International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 49 No. 1 February 2025, pp. 219-224

Development of PVA/Ag and PVA/NBT/Ag-Based Dosimeter Films with Optimized Concentration for Radiation Detection

[1]Fajar Maulana Sultan, [1]Pandji Triadyaksa, [2]Ilham Alkian, and [1,2]Heri Sutanto*

[1]Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Semarang 50275, Indonesia

[2]Smart Materials Research Center (SMARC), Diponegoro University, Semarang, Indonesia

*Corresponding email: herisutanto@live.undip.ac.id[1,2]

Abstract– This study aims to develop Polyvinyl Alcohol (PVA)-based dosimeter films with the addition of silver (Ag) and Nitroblue Tetrazolium (NBT) to enhance radiation detection. Two types of films were tested: PVA/Ag (0.75%) and PVA/NBT/Ag (0.75%). The film fabrication process involved dissolution, drying at room temperature, and cutting for testing with X-rays at varying voltages. Characterization was performed using UV-Vis spectra analysis and optical density measurements. The results showed that the PVA/NBT/Ag film exhibited higher absorbance compared to PVA/Ag, both before and after radiation exposure. A significant increase in optical density demonstrated a higher sensitivity for PVA/NBT/Ag, with an R^2 value of 0.9571, indicating better linearity compared to PVA/Ag (R^2 = 0.8821). Based on these findings, the PVA/NBT/Ag film is more effective in detecting radiation doses, making it a promising candidate for X-ray dosimetry.

Keywords – Polyvinyl Alcohol; Nitroblue Tetrazolium; Silver; Dosimeter Film; Concentration.

I. INTRODUCTION

Radiation is widely used in various fields, such as medicine, industry, research, and nuclear energy. However, radiation exposure poses harmful effects on human health. Therefore, it is essential to develop radiation detection devices, such as film dosimeters [1]. Film dosimeters offer advantages in enhancing radiation detection devices, such as ease of use, quick response to radiation doses, and the ability to provide information on the dose received. These advantages make them highly effective for use in irradiation facilities [2]. In recent decades, Polyvinyl Alcohol (PVA) has become one of the primary materials commonly used in film dosimeter fabrication due to its stable chemical and physical properties, non-toxicity, and responsiveness to radiation [3].

The addition of silver to PVA has the potential for dosimetry applications as it can enhance the sensitivity of the film dosimeter [4]. Additionally, Nitroblue Tetrazolium (NBT), which functions as a reactive dye, can extend the response range of the film dosimeter to radiation exposure and exhibits excellent radiosensitivity properties [5]. Therefore, this study aims to develop the efficiency of PVA/Ag-based dosimeter films with a concentration of 0.75% and PVA/NBT/Ag-based dosimeter films with a concentration of 0.75%. Moreover, the study also aims to identify the physical and chemical properties, as well as the dosimeter responses of both films, including change in optical properties and their ability to detect radiation doses accurately. Furthermore, this research explores the impact of the addition of silver and NBT compounds on the performance of the dosimeter film in terms of radiation dose detection. Thus, both films are expected to contribute to the development of efficient and sensitive dosimeters.

II. EXPERIMENTAL PROCEDURE

2.1. Materials

The materials used in this study included polyvinyl alcohol (PVA), Nitroblue Tetrazolium Chloride (NBT-Cl, Himedia), Silver (Ag, Merck, p.a.), distilled water, and ethanol (96% purity).

2.2. Film preparation

The PVA/Ag and PVA/NBT/Ag films were prepared with concentration, as shown in **Figure 1**. The 0.75% PVA/Ag film was made by dissolving 1,240.6 mg of PVA in 20 mL of distilled water, heating it to 80°C, and stirring for 40 minutes. A total of 9.4 mg of Ag powder (0.75%) was dissolved in 5 mL of distilled water and stirred at 20°C for 15 minutes. The two solutions were then combined and stirred again at 80°C for 40 minutes until homogeneous, resulting in a PVA/Ag mixture. The stirring process was performed using a magnetic stirrer.

