Effect polyethylene glycol (PEG 400) to the physical properties of gadolinium doped cerium (Ce$_{0.9}$Gd$_{0.1}$O$_{1.95}$) nanoparticles synthesized by co-precipitation method

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Abstract. Cerium oxide based materials have been attracting great attention as a promising electrolyte for intermediate temperature of solid oxide fuel cell (IT-SOFC) due to its excellent conductivity at a lower temperature. In this work, cerium from Indonesia local raw material was developed as a cheaper alternative precursor for preparing gadolinium doped cerium (Ce$_{0.9}$Gd$_{0.1}$O$_{1.95}$ or GDC10) electrolyte. The effects of polyethylene glycol 400 (PEG 400) as a surfactant on to physical properties of GDC10 electrolyte were studied. GDC10 powders were synthesized using co-precipitation method with the addition of various PEG 400 concentration i.e. 0, 1, 2 and 3 v/v%. Synthesized powders were characterized by using X-Ray Diffraction (XRD), Particle Size Analyzer (PSA), Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and Fourier Transform Infrared (FTIR) Spectroscopy. The XRD analysis indicates that crystallinity was enhanced and all of the peaks on samples correspond to the fluorite crystal structure of single phase CeO$_2$. The average crystallite size is about 11.37, 7.27, 6.75 and 7.02 nm for PEG 400 concentration of 0, 1, 2 and 3 v/v%, respectively. SEM images show different morphology of particle regarding with the addition of surfactant. Particle size analysis exhibits decreasing of particle diameter as the addition of PEG surfactant. The smallest particle size was about 1.47 µm for 1 v/v% of PEG concentration. The results of this work confirm that the addition of PEG 400 surfactant strongly affects particle size and morphology of GDC10 powders. However, addition PEG 400 as surfactant should be delivered in a certain amount to give optimum effects where according to this works it is about 1-2 v/v%.

Keyword: Gadolinium doped cerium, solid oxide fuel cell, polyethylene glycol, surfactant, co-precipitation

1. Introduction

In recent years, cerium based ceramic oxide materials have been attracting great attention of many researchers. It has many applications such as oxygen sensor, fluorescence material, catalyst, UV absorbents and solid oxide fuel cell (SOFC) [1], [2], [3]. However, the most application of cerium base ceramic oxide was focused on SOFC as solid electrolyte due to its excellent ionic conductivity in the intermediate temperature range of 500-800°C [4]. Gadolinium doped cerium (GDC) denotes as one of
cerium based ceramic oxide that excessively used for solid electrolyte. GDC with the composition of 10%mol of Gd dopant as known GDC10 is reported to possess better stability in reducing atmosphere at an intermediate temperature [5]. Moreover, GDC10 is also reported for having higher ionic conductivity than other compositions [6]. From the point of view fuel cell technology, intermediate temperature SOFC has some advantages such as the smaller thermal mismatch between its components and rapid startup with less energy consumption [7].

Some different methods of synthesis and processing have been reported to prepare GDC such as sol-gel [8], sol-combustion [9], hydrothermal [10], solid state [11] and co-precipitation. Among all of them, the co-precipitation method is widely employed due to low preparation cost, relatively simple process and high yield [4]. Furthermore, the wet-chemical method through co-precipitation provides powders with better reactivity as well as purity than solid-state method [12]. It has been reported the addition of PEG as a non-ionic surfactant to synthesize cerium base particle by chemical precipitation. Thus, the results demonstrate that it plays a significant role to prevent particle agglomeration and obtain finer particle. It can strongly bond on the particle surface and produce the particle with smaller size and lower PDI [13]. It is also actively absorbed monolayer of organic or inorganic molecules to prevent agglomeration in nanoparticles synthesis and then stabilize them [14].

Polyethylene glycol 400 (PEG 400) is reported to have low toxicity and soluble in water, acetone, alcohols and benzene [15]. It is a low molecular weight grade of polyethylene glycol and frequently used as the surfactant. The molecular weight of PEG governs the surface attraction or repulsion property [16]. It could be responsible for either inducing aggregation or stabilizing the dispersion. The rate of particle aggregation becomes a major factor that controls the crystallinity and morphology of products. So that, by adjusting the amount of PEG as the surfactant, particle size and morphology of powders can be modified. Some researchers have reported the use of PEG for powders synthesis where it was proved to decrease particle size and improve its notable properties [17], [18], [19], [20]. It is important information of nanoemulsion or microemulsion where it lowers the interfacial tension so that different tension between inside and outside of the droplets is reduced. Hence, stress needed for breaking up a drop is reduced and smaller droplets are formed. Smaller emulsion droplets tend to provide smaller particles. So that why PEG is important for particle synthesis due to its restricting effect of the microemulsion and the PEG molecules at the surface embrace the crystal and control their excess growth [21].

