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Engineering Innovation Challenge

2021

Application of Ionising Radiation as an Agricultural Wastewater Treatment Method
Project Code: P-07

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Project Abstract

The treatment of agricultural wastewater is a pressing issue for many, as it contributes to water pollution and scarcity. Several studies have proven the effectiveness of ionising radiation in its treatment. However, few have attempted to use their results to design a treatment system optimised for practical use; and evaluated based on sustainability and cost-effectiveness.

For the two main experiments included, experiment 1 was found in the paper ‘The Degradation of Some Pesticides in Aqueous Solutions by Gamma Radiation’ (D. Solpan), which studied the degradation of commonly used herbicides using ^{60}Co - γ rays. Experiment 2 belongs to ‘Effect of Accelerated Electron Beam on Pesticides Removal of Effluents from Flower Plantations’ (T. Ramírez, M. Armas, M. Uzcátegui), where degradation of herbicides using electron beams was studied.

Experiment 1 used solid phase extraction, organic phase extraction and the EPA 8151 method to analyse chemical intermediates and products. Experiment 2 used a liquid-liquid extraction process and High-Pressure Liquid Chromatography to analyse chemical compositions before and after irradiation.

The findings that γ -rays can penetrate deeper, while e-beams deliver a higher dosage of irradiation, were used to design the prototype. It was also found that herbicides exposed to e-beams reach a degradation asymptote at a 5 kGy dosage at a concentration interval of [50 ppm, 400 ppm], compared to γ -rays at 1.5 kGy and [3 ppm, 25 ppm]. Hence, the prototype uses a combination of the two types of irradiation at the above optimum dosages and concentrations to design a sustainable and cost-effective treatment system.

Project Report

Background and Purpose of Research Area

Agriculture, the practice of cultivating crops and livestock, is the largest global user of water. Agriculture produces large amounts of wastewater as a byproduct. In crop cultivation, chemical herbicides are frequently used to enhance the production rate, leaving toxic residues in the wastewater produced. Direct disposal of the wastewater produced by these activities is unsustainable, as it is a major contributor to water pollution.

Agriculture is also a victim of water scarcity, a serious issue that is being worsened by climate change; it is increasing demand for water and disrupting crop production, which leads to food shortages. Purification of agricultural wastewater can be used to greatly alleviate water scarcity, as agriculture is responsible for 70% of freshwater withdrawals. By treating wastewater, it can be reused for other purposes, or safely released into the environment.

Therefore, there is an urgent need for a method of purifying agricultural wastewater that is sustainable and economically viable. The purpose of this report is to find such a method that also involves ionising radiation.

Research Question: How sustainable and cost-effective is ionising radiation as an agricultural wastewater treatment method? If it performs well in these two criteria, what is the optimum ionising radiation treatment method (i.e. dosage, type and procedures) to treat agricultural wastewater?

Hypothesis: Ionising radiation is a very sustainable and cost-effective agricultural wastewater treatment method. An optimum ionising radiation treatment method will involve a combination of gamma rays and electron beams, of yet undetermined dosage and procedures.

Engineering Goals: To use ionising radiation to alleviate the problems of water scarcity and agricultural wastewater pollution in a sustainable and cost-effective way.

Expected Outcomes: To understand the impacts of untreated agricultural wastewater, the dosage and type of ionising radiation needed to reduce the impacts, and the required procedures.

Experimental Section

Introduction

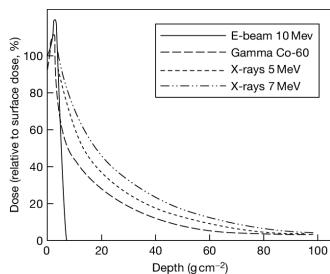
In this section, the effects of the two main types of ionising radiation used to treat wastewater containing commercial pesticides will be investigated in a series of experiments, in order to determine the ratio in which they should be optimally used.

Electron beams (betatrons)

Electron beams are particle accelerators (betatron) that generate a stream of high energy electrons, called beta particles (β). The maximum achievable energy level depends on the size of the betatron's particle accelerator.

Gamma irradiation

Gamma irradiators, unlike betatrons, cannot be turned off as gamma rays (γ) are produced from the decay of radioactive isotopes such as Cobalt-60. Energy released will decrease in time following ^{60}Co 's half-life of 5.3 years.



β -particles can only penetrate up to 5 centimeters of water while γ -rays can penetrate up to 4.2 meters of water. The depth is highly dependent on its energy level, as energy will be lost for each particle ionised.

Fig 1. Dose and penetration profile for ionising radiation

Experimental Procedures

A literature review was conducted. Experiment 1 details the experiment conducted in the paper 'The Degradation of Some Pesticides in Aqueous Solutions by Gamma Radiation' (D. Şolpan). Experiment 2 details the experiment conducted in the paper 'Effect of Accelerated Electron Beam on Pesticides Removal of Effluents from Flower Plantations' (T. Ramírez, M. Armas, M. Uzcátegui). Both papers were part of the research project 'Radiation Treatment of Polluted Water and Wastewater' published by the International Atomic Energy Agency (IAEA).

Experiment 1

In Experiment 1, the degradation of some commonly used herbicides using ^{60}Co - γ rays was studied. The herbicides studied were 4-chloro phenoxyacetic acid (4-CPA) and 2,4-dichlorophenoxyacetic acid (2,4-D).

For the first part of the experiment, the effect of a 0.07 kGy/h dose rate (in air) of radiation on different concentrations of (4-CPA) and (2,4-D) solutions was studied, with the concentrations ranging from 3 to 75 mg/L.

For the second part, 2,4-D sample of 50 ppm was prepared in deionized water. The herbicide sample (200 ml at 50 ppm) was irradiated at 0.07 kGy/h.

Experiment 2

In this experiment, the feasibility of using e-beams to break down commercial pesticides used in flower plantations are studied. The chemical compounds studied were carbofuran ($\text{C}_{12}\text{H}_{15}\text{NO}_3$), diazinon ($\text{C}_{12}\text{H}_{21}\text{N}_2\text{O}_3\text{PS}$), imidacloprid ($\text{C}_9\text{H}_{10}\text{ClN}_5\text{O}_2$) and metiocarb ($\text{C}_{11}\text{H}_{15}\text{NO}_2\text{S}$). These chemicals have a predetermined concentration from 100 ppm to 400 ppm. The sample was then irradiated with β particles with energy of 8.3MeV and power of 2kW.

