLI with UV-A/B light from a UV-mercury lamp in a vertical cylindrical photoreactor (as shown in Figure 2) is partially taken from EP Patent 1,762,586 on March 14, 2006 and U.S. Patent 0105,971 on May 10, 2007 (Schlögl et al., 2010). If proven valid in Europe and the USA, then the technology can be developed in Indonesia to be applied to micro-, small- and medium-sized enterprises in the field of agro-industrial rubber.

2.2. The Advantage of UV Light-Emitting Diodes (UV-LEDs) Compared with a UV-Mercury Lamp

The advantages of burning an LED compared to some other types of lamps are as follows: an LED lamp can run up to 100,000 hours with a light intensity (lumen) around 87%. Meanwhile, if a tubular lamp (TL) is used, specifically the T8 and T5 fluorescent varieties, for the same light intensity of 87%, then the burning hours would only be 5000, as shown in Figure 4 (Schupple, 2009; Widiyati & Poernomo, 2015).

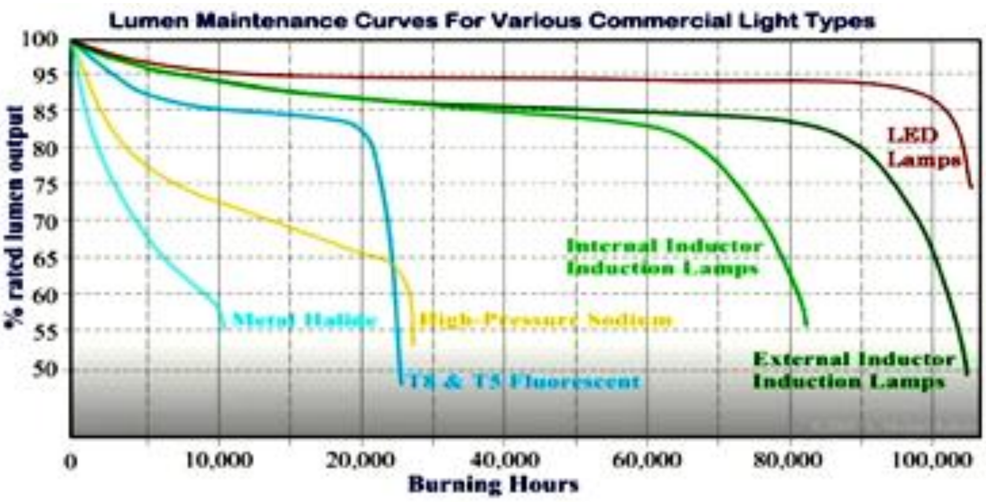


Figure 4 Burning hours for lights

The advantages of UV-A from UV-LED lamp compared to the UV-A/B of a UV-mercury lamp is that the wavelength spectrum of UV-A from UV-LED lamp has a wavelength range of λ = 360–380 nm narrower, but a UV-A/B from a mercury lamp has a spectrum with a wide range of λ at 240–420 nm, as shown in Figure 5. The spectrum of UV-A rays is narrow at λ = 360–380 nm for UV-LED lamps, which also have a radiation sensitivity of 100% at the wavelength λ = 375 nm, as shown in Figure 6 (Heathcote, 2010).