In this works, GDC10 powders were synthesized by co-precipitation methods using local raw materials of cerium precursor from Indonesia. The effects of PEG 400 addition as surfactant particularly its concentration on to properties of GDC10 was investigated.

2. Materials and Methods

2.1. *GDC10 synthesis by co-precipitation method*

GDC10 powders were synthesized through co-precipitation method as like previously performed by Ramasamy *et al.* [22]. Slight modification on that method was implemented with the addition of gadolinium as a dopant. Gd(NO$_3$)$_3$.6H$_2$O as precursor was commercially purchased from Sigma Aldrich, while Ce(OH)$_4$ was obtained from Center of Science and Accelerator Technology, BATAN, Indonesia. Monazite sand was leached in strong sulfuric acid for 1 hour. It was added with water for quenching and then it was filtered. Ammonia was added into the filtrate so that mixed precipitant of REOH (rare-earth hydroxide) and REP$_2$O$_7$ (rare earth pyrophosphate) were formed. REP$_2$O$_7$ was mixed with NaOH at 140°C for 1 hour to form REOH. It was filtered and washed until neutral pH was obtained. After that, it was dried in oven at 110°C. REOH concentration was dissolved in nitric acid and heated at 100°C. After oxidation, ammonia was added until pH of 1 where Ce compound including Ce(OH)$_4$ was precipitated. Ce(OH)$_4$ precipitant was calcined at 900°C for 4 hours.

For the synthesis of GDC10 powders, first, a stoichiometric amount of Ce(OH)$_4$ was diluted in 25v/v% of distilled water and then added with 0.1887v/v% of nitric acid (HNO$_3$ 65%) and to form cerium nitrate hexahydrate (Ce(NO$_3$)$_3$.6H$_2$O).
Gadolinium nitrate hexahydrate [Gd(NO$_3$)$_3$.6H$_2$O] was separately dissolved in 25v/v% of distilled water. Both of precursor solution that completely dissolved in distilled water were mixed and stirred for around 5 minutes. After that, PEG 400 as the surfactant was slowly added with various concentration of 0, 1, 2, 3v/v%. The solution was stirred for 10 minutes until a homogenenous solution was obtained.

Then, NH$_4$OH 32% was added drop by drop to the solution to control pH. Prior to the addition, NH$_4$OH was dissolved in 25v/v% distilled water. After addition of NH$_4$OH was completely performed, solution was stirred for 2 hours at room temperature to mix and then precipitate it. The solution was filtered and washed with distilled water and acetone subsequently. Distilled water was used to remove absorbed salt ion on resultant precipitant, while acetone was useful for eliminating absorbed water. The precipitant was dried at a temperature of 120°C for 24 hours to remove water content. It was subsequently powdered in an agate mortar and then the powders produced were calcined at 600°C for 24 hours. During calcination, the surfactant was removed and the yellow colored powder was obtained.

2.2. GD10 powders characterization

The GDC10 powders obtained from synthesis were characterized by means of X-Ray Diffractometer (XRD) (PANalytical EMPYREAN) with Cu-K$_\alpha$ operating at 40 kV and 30 mA. Step size used was 0.0260° 20 in the range of 10-90° at scan step time of 22.44 s with continuous mode and 0.5° of slit size. Particle size was revealed through Particle Size Analyzer (PSA) (NanoPlus HD) based on dynamic light scattering (DLS). Before measurement, the sample was performed sonication until completely dissolved. Deionized water was used as medium and analysis was carried out for 3 (three) times of repetition. The morphology of GDC10 powders was observed by Scanning Electron Microscope (SEM) (JEOL JSM-6510LA) with energy dispersive spectroscopy (EDS) attachment. The SEM observation didn’t perform for all of the samples but only for without PEG 400 and with 3v/v% addition of PEG 400. The Fourier transform infrared (FTIR) spectrum was measured using FTIR spectrometer (Thermo Scientific Nicolet iS50). FTIR measurement was done using at room temperature ranging from wavenumber of 4000 to 500 cm$^{-1}$. The spectrum was collected at a resolution of 0.964 cm$^{-1}$.