The PVA/NBT/Ag film was prepared by dissolving 1,231.6 mg of PVA in 20 mL of distilled water, heating it to 80°C, and stirring for 40 minutes. 9 mg of NBT were dissolved in 2 mL of 96% ethanol at 20°C for 5 minutes. A total of 9.4 mg of Ag powder (0.75%) was dissolved in 5 mL distilled water and stirred at 20°C for 15 minutes. The stirring process was carried out using a magnetic stirrer. The PVA/Ag and PVA/NBT/Ag mixtures were poured into petri dishes and dried at room temperature for 6 days until a thin film was formed. Once dried, the films were cut into 1.5 x 1.5 cm^2 pieces and stored in a light-protected area.

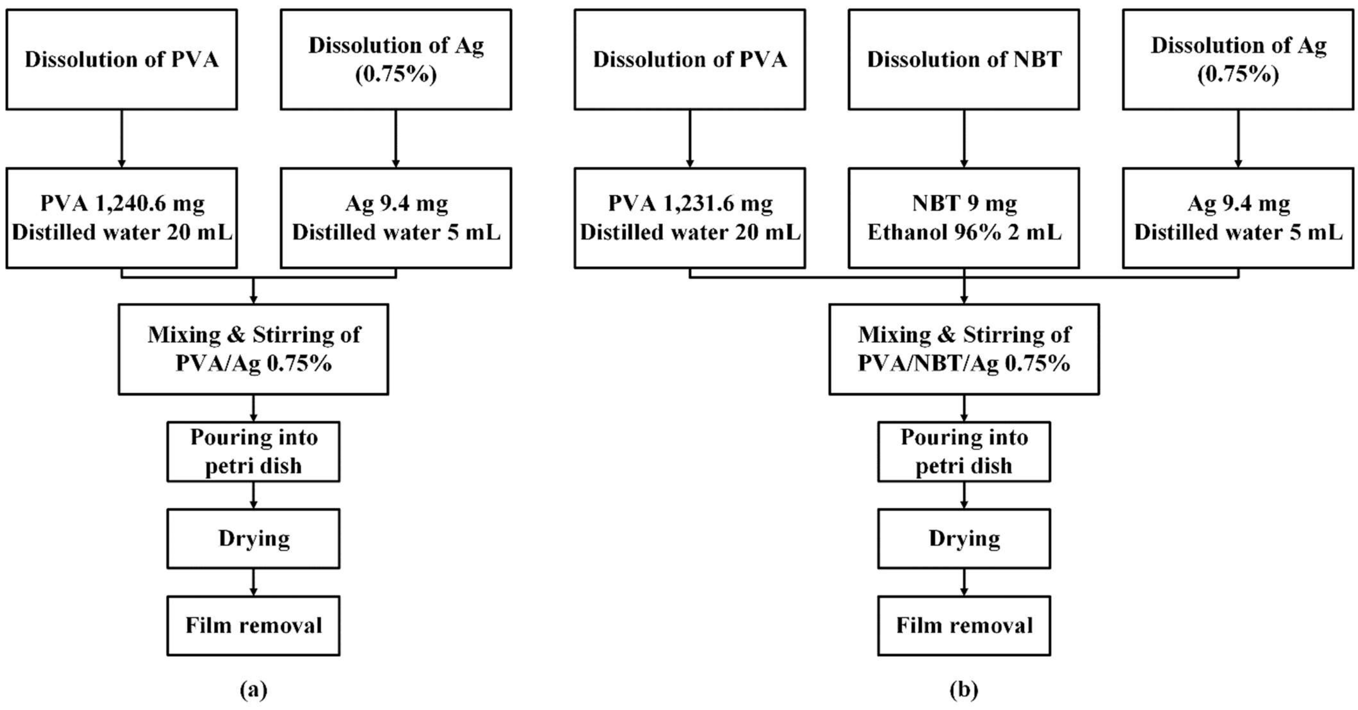


Fig. 1. The synthesis process of the dosimeter films: (a) PVA/Ag, and (b) PVA/NBT/Ag

2.3. X-ray irradiation

The PVA/Ag and PVA/NBT/Ag films, both with a concentration of 0.75%, were each cut into six 1.5 x 1.5 cm^2 pieces. These samples were then irradiated using X-rays at voltages of 60 kVp, 70 kVp, and 80 kVp, with two exposure variations: before and after exposures. The irradiation parameters included the tube current-time parameter of 63 mAs, a source-to-film distance of 50 cm, and a collimation area of 10 x 10 cm^2. The experimental setup is shown in **Figure 2**.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 49 No. 1 February 2025, pp. 219-224