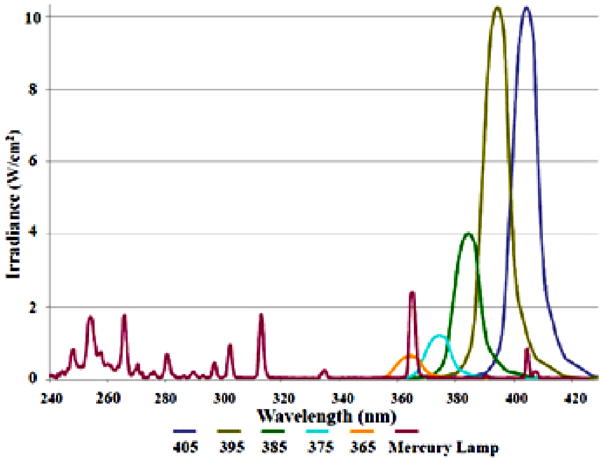


Figure 5 Spectrum irradiance of UV-LEDs compared to UV and other lamps

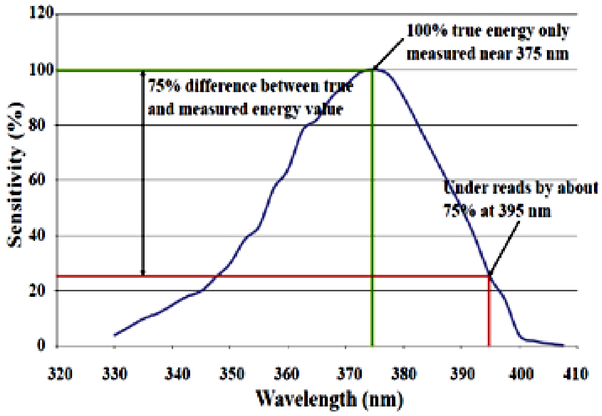


Figure 6 Type sensitivity of UV-A radiation

Figures 4, 5, and 6 show that UV-A rays with a wavelength λ = 375 nm emitted by a UV-LED lamp are the best options if used in a curing process such as vulcanizing NRL by irradiation.

The lifetime of UV-mercury lamps is about 1000–2000 hours (Putra et al., 2008), so to continue the VNRLI process for a year, the UV-mercury lamps would have to be replaced multiple times.

The collision of electrons from an electron beam machine, electromagnetic radiation, or photons (*hv*) of gamma irradiators or UV light irradiators with liquid natural rubber (LNR) may cause heat, resulting in the temperature of the LNR rising. Natural rubber latex can be degraded by the effect of temperature and time, as indicated by the decrease in the average molecular weight (Mn) of LNR, which also causes a decline in the quality of LNR. This has been proved, as shown in Figure 7 (Isa et al., 2007).

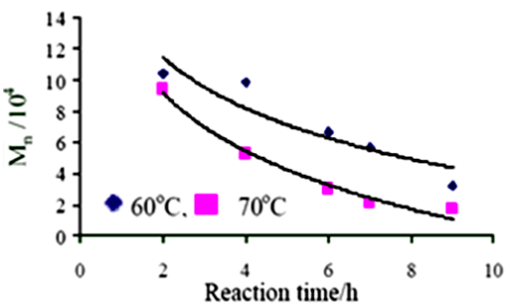


Figure 7 Effect of time and temperature on the Mn of LNR

The penetration of UV-C light with a wavelength of λ = 200−280 nm in water reverse osmosis (RO) = 3.0 m; in drinking water = 12.0 cm; in wine or juice = 2.5 mm; in syrup milk or blood = 0.5 mm (Pure Pro Water Corp., 2010).

Penetration thickness of several types of UV rays to (ink, coating, adhesive) shown in Figure 8 (Raymont, 2011).

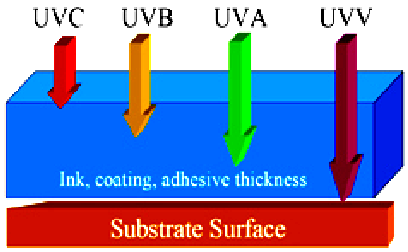


Figure 8 Penetration thickness of several types of UV rays to (ink, coating, adhesive)

If the number of rubber particles and proteins in the NRL colloidal system assumed to be analogous to the number of particles of protein and milk in a colloidal system of milk, then (as shown in Figure 8), the penetration ability of UV-A rays from a UV-LEDs lamp in the film NRL (t_b) would be > 0.5 mm.

Based on the advantages of UV-LEDs lights compared to a UV-mercury lamp, the current research aimed to design and build prototype UV-LED irradiators for the vulcanization of rubber latex that is irradiated.

3. METHODOLOGY

3.1. Calculation of VNRLI Capacity with Irradiators from a UV-Mercury Lamp

The life of a UV-mercury lamp only 2000 hours (Putra et al., 2008). If the operational process for making VNRLI is run 24 hours per day, then the UV-A will need to be replaced every 4.16 months. Thus, in the first operational year, the VNRLI process should consume three UV-A lamps. The UV-A lamps containing mercury necessitate solid waste management facilities because of the toxicity of mercury. If the replacement of a T8 fluorescent lamp UV-Hg takes about two days, then the remaining number of days in a year of operational processes VNRLI = (330–3 ×2) = 324 days.