3. Materials and Methods

Figure 1 shows XRD pattern data of GDC10 prepared by co-precipitation method with different addition of PEG concentration starting of 0, 1, 2 and 3v/v%. XRD analysis was performed after GDC10 powders were calcined at 600°C for 2 hours. Several peaks were found for all of the samples regarding with addition of PEG 400 as the surfactant. The diffraction peaks were indexed to (111), (200), (220), (311), (222), (400), (331), (420) and (422) crystal plane with (111) as a dominant peak. All of the peaks correspond to the fluorite structure of CeO$_2$ which demonstrated a single phase. This is in good agreement with the powder database from ICSD-98-002-8795. It was also observed no other diffraction peaks beside CeO$_2$ demonstrating high purity of GDC10 powders were obtained from synthesis. XRD crystalline peak corresponding to Gd$_2$O$_3$ wasn’t found for all of the samples which indicated well mixing of Ce$^{3+}$ and Gd$^{3+}$ cations in the precursor [23].
The peak intensity for XRD pattern shows changes, where the intensity of (111) peak for 2v/v% of 400 is higher than other concentration indicating crystallinity is enhanced. This peak becomes the highest among other concentration. It could also indicate the change of grain size possibly happened [24]. In addition, shifting of the peak is also slightly observed to higher angle as shown by Figure 2, which means crystal quality is improved. This might be due to the strain effect. The (111) peak that noted as preferred orientation is seen broadening as a result of the addition of PEG 400 concentration. The peak broadening is attributed to changes in crystallite size as well as chemical composition. Similar results are also reported by other researchers where they discovered if crystallinity enhancement of powders could be obtained by the addition of surfactant [25], [26].

From XRD analysis, the crystallite size that denoted by D is calculated using Scherrer’s formula as follows [22]:

$$D = \frac{0.9 \lambda}{\beta \cos \theta}$$  \hspace{1cm} (1)

Where $\lambda$ is X-ray wavelength ($\lambda = 0.15406$ nm), $\beta$ is full width at half maximum (FWHM) and $\theta$ expresses Bragg’s diffraction angle. The estimated crystallite size was calculated for all of the peaks found and then taken its average values, as shown in Table 1 and Figure 3.

**Table 1.** The average crystallite size of GDC10 powders with different PEG 400 concentration

| PEG Conc. | $2\theta$ (deg.) | Planes | FWHM | D (nm) | D Average (nm) |
|-----------|------------------|--------|------|--------|----------------|
| 0v/v%     | 28.39            | (111)  | 0.902| 9.49   | 11.37          |
|           | 32.90            | (200)  | 0.880| 9.83   |
|           | 47.09            | (220)  | 0.610| 14.83  |
|           | 55.84            | (311)  | 0.500| 18.78  |
|           | 58.94            | (222)  | 0.950| 10.03  |
|           | 69.26            | (400)  | 1.080| 9.34   |
|           | 76.54            | (331)  | 1.220| 8.66   |
|           | 78.90            | (420)  | 1.250| 8.60   |
|           | 88.00            | (422)  | 0.900| 12.82  |
The average crystallite size is about 11.37, 7.27, 6.75 and 7.02 nm for PEG 400 concentration of 0, 1, 2 and 3 v/v%, respectively. With the addition of 1 v/v% of PEG 400 surfactant, the crystallite size clearly decreases from 11.37 nm to 7.27 nm. It further decreases with the addition of 2 v/v% PEG became 6.75 nm and noted as the lowest average crystallite size obtained in this work. After 3 v/v% of PEG 400 was added, it slightly increased to be 7.02 nm. It is noted that the addition of a small amount of PEG 400 surfactant decreases the crystallite size of powders. From these results, it can be said the optimum addition of PEG 400 as surfactant on the co-precipitation method for GDC10 synthesis is around 2 v/v%.