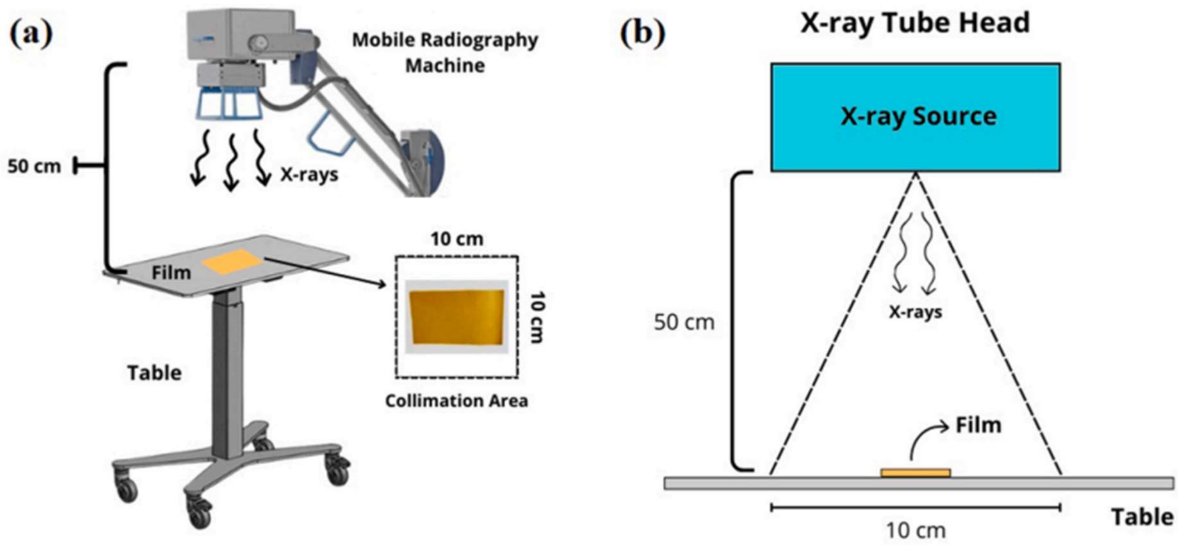


Fig. 2. (a) Experimental setup and (b) Geometric scheme of the X-ray beam [6]

2.4. Film characterizations

The PVA/Ag and PVA/NBT/Ag films with a 0.75% concentration were characterized by comparing the changes in the films caused by X-ray irradiation, specifically between the films before and after exposure. Optical analysis was based on UV-Vis absorption measurements and optical density. The UV-Vis spectra were obtained using a spectrophotometer in the wavelength range of 200 to 800 nm. Optical density measurements were performed using a radiographic film densitometer. A densitometer is an instrument used to measure the darkness level on a film. It functions to capture the amount of light passing through the film after being emitted from a light source. Before taking measurements, the densitometers need to be calibrated by measuring the light intensity from the source [7]. Optical density was measured to analyze the changes in optical density and compare the values between the films before and after exposure. The measurement results were then mapped to assess the sensitivity of the PVA/Ag and PVA/NBT/Ag films to X-rays.