Based on a thin layer (film) NRL is passed through the photoreactor wall using gravity at a flow rate of 1.3 liters/minute and then irradiated with a beam of UV-A/B photons derived from the UV-mercury lamp irradiators as shown in Figure 2, then the capacity of VNRLI (M) can be determined by the following equation (Widiyati & Poernomo, 2015):

$$M = Q \times \rho_{NRL} \tag{1}$$

where ρ_{NRL} is the density of NRL (g/cm^3).

3.2. Concept Prototype of UV-LED Irradiators to Process VNRLI

Based on the characteristics of the UV-A rays of the UV-LED lamp as shown in Figures 4, 5, and 6, it is possible to design a prototype UV-LED irradiators for the VNRLI process that adopts the UV-mercury irradiators prototype as shown in Figure 2 (Schlögl et al., 2010). The technology concept of design a prototype UV-LED irradiators to process VNRLI shown in Figure 9.

The explanation of Figure 9 is as follows: ACS = an air conditioning system that can be shifted, BV = ball valve and pipe of stainless steel (SS) ½ inch, CF = container funnel thin layer of NRL-irradiated, CR = container and regulating the flow of a thin layer of NRL, CW = cooling water to lower the temperature of the thin layer of NRL-irradiated, M = motors 1 HP to shift the

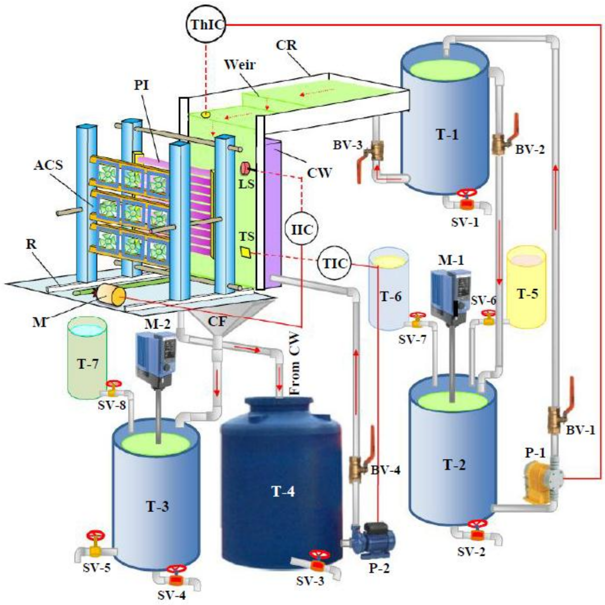


Figure 9 Technological concepts of prototype photoreactor UV-LEDs for the VNRLI process

photo irradiator, M-1 & M-2 = motors 1½ HP for stirring NRL, 0–500 rpm, helical ribbon-shaped stirrer (D = 12 cm, H = 60 cm), PI = photo irradiator that can be shifted, P-1 = dosing pump of Tacmina PZiG 1300 wtih Q = 1,3 L/min, P-2 = water pump 125 W, R = rail as a way to shift the PI and ACS, SV-1 through SV-5 = stop valve and pipe SS ½ inch, SV-6 through SV-8 = stop valve and glass pipe or PVC ¼ inch, T-1 = SS tank for feeder NRL (D = 35 cm, H = 60 cm), T-2 = SS tank for the container NRL (D = 35 cm, H = 60 cm), T-3 = SS tank for the container NRL-irradiated (D = 35 cm, H = 60 cm), T-4 = tank for water reservoir, volume = ± 300 L, T-5 = measuring cups as containers Lucirin TPO L (V = 1 L), T-6 = measuring cups as containers TriThiol (V = 1 L), T-7 = measuring cups as containers Phenolic (V = 1 L), IIC = irradiance indicator control, LS = light sensor, TIC = temperature indicator control, ThIC = thick indicator control, TS = temperature sensor.