Risk and Safety

Exposure to ionising radiation can damage DNA and cause health effects such as cancer. Higher levels of ionising radiation results in serious effects such as tissue and organ damage. Thus, precautions, time, distance, and shielding should be considered; the exposure time should be limited, distance from radiation sources maximised and proper shielding (e.g. lead and concrete shields) placed between researchers and the radiation source.

Methods for Data Analysis

Experiment 1

The solid phase extraction method (SPE) was used to extract chemical intermediates and undecomposed herbicides from aqueous media to an organic phase. Organic phase extraction (OPE) was then applied with 2ml of acetone, hexane or dichloro-methane. However, to identify acidic groups, such as undecomposed herbicides, methyl alcohol was used for OPE. The EPA8151 method was used to identify intermediates and methyl esters of undecomposed herbicides. The internal standard method was used to determine the amount of 2,4-DCP as an intermediate.

Experiment 2

High Pressure Liquid Chromatography (HPLC) was used to analyse the chemical composition before and after irradiation. The solution has to first go through a liquid-liquid extraction process and evaporated to dryness. This is to remove new chemicals formed during the irradiation process. 6ml of water was added to assist in HPLC analysis.

Experimental Results

Experiment 1

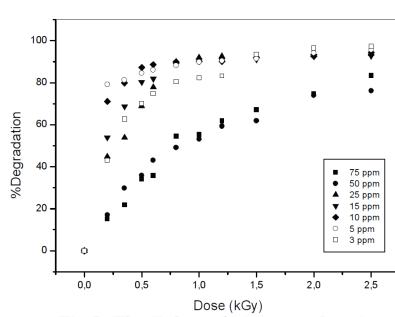


Fig 2. The %degradation as a function of irradiation dose at various concentrations of 4-CPA in air.

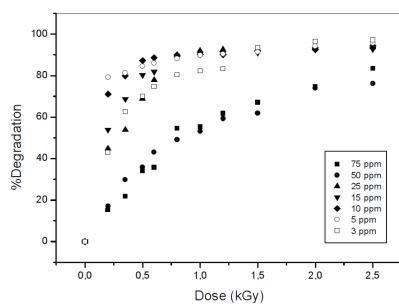


Fig 3. The %degradation as a function of irradiation dose at various concentrations of 2,4-D in air.

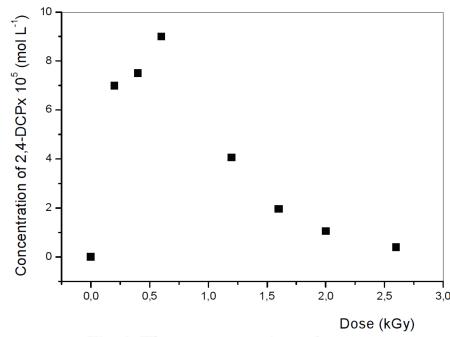


Fig 4. The concentration of degradation product (2,4-DCP) as a function of irradiation dose.

From Fig 2 and 3, the results of the preceding part of the experiment were summarised. For 4-CPA and 2,4-D, the greater the irradiation dose, the higher the percentage of degradation. It was observed that for lower concentrations of herbicide (from 3 to 25 ppm), the degradation percentage was higher and reached a degradation asymptote at a dose of 1.5 kGy; for 50 and 75 ppm concentrations, it decreased greatly. Thus, [3 ppm, 25 ppm] is the optimum concentration interval.

For the second part, from Figure 4, it can be seen that one of the degradation intermediates from the irradiated 2,4-D samples is 2,4-dichlorophenol (2,4-DCP), which is also hazardous. At increasing irradiation doses up to 0.6 kGy, the amount of 2,4-DCP increased. Once this dose was exceeded, the concentration of 2,4-DCP decreased. This shows that the 2,4-DCP was decomposed into less hazardous products. Therefore, the greater the irradiation dose above 0.6 kGy, the greater the amount of toxic substances degraded.

In conclusion, 1.5 kGy is the optimum irradiation dosage for decomposing 2,4-D and 4-CPA in a [3 ppm, 25 ppm] concentration interval.

Experiment 2

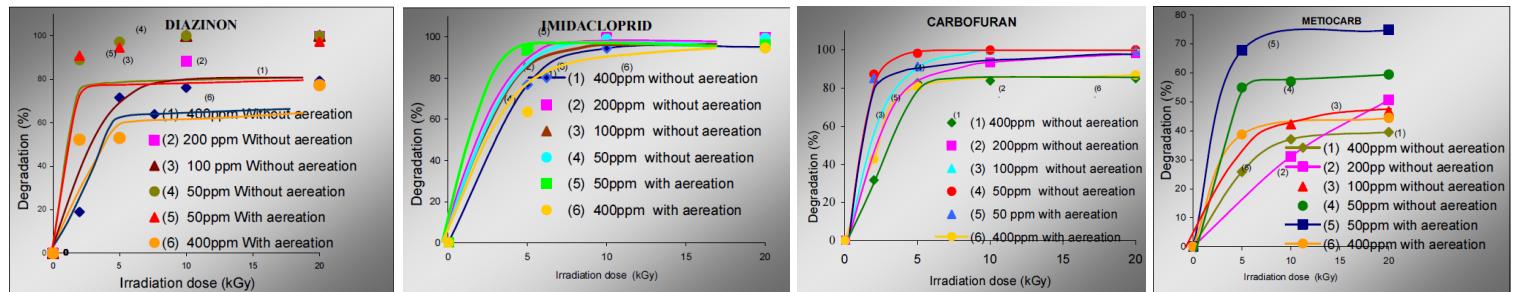


Fig 5(a), (b), (c), (d). Influence of electron beam on degradation percentage of diazinon, imidacloprid, carbofuran and metiocarb pesticides. The irradiation process includes 2 variables, the concentration of the chemicals and the aeration process. The aeration process improved the degradation of carbofuran and metiocarb pesticides by 5 to 10%. It is worth noting that increasing the radiation doses will yield diminishing returns, with most degradation rates leveling off at 5kGy, reaching an asymptote tendency. A lower concentration of chemicals results in an increased rate of degradation and degradation percentage for all chemicals.