| Concentration | 1v/v%       | 2v/v%       | 3v/v%       |
|----------------|-------------|-------------|-------------|
| d-spacing      | hkl         | α           | ε           | δ           |
|----------------|-------------|-------------|-------------|-------------|
| 1v/v%          |             |             |             |             |
| 28.41          | (111)       | 1.08        | 7.92        | 7.27        |
| 32.86          | (200)       | 1.14        | 7.59        |             |
| 47.27          | (220)       | 1.30        | 6.96        |             |
| 55.98          | (311)       | 1.11        | 8.46        |             |
| 58.91          | (222)       | 1.35        | 7.06        |             |
| 69.21          | (400)       | 1.30        | 7.75        |             |
| 76.50          | (331)       | 1.54        | 6.86        |             |
| 78.90          | (420)       | 1.64        | 6.55        |             |
| 88.26          | (422)       | 1.84        | 6.28        |             |

\[
\alpha = d_{hkl}\sqrt{h^2+k^2+l^2}
\]

Where \(d\) is d-spacing and \(hkl\) is the Miller indices. Meanwhile lattice strain (\(\varepsilon\)) and dislocation density are obtained with formulas below [22]:

\[
\varepsilon = \frac{\beta \cos \theta}{4}
\]

\[
\delta = \frac{1}{D^2}
\]
The lattice constant, lattice strain and dislocation density are tabulated on Table 2 and shown in Figure 3.

**Tabel 2.** The lattice constant and lattice strain of GDC10 powders with different PEG 400 concentration

| PEG 400 Conc. [v/v%] | Lattice constant (a) [nm] | Micro strain ($\varepsilon \times 10^{16}$) | Dislocation density ($\delta \times 10^{16}$ lines/m$^2$) |
|----------------------|--------------------------|--------------------------------------|-------------------------------------|
| 0                    | 1.000                    | 1.9460                               | 0.9247                              |
| 1                    | 1.043                    | 2.8760                               | 2.2159                              |
| 2                    | 0.976                    | 3.0804                               | 2.2131                              |
| 3                    | 1.512                    | 2.9862                               | 2.0940                              |

**Figure 3.** Schematic to measurement percentage of surface dose (PSD)

The average lattice constant for PEG 400 concentration of 0, 1, 2, and 3v/v% is 0.5435, 0.5431, 0.5418 and 0.5427 nm, respectively. The pure CeO$_2$ is recorded to have theoretical lattice parameter of about 0.5411 nm [24]. However, lattice constant value found in this work is higher than pure CeO$_2$ because of the presence of Gd$^{3+}$ that replacing Ce$^{4+}$ lattice in the fluorite structure of CeO$_2$ [12]. With the addition of PEG 400 surfactant, the lattice constant is observed to decrease and reach the lowest value at 2v/v% of PEG 400. After that, it slightly increases. On the other hand, microstrain is noted to gradually increase as PEG 400 concentration an increase. Similarly, dislocation density also tends to increase with surfactant addition.

The particle size distributions of GDC10 powders regardless with the addition of PEG 400 as a surfactant at different concentration are shown by Figure 4. Meanwhile, Table 3 shows the average diameter and polydispersity index (PDI) number. As seen from Figure 4, the addition of PEG 400 obviously affects particle size distribution as well as particle size. Without the addition of PEG 400, multiple peaks were initially observed on the particle size distribution graph, as shown by Figure 4(a). After the addition of PEG 400 as the surfactant, it became only a single peak appear for 1v/v% and 2v/v% concentration where PDI number was also noted to decrease. The presence of a single definite peak suggests the monodispersed distribution of particle [27]. PDI number was 1.154 for the sample without PEG 400 addition, and it decreased to 0.716 after addition of 1v/v% of PEG 400. But then, it slightly increased as the value of 0.823 and 0.918 for 2v/v% and 3v/v% of PEG 400, respectively. However, these numbers are still much lower compared to sample with no addition of PEG 400. PDI is used to describe the non-uniformity degree of size distribution [27]. The lowering of PDI number after addition of PEG 400 could be related with the homogeneity of particle where it became more uniform.
in size. When Ce(NO$_3$)$_3$.6H$_2$O and Gd(NO$_3$)$_3$.6H$_2$O were dissolved in water, microemulsion was formed. PEG surfactant molecules played a role in creating the interfacial layer which separates the aqueous layer and the inorganic phases. It also reduced the interfacial tension between the microemulsion and the excess phase and act as a steric barrier layer for preventing the coalescence of droplets [28]. This would allow particle size to be controlled just by controlling the droplet size where smaller droplets would produce the smaller size of the particle.