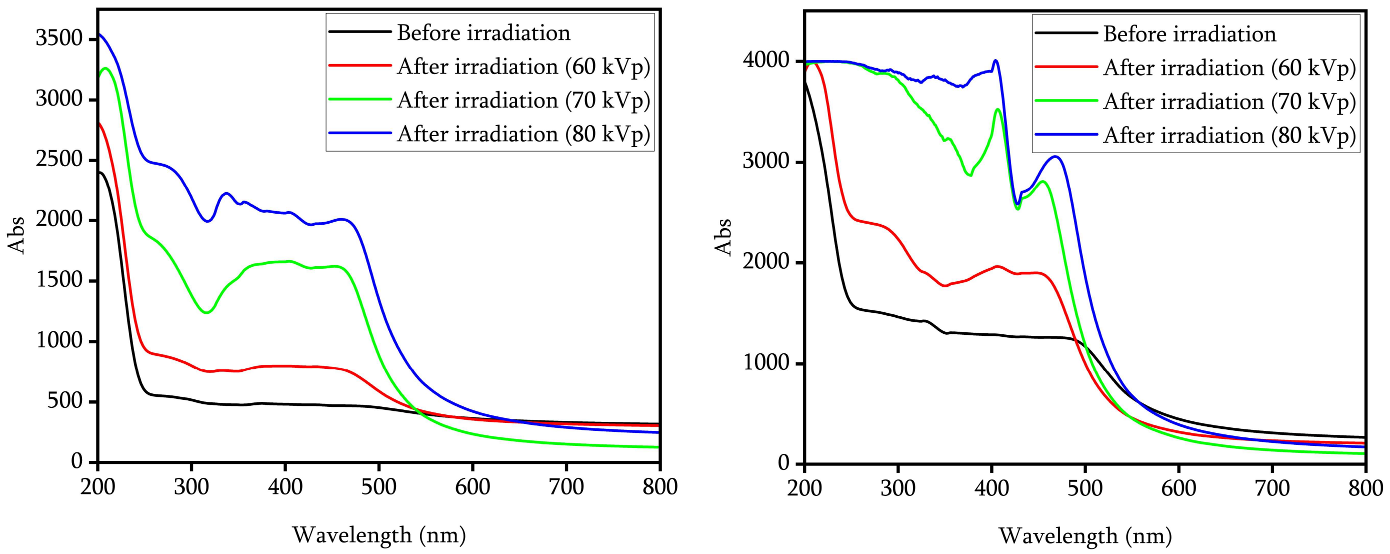
III. RESULT AND DISCUSSION

3.1. UV-Vis absorbance

The analysis of the absorption peak (λmax) in the films was used to evaluate change in the optical structure before and after a specific treatment. The PVA/Ag and PVA/NBT/Ag film samples were tested using UV-Vis, with the results of before and after exposure absorbance, wavelength, and absorption peak shown in **Figure 3**. The UV-Vis absorption spectra compare the PVA/Ag 0.75% and PVA/NBT/Ag 0.75% films. Before exposure, the PVA/NBT/Ag 0.75% film showed higher absorbance than the PVA/Ag 0.75% film. After exposure, both films showed an increase in absorbance, with the PVA/NBT/Ag 0.75% film experiencing a greater increase compared to the PVA/Ag 0.75% film.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 49 No. 1 February 2025, pp. 219-224



(a) **(b)**

Fig. 3. UV-Vis absorption spectra of (a) PVA/Ag 0.75%, (b) PVA/NBT/Ag 0.75%

The absorption peak in the PVA/Ag 0.75% film was observed in the range of 400-450 nm, indicating plasmon resonance in the silver nanoparticles. Plasmon resonance in silver nanoparticles occurs when free electrons on the particle surface oscillate collectively in response to the electric field of incoming light waves. This phenomenon enhances the efficiency of light absorption and scattering, making Ag highly potential for applications in biosensors and the biomedical field [8]. Additionally, it can be utilized to improve sensor sensitivity in detecting specific substances [9]. This peak increased after exposure, signalling changes in the electronic structure due to interactions with X-rays.

Meanwhile, in the PVA/NBT/Ag 0.75%, the absorption peaks appeared in two wavelength ranges: 250-350 nm (π to π^* and n to π^* transitions from the nitro group and tetrazolium ring in NBT) and 400-450 nm (plasmon resonance in Ag). The π to π^* transition occurs when an electron in a π bonding orbital absorbs light energy and excites to a π^* anti-bonding orbital and n to π^* transitions. The n to π^* transition occurs when an electron from a non-bonding (n) orbital absorbs energy and moves to a π^* anti-bonding orbital [10]. The nitro group in NBT is part of the molecular structure that acts as an electron acceptor in redox processes. Meanwhile, the tetrazolium ring is a cyclic structure containing four nitrogen atoms, making it electrophilic and highly reactive toward reactive oxygen species [11]. After exposure, the increase in absorbance in the 250-350 nm range was more significant in the PVA/NBT/Ag 0.75% film, indicating that NBT underwent a reduction reaction due to interaction with X-rays

3.2. Optical density

The changes in optical density were analyzed by comparing the optical density values between the unexposed and exposed films. These values were then plotted and subjected to linear regression to assess their linearity (R^2) to compare the quality and sensitivity of the films as a dosimeter device. The optical density results are shown in **Figure 4**. Sensitivity can be measured based on the optical density variation with exposure voltage, where both types of films show an increase in optical density as the voltage increases. The PVA/NBT/Ag 0.75% film has a higher initial optical density and a more consistent increase compared to the PVA/Ag 0.75% film, indicating that the former is more sensitive to changes in radiation dose.