The imidacloprid and metiocarb pesticides trend of degradation percentages and irradiation dose are kinetically related. The accelerated degradation zones for doses of 5kGy are within the interval [50 ppm, 400 ppm]. Meanwhile, the retard degradation zones as a function of doses are within the interval [5 kGy, 20 kGy].

Out of all the chemicals irradiated, metiocard is the least radiosensitive and resulted in the lowest degradation rate. All of the irradiated chemicals broke down into simpler, less volatile substances, such as nitrite, nitrate, ammonium, sulfate, sulfide, phosphate, and chloride ions, depending on the initial chemical composition.

In conclusion, from experiment 2, the optimum irradiation dose was found to be 5kGy, without aeration process, as it was found to provide marginal improvements in degradation rates for most chemicals.

Discussion of Literature Review

From the experiments quoted, β particles require a higher dosage of 5 kGy compared to γ -rays of 1.5 kGy to achieve overall degradation asymptote. However, the concentrations differ from experiment 1 to 2. For γ -rays, the optimum degradation rate is reached on the concentration interval [3 ppm, 25 ppm]; for e-beams, it is [50 ppm, 400 ppm]. All of the chemicals explored will degrade after ionising radiation treatment, but some chemicals, such as metiocarb, are less susceptible to degradation through this method.

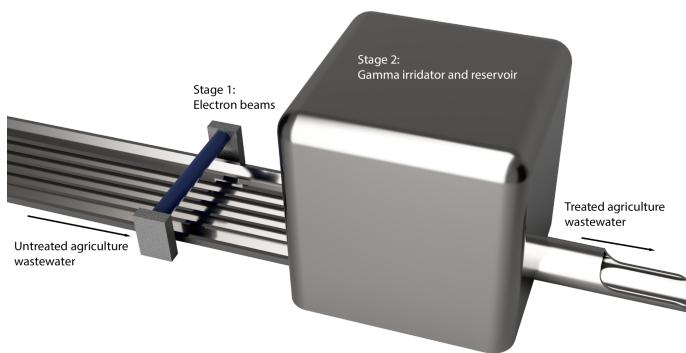
Overall, reviews of numerous studies have demonstrated that ionising radiation is a very sustainable and cost-effective agricultural wastewater treatment method, as alternatives such as chemical baths and electrolysis require the use of sacrificial material. The paper ‘Application of Ionizing Radiation in Wastewater Treatment: An Overview’¹ espouses the sustainability and economic feasibility of both the e-beam and γ irradiation technologies demonstrated in several studies, thus supporting this view. Hence, we can now move on to proposing a solution involving ionising radiation.

¹Abdel Rahman, R.O. & Hung, Y.T. (2019). Application of Ionizing Radiation in Wastewater Treatment: An Overview. <https://www.mdpi.com/2073-4441/12/1/19/pdf>

Proposed Solution

Through our experiment, we observed that e-beams are more efficient at higher concentration levels (400 ppm) than the gamma irradiation process (25 ppm). Hence, we propose a combination of both irradiation methods. Stage 1 will utilize e-beams to irradiate chemicals and lower the chemical concentration for stage 2, where gamma irradiation will further irradiate the chemicals.

Treatment Stage 1: Electron beams



As β particles can only penetrate up to 4 cm of water, the wastewater will be divided in parallel to the electron beams. Betatrons are able to deliver a high dosage of β particles, which means that the irradiation will only take seconds. This will reduce the chemical concentration in wastewater by about 85%. Assuming that the untreated agriculture wastewater has a chemical concentration of 200 ppm, the treated wastewater will have a lowered chemical concentration of 30 ppm.

Fig 6. Proposed Prototype for treatment of agriculture wastewater

Treatment Stage 2: Gamma irradiation

This sequence takes advantage of γ rays' penetrating properties to treat huge volumes of wastewater at once. Furthermore, it also acts as a reservoir, allowing the operator to discharge the treated wastewater only when required. While this process takes a few hours, a larger volume of water can be treated at once and it also allows it to double as storage for treated water. Since gamma irradiation works better at lower chemical concentration [3 ppm, 25 ppm], it further treats the wastewater, reducing the chemical concentration by about 90%. This results in the treated wastewater discharge to have a chemical concentration of 3 ppm.

To summarise, through this treatment solution, we manage to reduce the overall chemical concentration by 98.5%. Stage 1 acts as the untreated wastewater input and stage 2 acts as the output.

Conclusion

Overall, reviews of numerous studies have demonstrated that ionising radiation is a very sustainable and cost-effective agricultural wastewater treatment method. The differing strengths of γ -rays and e-beams were used to develop a prototype that leverages on the advantages of both types of irradiation techniques. The optimum irradiation dosage of 5 kGy on a concentration interval of [50 ppm, 400 ppm] for e-beams, and 1.5 kGy on [3 ppm, 25 ppm] for γ -rays, was also applied.

If the prototype were to be implemented, it would be advantageous to choose several types of commercial herbicide that degrade at a high rate in response to irradiation, as herbicides vary in degradation rate.

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Risk of ionising radiation:

<http://nuclearconnect.org/know-nuclear/science/protecting>,

<https://www.osha.gov/ionizing-radiation/control-prevention>

Summary of different cities' attempts on wastewater irradiation:

<https://link.springer.com/article/10.1007/s13201-018-0645-6>

Ionising radiation in wastewater:

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<https://www.mdpi.com/1660-4601/3/4/360/pdf>

Gamma Irradiation

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Electron Beams

<https://www.iaea.org/newscenter/news/chinas-first-wastewater-plant-using-radiation-opens>

Paper used for experiment 1:

https://www-pub.iaea.org/MTCD/Publications/PDF/te_1598_web.pdf

‘The Degradation of Some Pesticides in Aqueous Solutions by Gamma Radiation’ (D. Şolpan),

https://www.researchgate.net/publication/338048529_Application_of_Ionizing_Radiation_in_Wastewater_Treatment_An_Overview

Paper used for experiment 2:

https://www-pub.iaea.org/MTCD/Publications/PDF/te_1598_web.pdf

‘Effect of Accelerated Electron Beam on Pesticides Removal of Effluents from Flower Plantations’ (T. Ramírez, M. Armas, M. Uzcátegui)

Phase B Report

Engineering Innovation Challenge 2021

Team P-07 (Nanyang Polytechnic)

Introduction

Driving Question

Do areas near water have higher background levels of ionising radiation?