With the addition of PEG 400 surfactant at a certain concentration, the average diameter of GDC powders was reduced. All samples regardless of surfactant addition demonstrate lower particle size diameter compared to sample without surfactant addition. Yao et al. mentioned that indentation-like amphiphilic molecular of PEG 400 could provide a steric hindrance effect with hydrophobic ends adsorbed onto particle surface [4]. As a result, the neighboring particle is prevented from getting close to each other. It means re-agglomerated is also prevented so that particle size becomes smaller. However, as seen in Table 3, particle size decrease until reach optimum value and then increase again. Here, the smallest particle size was about 1.84 µm for 1v/v% of PEG 400 concentration. This result matched well with crystallite size calculation from XRD result even though the smallest crystallite size was given by a sample with 2v/v% addition of PEG 400. It was acceptable since the term of crystallite size is considered for individual crystalline calculation, and particle is constructed from several different crystallites.

Figure 4. The particle size distribution of GDC10 powder with different concentration of PEG 400 addition (a) 0v/v% (b) 1v/v% (c) 2v/v% (d) 3v/v%

Yao et al. reported that de-agglomeration treatment to the precursor by both ultrasonic and surfactant was effective to improve particle size distribution of doped-ceria nanoparticle synthesized by co-precipitation route [4]. PEG 400 was also used as a surfactant, however, with higher the concentration of 15% as optimal dosage. In this case, a small amount of PEG 400 was used and it demonstrated enough for providing particle size reduction effects.
It was also reported by Ketzial et al. the effect of surfactant on the particle size distribution of CeO$_2$ by chemical precipitation [3]. By the addition of 1 v/v% PEG 400, the particle size of powder was in the range 0.510 – 39.23 µm with 53% of a particle smaller than 13 µm and average diameter of 12.8 µm. Furthermore, particle size in the range of 0.339-51.47 µm was observed for 2 v/v% of PEG 400 addition with 60% of particle smaller than 13 µm and average diameter of 9.9 µm. Our results exhibited smaller value where the average diameter of 1 v/v% of PEG 400 was 1.47 µm and it was 1.84 µm for 2 v/v%.

The effect of PEG as the surfactant was also studied by Cholan et al. on cerium doped nanoparticle ZnS prepared by precipitation method [18]. They suggested 2.5% of PEG as optimum concentration to control particle size. Introduction of PEG into during synthesis process will not only stabilize small particle but also restrict agglomeration. It was observed in this work that at 3 v/v% of PEG 400, particle size somewhat increased suggesting that there was a certain amount of surfactant addition to give optimum effect on particle size reduction.

Tabel 3. The average diameter and polydispersity index (PDI) of GDC10 powders with different PEG 400 concentration

| PEG 400 concentration (v/v%) | Average Diameter (nm) | Polydispersity index (PDI) |
|-----------------------------|----------------------|--------------------------|
| 0                           | 2410                 | 1.154                    |
| 1                           | 1472                 | 0.716                    |
| 2                           | 1842                 | 0.823                    |
| 3                           | 2015                 | 0.918                    |

Surfactant concentration affects the size of particle related to Critical Micellar Concentration (CMC) value. If surfactant concentration is above CMC, particle size will be smaller than below CMC. Particle size has to be increased with higher surfactant concentration due to the presence of more micelles for particle formation [18]. However, if the concentration of surfactant is too high, it might destabilize micelle and then lead particle to grow bigger. Micelle is a colloidal dispersion that spontaneously formed at certain surfactant concentration.

Figure 5 shows SEM images of GDC10 powders without and with the addition of PEG 400 surfactant at 500X magnification. It definitely indicates different morphology of particle and shape where without surfactant, particles are likely to agglomerate. It is also observed that the addition of PEG 400 surfactant resulted in more uniform particle size and distribution compared with no surfactant was added, as shown in Figure 5(b). This confirms the results from particle size analysis and also crystallite calculation from XRD data. It should be noted that SEM images show aggregated particles which made up of crystallite as a primary particle with an average size of 11.37 nm (without PEG 400) and 7.02 nm (with 3 v/v% of PEG 400 as a surfactant).
Figure 5. SEM images of GDC10 powders synthesized by co-precipitation method at 500X magnification (a) without addition PEG 400 (b) with the addition of 3v/v% of PEG 400

Figure 6. SEM images of GDC10 powders synthesized by co-precipitation method at 5000X magnification (a) without the addition PEG 400 (b) with the addition of 3v/v% of PEG 400

The use of surfactants has been many reported having a strong effect on morphology of synthesized metal oxide powders and nanoparticles. Erten-Ela et al. reported the presence of PEG 400 led ZnO to form rod-like structure and without PEG 400 flower-like structure was revealed [29]. Cholan et al. also observed flower-like nanostructure of cerium doped ZnS without PEG, while spherical nanoparticles were found mixed with some rod-like structure [18].