International Journal of Progressive Sciences and Technologies (IJPSAT)
ISSN: 2509-0119.

https://ijpsat.org/
Vol. 49 No. 1 February 2025, pp. 219-224

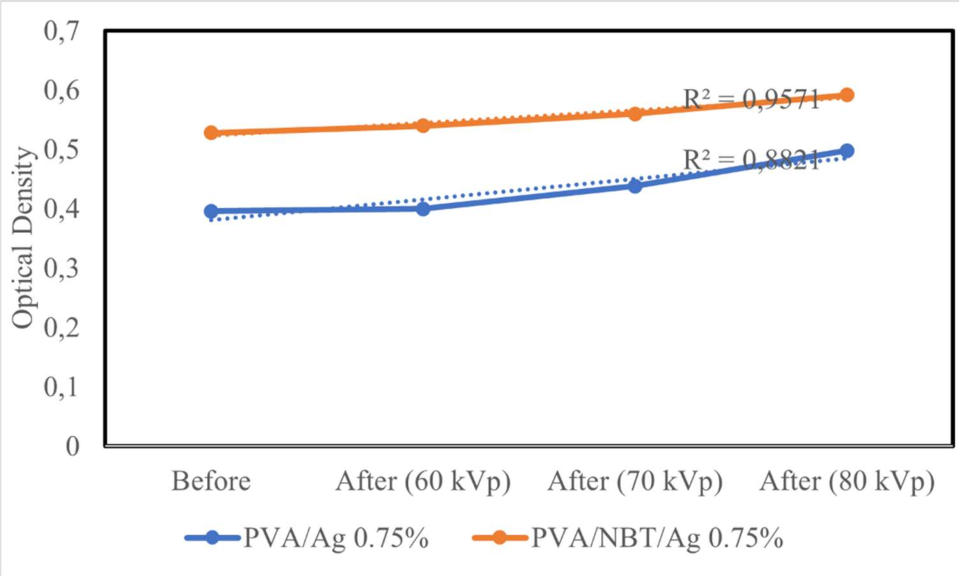


Fig. 4. Optical Density

Linearity is evaluated based on the R^2 value displayed in **Figure 4.** R^2 is considered good if it is greater than 0.5, as R^2 ranges from 0 to 1, with values closer to 1 indicating a more accurate model in explaining the relationship between the two variables [12]. The PVA/NBT/Ag 0.75% film has an R^2 of 0.9571, while the PVA/Ag 0.75% film has an R^2 of 0.8821. The closer the R^2 value is to 1, the more consistent and linear the relationship between optical density and exposure voltage is in the PVA/NBT/Ag 0.75% film compared to the PVA/Ag 0.75%

IV. CONCLUSIONS

The PVA/NBT/Ag 0.75% film demonstrates superior performance compared to the PVA/Ag 0.75% film in terms of absorbance, sensitivity, and linearity. Before exposure, the PVA/NBT/Ag 0.75% film exhibits higher absorbance, and after exposure, its absorbance increases more significantly, particularly within the 250-350 nm wavelength range. The absorption peaks of the PVA/NBT/Ag 0.75% film are detected in two wavelength ranges (250-350 nm and 400-450 nm), whereas the PVA/Ag 0.75% film only shows an absorption peak within the 400-450 nm range. The PVA/NBT/Ag 0.75% film also exhibits better sensitivity, with a more stable increase in optical density. Additionally, its linearity is more optimal, as indicated by a higher R^2 value (0.9571), demonstrating a more consistent relationship between optical density and exposure voltage.

ACKNOWLEDGMENT

We sincerely extend our deepest appreciation to all member of the Smart Material Research Center (SMARC) for their exceptional support and collaboration. The dedication, contributions, and assistance from each member have played a crucial role in the success of this research.