Research Parameters

Definition of water bodies

For this research, water bodies will be defined as areas with at least one hectare of water area.

Precautions

Radiation levels will only be measured during dry weather conditions

Since the driving question aims to find out if there is a connection between areas near water and ionising radiation levels, other water sources may skew the measurements. The NEA rain-area service¹ will be used to gauge the weather conditions before collecting data.

Radiation measurements will only be measured on ground level

Since water bodies are located at ground level, consistency should be ensured by only taking measurements at ground level. This means that measurements cannot be measured from buildings.

Time of recording

Ideally, a network of Rad-X devices would be arranged such that they would measure the radiation levels at the same time of day. However, as the Rad-X devices are limited to 2, the extent to which the time of day affects measurements can be reduced by measuring the radiation levels within a set time period, from 2pm to 4pm.

All the precautions listed above will minimise the impacts of other factors from affecting the measurements.

¹ <https://www.nea.gov.sg/weather/rain-areas>

Research Methodology

Following the above definition, two suitable water bodies were identified. For each respective water body, points of reference were identified as origins. All distances were measured with respect to the origin that provided the shortest distance to the measurement point. The RAD-X device was then used to measure the radiation level at each measurement point. 21 readings within 0-600 metres from their respective origins were chosen as data points.

For measurements taken close to the origin², a visual estimate of the distance from the water body was used, as short distances calculated using recorded coordinates were found to be inaccurate. However, for measurements taken from further distances which cannot be estimated with confidence, the GPS coordinate data was used for distance calculation. Coordinates recorded by the Rad-X app were inaccurate at times. Hence, the coordinates were first validated and corrected (if necessary) using google maps to ensure accuracy.

The Haversine Formula³ was used to find the distance between the origin and the measurement coordinates, taking into account the curvature of the earth for a more accurate distance.

² Within 0 to 20 metres

³ https://en.wikipedia.org/wiki/Haversine_formula

Research Data

Punggol Park (RAD-X 281)

A river fulfilling the definition of a water body was identified at Punggol Park. Using Google Maps, the coordinate (1.22394, 103.53529) was identified as the point of origin. The readings with IDs 6 to 12 were taken very close to the origin, thus their distance from the origin was estimated.

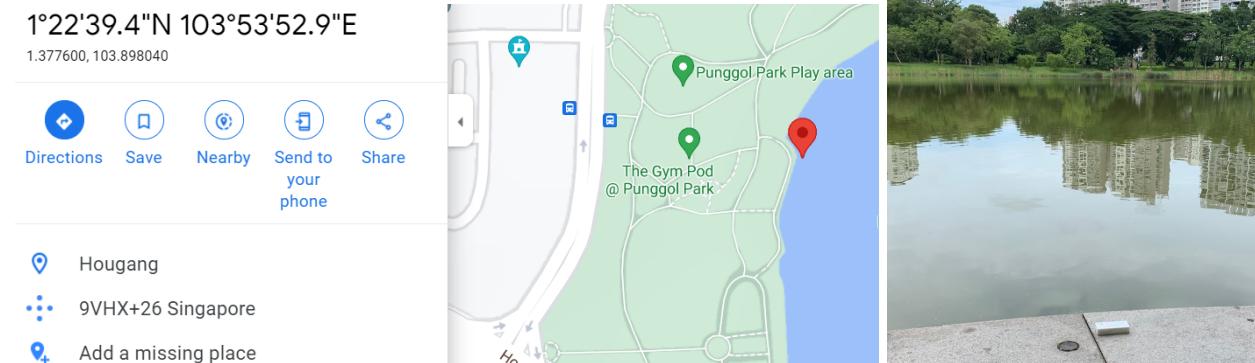


Fig 1. Location of origin at Punggol Park

Position of first measurement



Fig 2. GeoPlot of locations where radiation measurements were taken near Punggol Park

A different origin coordinate was selected using Google Maps for **ID 23** and **ID 24** (red), as the origin coordinates (yellow) no longer provide the shortest distance relative to the water body.

During the data validation process, historical data **ID: 21** and **ID: 27** had to be removed as the measurements recorded were inaccurate due to connection issues.

Sengkang Riverside Park (RAD-X 203)

A river fulfilling the definition of a water body was identified at the Sengkang Riverside Park. Using Google Maps, the points with the coordinates (1.390528, 103.882) and (1.391386, 103.881953) were chosen as the origin 1 (*Fig 3*) and origin 2 (*Fig 4*).

The readings with IDs 5 and 7 were taken very close to the origin, thus their distance from the origin was estimated.