3.3. Process Description

The description of the VNRLI process in Figure 9 is as follows: the TL T8 lamp UV-LED has as many as six pieces used as irradiators, each with a length L = 2 ft, diameter = 30 mm, and irradiation intensity $I \geq 1.1$ W/cm^2 is used as a UV-A radiation source. A thin layer of NRL that has been mixed with a Lucirin TPO L and TriThiol sensitizer of 1.0 phr each is gravitated on the surface of the vertical glass plate. The selection of glass materials should consider glasses having a rough surface so that some adhesion of NRL against the glass material would be relatively small. The heat arising during the operation of the LED semiconductor chip on the system's T8 fluorescent lamp UV-LED is cooled by blowing air from the air conditioning system to the diode component of the T8 fluorescent lamp UV-LED. NRL films were irradiated by UV-A accommodated in the tank; then, 0.5 phr phenolic was added for the dipping process for the manufacturing of medical devices such as surgical gloves.

4. RESULTS

4.1. Capacity of VNRLI with Irradiators from UV-Mercury Lamp

Mechanical tests of the surgical gloves made of pre-cured NRL that resulted in VNRLI show that the tensile strength and the cross-link density are best achieved at twice the illumination of the NRL film. If the discharged NRL flows in the annulus glass fotoreactor at 1,300 cm^3/min, then the VNRLI process capacity (M) can be calculated as follows:

M = 1,300 cm^3/min × 0.913 g/cm^3 × 0.5 = 593.45 g/min
M = 593.45 g/min × 60 minutes/hour × 24 hours/day × 324 days/year
M = 276,880,032 g/year = 276.88 tons/year.

If it is assumed that in the film isoprene, the isoprene NRL can be irradiated (i-isoprene), caused by radiation cross-linking of isoprene by UV-A/B with a conversion of about 90%, then the following is true:

M_{VNRLI} = 0.90 × 276.88 tons/year = 249.2 tons/year.

4.2. VNRLI Technology in Falling Film NRL on a Vertical Glass Plate Irradiated with UV-A Rays from UV-LED Lamp Irradiators

One effective and efficient way to expand the volume of NRL irradiated in the VNRLI process and multiply the occurrence of cross-linking isoprene in the NRL into poly-isoprene is irradiating a flow of an enlarged thin layer of NRL continuously in the broad field of irradiation or using UV-LED with magnified irradiance.

Based on the UV-A light characteristics of UV-LED irradiators superior to UV-A/B from UV-mercury irradiators as described above, we can draw a prototype UV-LED photoreactor for the VNRLI process as shown Figure 10. Based on Figure 10, we can design a prototype UV-LED photoreactor for the VNRLI process as shown in Figure 11.

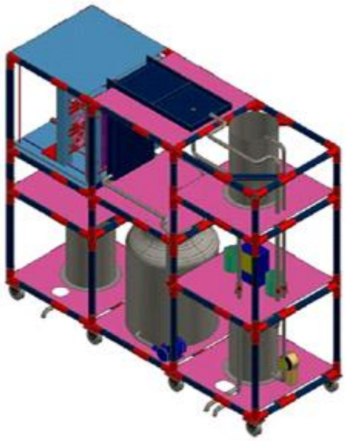


Figure 10 Drawing of a prototype photoreactor UV-LEDs to VNRLI

Figure 11 Prototype of a photoreactor UV-LEDs to VNRLI

4.3. Capacity of the VNRLI Process with Irradiators from an UV-LED Lamp

Based on data from volumetric flow rate of NRL (Q) in the experimental pilot plant, the VNRLI are made with falling film irradiators using UV-A/B radiation from a UV-mercury lamp, the linear flow rates for a thin layer of NRL (v) for the vulcanization of NRL with the best results are as follows (Widiyati & Poernomo, 2015):

$$v = Q/(\pi \times ID \times t_b) \tag{2}$$

where v is the flow rate of NRL (cm^3/min), ID is the inside diameter of the column (cm), and t_b is the thickness penetration of UV-A (cm). Therefore, this can be calculated as follows:

$$v = (1{,}300 \text{ cm}^3/\text{min})/[(\pi \times 13.5 \text{ cm})(0.05 \text{ cm})] = 612.794 \text{ cm/min}$$

Figure 5 shows that the wavelength range of the UV-mercury lamps are very wide, 240–420 nm with varying irradiance. If UV-LEDs light are used with a wavelength of about 365–375 nm, the obtained irradiance becomes more focused to about 1.1 W/cm^2.

