# PHYCODEGRADATION OF POLYETHYLENE BY PHOTOSYNTHETIC MICROALGAE

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DOCTOR OF PHILOSOPHY

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I hereby declare that I have checked this thesis, and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
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## DEDICATION

*Dedicated to my parents, relatives and friends, who gave me everlasting inspiration, never-ending encouragement, and priceless support towards the success of this study.*

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## ABSTRAK

Pencemaran plastik telah menjadi salah satu masalah alam sekitar yang paling sering dilaporkan, kerana pengeluaran produk plastik guna pakai yang meningkat dengan pesat mengatasi kemampuan dunia untuk menanganinya. Malaysia adalah negara kelapan terbesar menghasilkan sisa plastik dalam senarai negara membangun. Kaedah konvensional polietilena degradasi termasuk pembakaran, pelupusan sampah, dan rawatan kimia mencemarkan persekitaran dan menyebabkan kesan berbahaya pada organisma hidup. Tidak ada penyelesaian yang efisien, ekonomik, dan kaedah hijau untuk degradasi lengkap polietilena di kedua-dua pihak akademia dan industri. Namun, untuk menyelesaikan masalah global ini, mod biologi mungkin dapat dinilai dan dikembangkan pada masa akan datang. Dalam penyelidikan penyelidikan ini, potensi alga hijau konsorsium (*Chlorella* sp.) dan alga biru-hijau (*Cyanobacteria* sp.) dikaji untuk biodegradasi polietilena berketumpatan rendah dan tinggi. Objektif penyelidikan ini adalah untuk mengkaji struktur fisio-kimia polietilena berketumpatan rendah dan tinggi dan untuk mengenal pasti potensi mikroalga untuk biodegradasi kedua-dua polietilena dan mengkaji ciri analitik polietilena yang dirawat. Akhirnya, sebatian biodegradatif telah dianalisis. Hasil yang diperoleh menunjukkan bahawa pemerhatian mikroskopik elektron pendarfluor dan pemindaian lembaran polietilena telah menunjukkan penjajahan mikroalga dengan eksopolisakarida pada filem polietilena yang memulakan kakisan pada permukaan polimer. Hasil penurunan berat menunjukkan bahawa penurunan berat polietilena berketumpatan rendah yang didegradasi oleh konsortium diperhatikan sekitar 8.18% ± 0.66 dan polietilena berketumpatan tinggi sekitar 6.43% ± 0.59. Analisis sinar X penyebaran tenaga menunjukkan kandungan karbon rawatan selepas konsorsium menurun kepada 53.18% untuk kepadatan rendah dan 31.15% untuk polietilena berketumpatan tinggi. Analisis CHNO menunjukkan 37.91% dan 41.74% pengurangan kandungan karbon untuk filem polietilena berketumpatan rendah dan tinggi masing-masing selepas degradasi. Hasil analisis termal menunjukkan pengurangan pencairan polietilena yang dirawat dengan berkesan berbanding dengan kawalan. Spektrum inframerah Fourier membuktikan bahawa kedua-dua polietilena merosot dengan penurunan ketara dalam penghantaran ikatan C-H dan peningkatan isyarat ikatan OH dan C-O. Akhirnya, analisis eksopolisakarida menunjukkan konsortium mikroalga menunjukkan kuantiti eksopolisakarida yang lebih besar seperti karbohidrat dari 0.256 ± 0.013 hingga 0.637 ± 0.014 dan protein dari 0.124 ± 0.028 hingga 0.361 ± 0.016 yang memulakan pengumpulan tegas pada permukaan polimer, dan menyebabkan penurunan degradasi polietilena dengan mineralisasi. Kajian ini memberikan hasil yang komprehensif untuk mempercepat biodegradasi polietilena pada skala yang lebih besar menggunakan spesis dan konsortium mikroalga yang berbeza. Kajian masa depan mengenai enzim yang terlibat dalam proses biodegradasi akan menghasilkan kaedah pembuangan sisa polimer yang berkesan dan berpotensi.