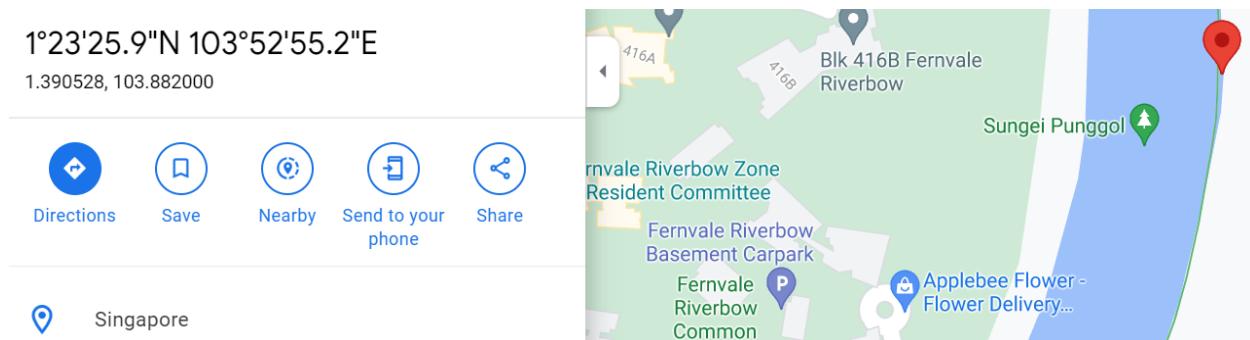


Fig 3. Location of origin 1 at Sengkang Riverside Park

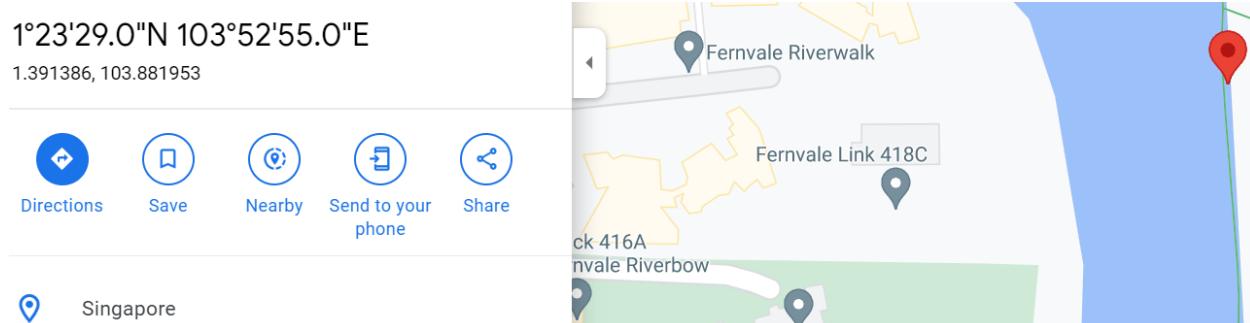
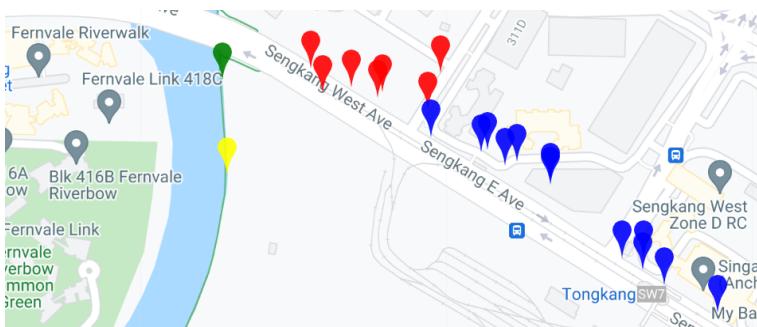


Fig 4. Location of origin 2 at Sengkang Riverside Park



As the measurements with the IDs 10, 40, 41, 42, 43, 44 and 45 (red) were closer to the origin 2 (*Fig 4*), origin 2 (green) was used as the point of reference for the distance from the river. For the other measurements (blue), origin 1 (*Fig 3*), illustrated in yellow, was used to measure the distance.

Fig 5. GeoPlot of locations where measurements were taken near Sengkang Riverside Park

Rad-X measurements

Data Analysis

The best-fit line is created using the polynomial function. For all 3 graphs shown in the figures below, the best-fit line shows an overall gradual increase in radiation level as the distance from the water body increases from 0 to 600 metres.

Combined Measurements

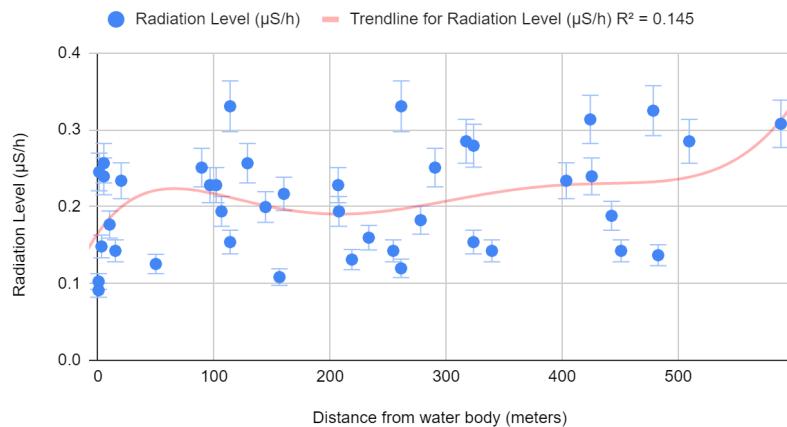


Fig 6. Graph showing combined measurements

For this graph, the measurements from the 2 locations were combined (Fig 6). The increasing trend is mostly consistent but shows a slight decrease in radiation level as the distance from the water body increases from about 50 to 100 metres.

Measurements taken near Punggol Park

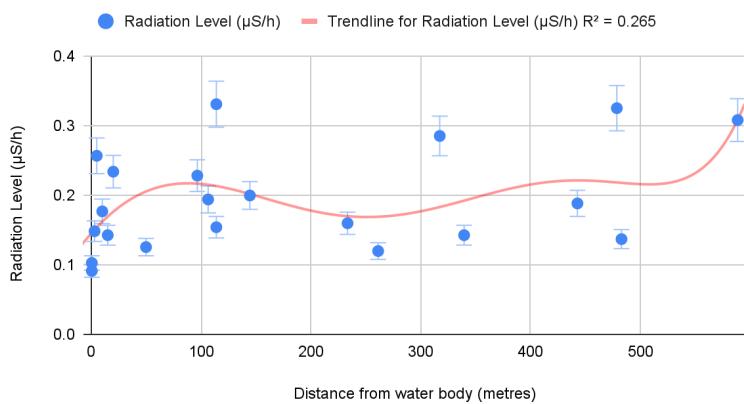


Fig 7. Graph showing measurements taken near Punggol Park

The above Graph (Fig 7) revealed an increasing trend that is mostly consistent, despite some slight decreases as the distance increases from about 100 to 250 metres, and from about 400 to 450 metres.