REFERENCES

[1] Berces, A., Fekete, A., Gaspar, S., Grof, P., Rettberg, P., Horneck, G., Ronto, G., (1999). Biological UV dosimeters in the assessment of the biological hazard from environmental radiation. *J. Photochem. Photobiol. B: Biol.*, *53–53*, 36–43. https://www.elsevier.nl/locate/jphotobiol.

[2] Yunus, M. Y., Nurlidar, F., Soekirno, S., Fitriana, R., Putri, M. a. E., Rachmanto, A., & Kusuma, A. T. (2024). The effect of methyl yellow concentrations on the optical properties of polyvinyl chloride-methyl yellow film as a radiation dosimeter.

Nuclear Engineering and Technology, *56*(10), 4097–4102. https://doi.org/10.1016/j.net.2024.05.012.

[3] Albejadi, R., Alashrah, S., El-Ghoul, Y., Ullah, Z., & Almatroodi, S. A. (2024). Radiation Dosimetry Performance Appraisal of the optimal concentration of Nitro blue tetrazolium dye in PVA composite film at low X-ray doses. *Heliyon*, *11*(1), e41319. https://doi.org/10.1016/j.heliyon.2024.e41319.

[4] Eldoma, A. M., Al-atta, N. O., Ahmed, K. Y. (2019). Effect of Doping Concentrations on the Sensitivity of PVA/AgNO3 Films to low x-ray doses. *International Journal of Advanced Research in Science, Engineering and Technology*, *6*(3), 8460. https://www.researchgate.net/publication/332565042.

[5] Alashrah, S., El-Ghoul, Y., & Omer, M. a. A. (2021). Synthesis and characterization of a new nanocomposite film based on polyvinyl alcohol polymer and Nitro Blue tetrazolium dye as a low radiation dosimeter in medical diagnostics application. *Polymers*, *13*(11), 1815. https://doi.org/10.3390/polym13111815.

[6] Sutanto, H., Lo, N. K., Alkian, I., Triadyaksa, P., Marhaendrajaya, I., Jonathan, F., Irviandi, R., & Arifin, Z. (2024). Developing a novel radiosensitive metal ion-loaded PVA/NBT film as medical low-dose X-ray dosimeter. *Radiation Physics and Chemistry*, *224*, 112078. https://doi.org/10.1016/j.radphyschem.2024.112078.

[7] Hidayah, R., Hidayanto, E., Arifin, Z,. (2015). Analysis of the Effect of pH on Changes in Optical Density Values in Films with Different Types of Developers. In *Youngster Physics Journal*: Vol. Vol. 4 (Issue No. 1, pp. 73–78) [Journal-article].

[8] Alzoubi, F. Y., Ahmad, A. A., Aljarrah, I. A., Migdadi, A. B., & Al-Bataineh, Q. M. (2023). Localize surface plasmon resonance of silver nanoparticles using Mie theory. *Journal of Materials Science Materials in Electronics*, *34*(32). https://doi.org/10.1007/s10854-023-11304-x.

[9] Mahmudin, L., Suharyadi, E., Utomo, A. B. S., & Abraha, K. (2015). Optical properties of silver nanoparticles for Surface plasmon resonance (SPR)-Based biosensor applications. *Journal of Modern Physics*, *06*(08), 1071–1076. https://doi.org/10.4236/jmp.2015.68111

[10] Al-Araji, Y. H., Shneine, J. K., Ahmed, A. A., & Department of Chemistry, College of Science, Al-Nahrain University, Baghdad, Iraq. (2015). HEMISTRY OF FORMAZAN. *International Journal of Research in Pharmacy and Chemistry*, *5*(1), 41–76. https://www.ijrpc.com.

[11] Javvaji, P. K., Dhali, A., Francis, J. R., Kolte, A. P., Mech, A., Roy, S. C., Mishra, A., & Bhatta, R. (2020). An efficient NitroBlue tetrazolium staining and Bright-Field microscopy based method for detecting and quantifying intracellular reactive oxygen species in oocytes, cumulus cells and embryos. *Frontiers in Cell and Developmental Biology*, *8*. https://doi.org/10.3389/fcell.2020.00764

[12] Rhamadhani, D. A., Saputri, E. E. D,. (2023). Analysis of Machine Learning Models in Predicting Oil Well Production. In *Journal of Sustainable Energy Development* (Vol. 1, Issue 1, pp. 48–49).