At a higher magnification of SEM images, shape and structure of particle are clearly observed of difference as shown by Figure 6. The irregular shape of the particle was revealed for the sample without PEG 400, whereas with the addition of PEG 400 as a surfactant resulted in sub-angular particle shape resembling rock like grain. The change of particle shape can be related to surfactant role that it acts as a capping agent and a strong influence on the formed particle [15]. By the addition of PEG 400, the growth rate of various crystallographic is controlled and orientation in crystal formation is created. As a result, more uniform shape and size of particles could be obtained.

Elemental analysis of GDC10 powders was also performed by using EDS and the result is shown in Table 4 and Figure 7. It was detected only oxygen (O), cerium (Ce) and gadolinium (Gd) element suggesting that synthesized product was gadolinium doped cerium (GDC10). As expected, no other elements were detected indicating high purity of GDC10 powders.
4. Results and Discussion

4.1. Relative Electron Density (RED)

In this results, the relative electron density (RED) from bolus made of silicone rubber (SR) is 1.176, for the RED value of some tissue can be seen in Table 1 below.

| Tissue/Material   | Relative Electron Density | Reference |
|------------------|---------------------------|-----------|
| Water            | 1.000                     | [16]      |
| Muscle           | 1.043                     | [16]      |
| Breast           | 0.976                     | [17]      |
| Dense Bone       | 1.512                     | [17]      |

Based on Table 1, the RED produced by the bolus is above the RED value of water and soft tissue such as muscle and breast. This is because of different material compositions between soft tissues and boluses. Soft tissue consists of hydrogen (H), carbon (C), oxygen (O), nitrogen (N), phosphor (P), sulphur (S), chlorine (Cl), and potassium (K) [18,19]. On the other hand, bolus with SR material consists of inorganic polymer bond composed by polysiloxan (Si-O) bonds and methyl (CH$_3$) bonds [20]. When compared with a solid tissue such as dense bone material, the electron density of bolus is below the value of electron density dense bone. If viewed from the composing dense bone material, the dense bone consists of mineral phase, hydroxyapatite (Ca$_{10}$(PO$_4$)$_6$(OH)$_2$), an organic phase, and water [21]. So it has different material density both with bolus material and soft tissue. When compared with alternative materials such as ethyl methacrylate [15] and durian seed [17], RED value is much smaller than SR. This is because the two materials have a material composition similar with water. However, the results of this study support the results of research conducted by Li et al [14] who have used SR as an ingredient in prostate group organs synthesis. Thus, SR can be an alternative material that is equivalent to a tissue.
4.2. Relative Electron Density (RED)
For PSD results on solid phantom surface can be seen in Figure 4. Based on Figure 4, the PSD value without using bolus on 8 MeV and 10 MeV are 89.18% and 90.55%, respectively. At the time of using bolus, the PSD value for 8 MeV and 10 MeV has increased to 102.32% and 101.32%, respectively. These results indicate the use of bolus with SR material can provide an increase in PSD value with a percentage above 100%, when using radiation energy greater than 8 MeV, the value of PSD was decreased. Supposedly, a greater radiation energy can increase the value of PSD [1]. This is because the amount of radiation energy can provide an increase in kinetic energy of electron particles so that electrons can penetrate deeper solid water phantom. When compared with elasto gel, the resulting PSD value is 98.2% at 9 MeV with a thickness of 1.25 cm [2]. This result shows that SR with a thickness of 1 cm can provide a higher PSD value than using elasto gel. However, based on the aim of used a bolus, bolus with SR material has been succeeded in increasing PSD value on solid water phantom surface. The use of SR can be an alternative material that can be used as a bolus. For the future, a further research is needed to investigate of varying composition between SR and hardener to measure an RED and PSD for each composition variation.

![Figure 7. Percentage of surface dose (PSD) graph](image)

5. Conclusion
Based on the results of this research, bolus with silicone rubber material has electron density value of 1.176. These results show the value of RED bolus between soft tissue and solid tissue. The PSD value at 8 MeV and 10 MeV are 102.32% and 101.32%, respectively. These results indicate that the silicone rubber material can be used as an alternative bolus material because it corresponds to the bolus function in radiotherapy.

6. Conclusion
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