Measurements taken near Sengkang Riverside Park

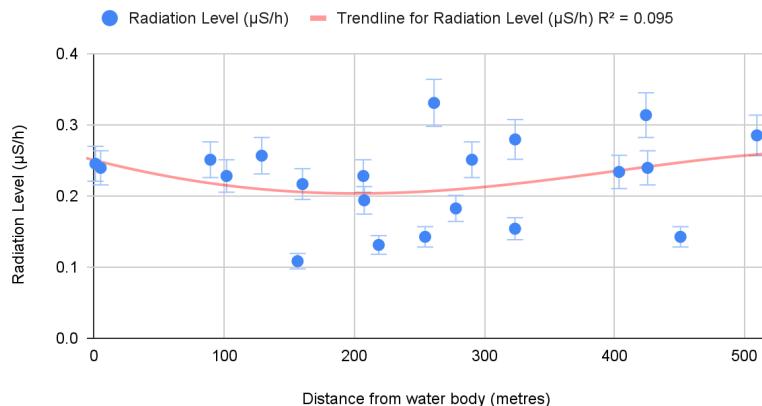


Fig 8. Graph showing measurements taken near Sengkang Riverside Park

The above graph (Fig 8) revealed an increasing trend as well. However, there is a slight decreasing trend from 0 to 200 metres.

Conclusion

The statistical interpretation of the measurements obtained from the RAD-X devices revealed a positive correlation between the distance from a water body and the level of ionising radiation measured.

Therefore, to answer the driving question, areas near water bodies have lower background levels of ionising radiation than areas further from them.

However, the strength of this correlation cannot be firmly established, due to the relatively small number of measurements taken and the limited number of locations studied. Furthermore, it is currently not known if causation is present between these variables.

For future development, it would be ideal for more measurements to be taken near differently located water bodies, in order to obtain more research data and further analyse the relationship between the two variables.

Appendix

Tools Used:

GeoPlotter: <https://mobisoftinfotech.com/tools/plot-multiple-points-on-map/>

Google Sheets: <https://docs.google.com/spreadsheets/>

Google Maps: <https://www.google.com/maps>

Engineering Innovation Challenge 2021

Application of Ionising Radiation as a Wastewater Treatment Method

Project Code: P-07

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Project Abstract

Traditional agriculture wastewater uses chemical bath treatment, contributing to increased waste material. Multiple studies have proven that ionising radiation can more effectively treat wastewater, by separating chemicals into safer substances, for discharge and potential reuse.

The prototype aims to justify and explore the feasibility of using multiple ionising radiations. β particles are able to be produced in higher dosages and were used in the first stage. γ -rays have a deeper penetrating depth and were used in the second stage, to further treat water while awaiting discharge.

Chemical analysis methods were explored. HPLC and gas chromatography were used to measure and feed feedback to a central computer which will intelligently adjust the dosage level of β particles to optimize flow rate and energy.

Following a literature review, carbofuran ($C_{12}H_{15}NO_3$) was selected as a benchmark for treatment efficiency. Carbofuran's treatment by β particles was detailed in 'Effect of Accelerated Electron Beam on Pesticides Removal of Effluents from Flower Plantations' while its treatment by γ -rays was detailed in 'The Degradation of Some Pesticides in Aqueous Solutions by Gamma Radiation' (D. Solpan). The costs and sustainability of the prototype were found in the paper 'Application of Ionizing Radiation in Wastewater Treatment: An Overview' (Rehab O. Abdel Rahman, Yung-Tse Hung).

The optimisation of water flow and treatment methods such as water flow, water depth and radiation dosages were explored when designing the prototype. Electronic works such as soldering and installation boost converters were included, to better illustrate the types of radiation and their properties.

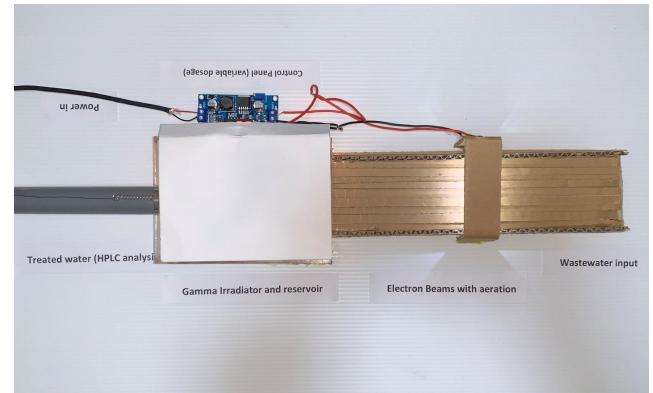
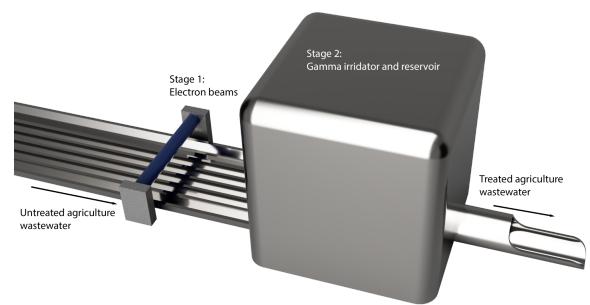
Project Report

Background and Purpose of Prototype

Engineering Goals: To build a prototype that simulates the use of ionising radiation to treat agricultural wastewater in a sustainable and cost-effective way.

Purpose of prototype: The prototype will be used as a proof of concept for the application of multiple ionising radiations to treat agriculture wastewater in an environmentally friendly and sustainable manner.

Expected Outcomes: To finalise the design of the prototype, and also the treatment procedures and dosage of ionising radiation proposed. Cost and sustainability optimisation will be demonstrated and explained.