## ABSTRACT

Plastic pollution has become one of the most reported environmental issues, as rapidly increasing production of disposable plastic products overwhelms the world's ability to deal with them. Malaysia is the eighth largest country to generate plastic waste in the list of developing countries. Conventional methods of polyethylene degradation including incineration, landfill, and chemical treatment are lethal to the neighboring environment and causing hazardous effects on living organisms. There is no efficient, economical, and green solution for the complete degradation of polyethylene formulated at both academia and industrial scale. However, to solve this global issue, biological mode could possibly be evaluated and developed in the upcoming future. In this research investigation, the potential of consortium green algae (*Chlorella* sp.) and blue-green algae (*Cyanobacteria* sp.) was investigated for biodegradation of low-density and high-density polyethylene. The objectives of this research were to study the physio-chemical structure of low- and high-density polyethylene and to identify the potential microalgae for the biodegradation of both polyethylene followed and to study analytical characterization of treated polyethylene. Finally, the biodegradative compounds has been analyzed. Results obtained showed that fluorescent and scanning electron microscopic observation of polyethylene sheet has shown the colonization of microalgae with exopolysaccharides on the polyethylene film which initiates the corrosion of polymer surface. The weight loss results reveled that consortium traded low-density polyethylene weight reduced was observed about 8.18% ± 0.66 and the high-density polyethylene about 6.43% ± 0.59. Energy dispersive x ray analysis revealed the after the consortium treatment carbon content decreased to 53.18 % for low- density and 31.15 % for high density polyethylene. The CHNO analysis shown 37.91% and 41.74% of carbon content reduction for low- and high-density polyethylene film respectively after degradation. Thermal analysis results displayed efficient reduction in melting of treated polyethylene compared with control. Fourier infrared spectrum evident that both the polyethylene's are degrading with prominent decrease in transmittance of C-H bond and increase in OH and C-O bond signal. Finally, exopolysaccharide analysis showed the microalgae consortium exhibited the larger quantity of exopolysaccharides such as carbohydrates from 0.256 ± 0.013 to 0.637 ± 0.014 and proteins from 0.124 ± 0.028 to 0.361 ± 0.016 which initiates firm accumulation on the polymer surface, and which leads the degradation of polyethylene by mineralization. This work provides a comprehensive result to accelerate the biodegradation of polyethylene at larger scales using different species and consortium of microalgae. The future study of enzymes involved in the biodegradation process will lead to effective and potential method of polymer waste disposal.

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## LIST OF SYMBOLS

| | |
|---|---|
| % | Percentage |
| °C | Degree Celsius |
| µL | Micro litre |
| A | Absorbance |
| cm | Centimetre |
| g | Gram |
| $g/cm^3$ | Gram per cubic centimetre |
| g/L | Gram per litre |
| mg/L | Milligrams per litre |
| GPa | Giga Pascal |
| L | Litre |
| M | Molar |
| min | Minutes |
| mL | Millilitre |
| mm | Micro metre |
| MPa | Mega Pascal |
| nm | Nanometre |
| ˚C | Degree Celsius |
| OD | Optical density |
| pH | Hydrogen ion concentration |
| psi | Pounds per square inch |
| rpm | Revolutions per minutes |
| Shore D | Shore durometer |
| RCF | Relative Centrifugal Force |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| 3D | 3-Dimension |
| BG-11 | Blue-Green Medium |
| $CO_2$ | Carbon dioxide |
| DDT | Dichlorodiphenyltrichloroethane |
| DSC | Differential scanning colorimetry |
| EDX | Energy dispersive analysis |
| FTIR | Fourier transform infrared spectroscopy |
| HDPE | High-density polyethylene |
| LDPE | Low-density polyethylene |
| LLDPE | Linear low-density polyethylene |
| PAHs | Polycyclic aromatic hydrocarbons |
| PE | Polyethylene |
| PET | Polyethylene terephthalate |
| PP | Polypropylene |
| SEM | Scanning electron microscope |
| TGA | Thermal gravimetric analysis |
| UV | Ultraviolet |
| XRF | X-ray fluorescence |
| PVC | polyvinyl chloride |
| DNA | Deoxyribonucleic Acid |
| UV-Vis | Ultraviolet–visible spectroscopy |
| FESEM | Field emission scanning electron microscope |
| XRD | X-ray diffraction crystallography |
| EPS | Electron phenomenological spectroscopy |
| SDS-PAGE | Sodium dodecyl sulphate polyacrylamide gel electrophoresis |
| PTFE | Polytetrafluoroethylene |
| ASTM | American Society for Testing and Materials |
| PU | polyurethane |
| PCR | Polymerase chain reaction |
| LDE | Low Density ethylene |
| HDE | High Density ethylene |

| | |
|---|---|
| PGA | Phosphoglyceric acid |
| PLA | Poly lactic acid |
| PET | Polyethylene terephthalate |
| MSM | Methyl sulfonyl methane |
| FTIR | Fourier Transform Infrared Spectroscopy |
| CER | Cation exchange resin |
| USA | United States of America |
| DTA | Differential thermal analysis |
| DTG | Thermogravimetric analysis |
| NADPH | Nicotinamide adenine dinucleotide phosphate |
| BBM | Bold's Basal Medium |
| RNA | Ribonucleic acid |
| SEM | Scanning electron microscope |
| XRF | X-ray fluorescence |
| OHB | Oligomers of 3-hydroxybutyrate |
| PHB | Polyhydroxy butyrate |
| LA | Lactic acid |
| MT | Metric ton |
| MMT | Million metric ton |
| HIPS | High Impact Polystyrene |
| UMI | Upper middle income |
| LMI | Low middle income |
| LI | Low income |
| HIC | High income country |
| LOD | Loss of density |
| GHG | Greenhouse gases |
| EPS | Exopolysaccharide |
| $CO_2$ | Carbon dioxide |
| $CH_4$ | Methane |
| BSA | Bovine serum albumin |
| TPS | Thermo plastic starch |
| C | Carbon |
| PCR | Polymerase chain reaction |

| | |
|---|---|
| RFLP | Random fragment length polymorphism |
| S | Sulphur |
| H | Hydrogen |
| N | Nitrogen |
| O | Oxygen |

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