Figure 6 shows that wavelengths of 375 nm in the UV-A rays rising from UV-LED lamps have a sensitivity of 100%. Thus, UV-A radiation from the UV-LED lamps have a greater ability to cure (cross-linking) polyisoprene in the NRL compared with UV-A/B from UV-mercury lamps.

The calculation of VNRLI capacity from photoreactor with UV-LED irradiator as shown Figure 11 as follows (Widiyati & Poernomo, 2015):

$$Q = v \times t_b \times L \quad (3)$$

where L is the width of vertical glass plate flow-thin layer NRL = 40 cm, so that

Q = 612.794 cm/min × 0.05 cm × 40 cm = 1,225.6 cm^3/min = 1.225 L/min
M = 1,225.6 cm^3/min × 0.913 g/cm^3 1,118.97 g/min
M = 1,118.97 g/min × 60 min/hour × 24 hours/day × 330 days/year
M = 580,075,499.52 grams/year = 580 tons/year

It is assumed that the conversion of polyisoprene in NRL film to polyisoprene irradiated (i-polyisoprene) is 90%, then:

Capacity of *VNRLI* = 0.90 × 580 tons/year = 522 tons/year

The prototype photoreactor UV-LEDs in Figure 11 when compared with the prototype photoreactor UV-mercury for VNRLI process as shown in Figure 2 show some differences, as follows:

a. The level of difficulty and the cost of construction work for the photoreactor prototype UV-LEDs are easier and cheaper when compared to photoreactor prototype UV-mercury in the vertical glass cylinder column.
b. The intensity of radiation (irradiance) is affected by the age of UV-LED lamps. If the radiation intensity of UV-LED lights decreases due to reduced age and for NRL film to receive UV-A irradiation with fixed irradiance, it can be done by moving the photoiradiator irradiator (PI) using stepper motor (M) because it is ordered irradiance signal from irradiance indicator control (IIC).
c. Precision NRL film thickness on the discharge of UV-mercury irradiators is controlled by a piston pump and overflow NRL on a vertical glass cylinder. Although, the NRL film thickness on UV-LED irradiators are more precise because it is controlled by a piston pump discharge, the overflow NRL tank T-1, and a thick control indicator (ThIC).
d. Cost reduction in NRL molecular damage caused by NRL film temperature rise due to UV-A / B heat radiation generated from UV-mercury irradiators as described in Figure 7 is relatively more expensive. This is because the cooling system used by N2 gas injection is relatively expensive. The UV-A radiation heat generated from the UV irradiator LED is much smaller than UV-A / B heat radiation from UV-mercury lamps. Thus, the cost of reducing the temperature rise in NRL films from UV-A radiation is cheaper because the cooling system uses water only.
e. The process of installation and replacement of UV-LED irradiators and surface cleaning for vertical glass plate which the thin layer of NRL moves as shown Figure 9 and Figure 11 is easier and faster when compared to the installation and replacement of UV-mercury irradiators and cleaning glass cylindrical column through which the thin layer of NRL moves as shown Figure 2.
f. Replacement irradiators for the UV-LED are rarely needed because the lifespan of UV-LED lamps are around 50,000 hours while replacing the UV-mercury irradiators is done often the UV-mercury lamp's life span is only 2000 hours.

g. The capacity of VNRLI on the prototype of UV-LEDs photoreactor is greater when compared with the prototype of UV-mercury photoreactor.

5. CONCLUSION

From the design of UV-LED photoreactor prototypes, it can be concluded that UV-LED photoreactor prototypes can be tested for the VNRLI process to obtain irradiated NRL-free carcinogens and proteins allergen. Furthermore NRL-free carcinogens and proteins allergen can be used as raw material for the manufacturing of medical devices such as elastic bandages, medical bandages, surgical gloves, bactericidal plaster, catheters, condoms, nipples, mattresses, and pillows.

6. ACKNOWLEDGEMENT

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