Experimental Section

Prototype description

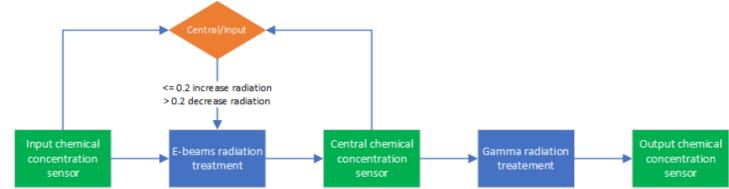


Fig 1. Block diagram of the process of treatment using prototype

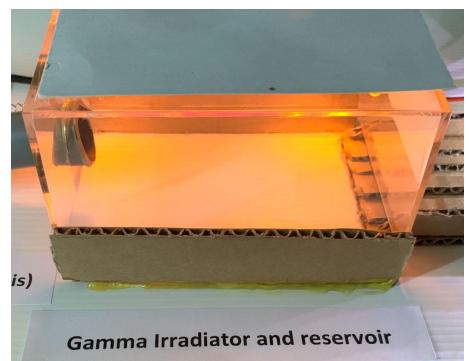
Phase A of the report concluded that electron beam treatment, followed by gamma irradiation, is the most efficient method to treat wastewater. The visible light (400 - 700nm) was used to simulate ionising radiation, due to cost and safety constraints. The chemicals treatable by ionising radiation will reach asymptote tendency as radiation dose increases, hence yielding marginal returns for further treatment. This can result in over-treatment - increasing energy cost to an unsustainable level. Chemical concentration sensors will be used to measure, and feedback, to a central computer (Fig 1) to optimise the treatment coefficient¹ to 0.2.

In the first stage of the irradiation, white LED lights were used to simulate e-beams as they are higher in intensity than γ -rays. The untreated wastewater in the first stage is divided into many parallel pipes due to the low penetration of e-beams (only up to 4 cm). After only a few seconds, the first stage will conclude as e-beams are able to deliver a high dosage of β particles.



¹ Treatment coefficient = output concentration/input concentration

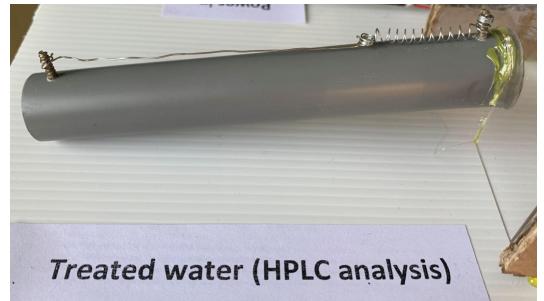
In the second stage, the partially treated wastewater is diverted to a large container, where γ -rays are directed at it. Gamma rays penetrate more deeply, thus a large volume of wastewater can be treated at once. The lower-intensity yellow LED lights used in the prototype mirror the lower intensity of γ -rays compared to e-beams. The second stage will take a few hours, after which the water can be stored in the container until an operator discharges it. In this way, the container doubles as a storage reservoir.



To simulate the change in radiation dosages, the LEDs are connected to a boost converter, to vary the light intensity. This provides us with a visualisation of the radiation doses delivered to treat the wastewater, similar to the constantly adjusting β particles dosage.



Finally, after treatment is complete, the wastewater can be discharged into the environment, the treated product will be analysed using High-Pressure Liquid Chromatography (HPLC) to determine that no environmentally harmful byproducts, such as chlorine, remain. Once it is ensured that the wastewater is sufficiently treated, the operator can discharge the treated water through a pipe.



Limitations of prototype

The prototype is unable to demonstrate the water treatment process, and its effectiveness since the radiations are simulated. To demonstrate feasibility, research and calculations were done. The prototype also does not include radiation management systems, such as concrete enclosures. A full-scale version will have to consider these measures, to reduce and manage the operators' radiation exposure.

Procedures

A literature review was conducted to determine the chemicals most suited to be degraded using this prototype, the optimal dosage of irradiation, and expected costs. Carbofuran ($C_{12}H_{15}NO_3$) degradation by e-beams and γ -rays was studied. Experiment 1 details the experiment conducted in the paper 'Effect of Accelerated Electron Beam on Pesticides Removal of Effluents from Flower Plantations' (T. Ramírez, M. Armas, M. Uzcátegui), part of the research project 'Radiation Treatment of Polluted Water and Wastewater' published by the International Atomic Energy Agency (IAEA). Experiment 2 details the experiment

'Radiolytic degradation of Carbofuran by using Gamma and Gamma/hydrogen peroxide Processes' (K. Elmamoun, A. Ibrahim, A.A Elbashir, M.M.O. Ahmed, D. Solpan).

Experiment 1

In this experiment, the feasibility of using e-beams to break down commercial pesticides used in flower plantations was studied. The chemical compounds studied were carbofuran ($C_{12}H_{15}NO_3$), diazinon ($C_{12}H_{21}N_2O_3PS$), imidacloprid ($C_9H_{10}ClN_5O_2$), and metiocarb ($C_{11}H_{15}NO_2S$). These chemicals have a predetermined concentration from 100 ppm to 400 ppm. The sample was then irradiated with β particles with an energy of 8.3MeV and power of 2kW.

Experiment 2

In this study, different γ -ray doses in the range from (0.25-3.0 kGy) were used to remove carbofuran (CBF) from aqueous solution. Gas chromatography-Mass spectrometry (GC-MS) and ion chromatography were used to determine the intermediates, by-products, aliphatic acids, and inorganic species. The changes in dissolved oxygen, total acidity and pH were measured before and after γ -irradiation.

Risk and Safety

For this simulation prototype, the risks are comparatively reduced compared to a practical application. As there is a voltage source connected to the light sources, there is a risk of electrical shock and burns. To prevent this, when using the prototype, all components, particularly connecting wires, should be examined regularly for damage, and touching the electrical components with bare hands should be avoided.

For an actual prototype, there is a risk of over-exposure to ionising radiation as it can damage DNA, tissues and organs, and cause health effects such as cancer. Researchers should follow standard safety measures, namely placing lead and concrete shields between radiation sources and humans, maximising the distance between them and radiation sources, and limiting radiation exposure time. All researchers and workers should be provided with safety assessment documents to ensure compliance.

Methods for Data Analysis

Experiment 1

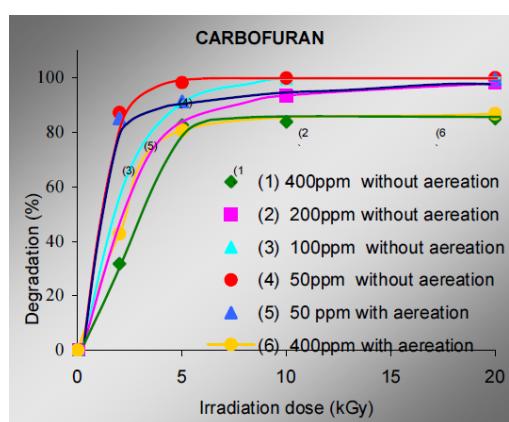
High Pressure Liquid Chromatography (HPLC) was used to analyse the chemical composition before and after irradiation. The solution has to first go through a liquid-liquid extraction process and evaporated to dryness. This is to remove new chemicals formed during the irradiation process. 6ml of water was added to assist in HPLC analysis.

Experiment 2

A 50 mg/L of carbofuran solution was prepared using distilled water. Using the GC-MS system, gas chromatography was applied to carbofuran to determine the retention time and mass spectra. Retention time and purity was also determined using ion chromatography. 400 mL of the aqueous solution of carbofuran was irradiated in the presence and absence of hydrogen peroxide at room temperature. The chemical properties such as pH, dissolved oxygen and total acidity were determined before and after irradiation.

Experimental Results

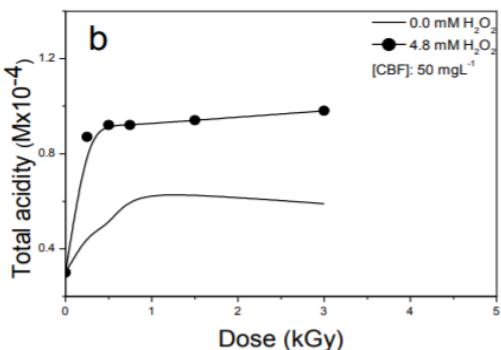
Experiment 1



Carbofuran was able to degrade more efficiently with aeration, by 5 to 10%. The degradation rate also slows substantially after 5kGy dosage, depending on the initial concentration. It was concluded that an 80% degradation rate will be a reasonable benchmark for determining the irradiation dose. Hence, by intelligently adjusting the dosage level, the system for water purification will aim to achieve a 80% degradation rate of 5kGy.

Fig 2. Graph of degradation of carbofuran solution against electron irradiation dose

Experiment 2



The increase in acidity can be taken as an indicator of the degradation of carbofuran, as organic acids such as formic and acetic acids form due to chemical reactions between hydroxyl radicals and aldehyde compounds, leading to an increase in acidity of the solution. The graph with γ -ray irradiation without hydrogen peroxide will be used (Fig 3), as it is lower-cost.

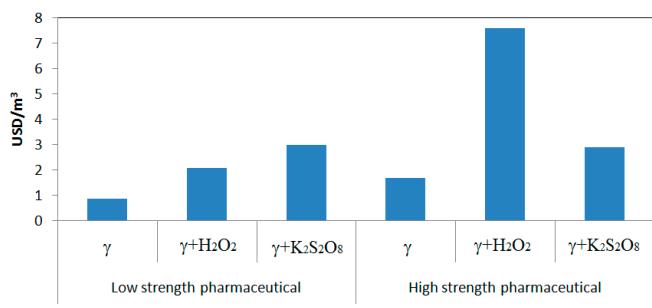
Fig 3. Graph of total acidity of carbofuran solution against dose of γ -irradiation applied

From Fig 3, it can be seen that for a carbofuran aqueous solution with 50 mg/L concentration, acidity increases as radiation dose increases, with the curve reaching an asymptotic tendency at about 0.4 kGy. Hence, 0.4 kGy is the optimum radiation dose for γ -irradiation.

Discussion of Results

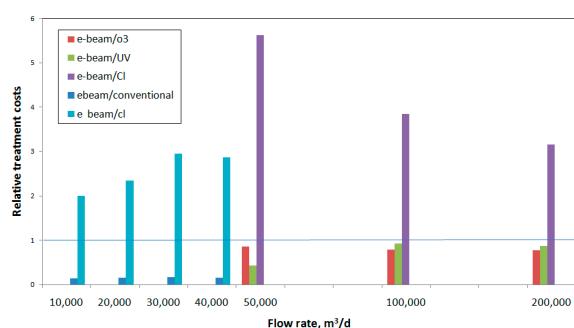
Experiment 1 showed that e-beams are able to degrade carbofuran quickly and effectively, to at least 80% degradation. Similarly, experiment 2 showed that the γ irradiation process can degrade a larger volume of carbofuran effectively. As e-beams are able to generate higher doses than γ irradiation, they can treat wastewater with a faster flow rate. Meanwhile, γ irradiation can treat larger volumes at once. This allows the wastewater to go through a second round of continuous treatment, in preparation for its discharge. By including both treatment methods, the treatment process will be faster and more cost-effective.

Cost and Sustainability



From Fig 4, it can be seen that for γ -irradiation, the cost of using only γ -irradiation without hydrogen peroxide is greatly reduced, regardless of whether a pharmaceutical is low- or high-strength. This supports the decision made to use only γ -irradiation, as it costs less than 1 USD/m³.

Fig 4. Costs in USD/m³ for different types of γ -irradiation



From Fig 5, it was concluded that conventional e-beam, combined with a high flow rate, will reduce treatment cost. Moreover, β particles are generated electrically. This energy can be obtained from renewable sources such as solar and wind. E-beams are also sustainable, considering that they do not generate harmful waste materials.

Fig 5. Costs in USD/m³ for different types of γ -irradiation

Hence, the e-beams (first stage) and γ -irradiation (second stage) used in this prototype are cost-effective and sustainable. Treating wastewater using both types of irradiators will reduce the energy cost from e-beams, and reduce the need to contain radiation isotopes used to generate γ rays.

Conclusion

The differing strengths of γ -rays and e-beams were used to develop a prototype that leverages the advantages of both types of irradiation techniques. The prototype and research had demonstrated the feasibility, sustainability, and cost-effectiveness of using multiple radiations to treat wastewater. Energy can be sourced sustainably, and waste products are kept to a minimum as compared to traditional treatment methods.

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