

The kinetics oxidative degradation of chitosan in formic acid with the presence of hydrogen peroxide

E Purwanto^{1,2}, J Connor¹ and Y Ngothai¹

¹School of Chemical Engineering and Advanced Materials, The University of Adelaide, South Australia, 5005, Australia

²Department of Chemical Engineering, University of Surabaya, Raya Kalirungkut, Surabaya, 60293, Indonesia

E-mail: edy.purwanto@adelaide.edu.au

Abstract. The chitosan degradation in formic acid solution with the presence of hydrogen peroxide was investigated in this work. Temperature and reaction time had a significant effect on reducing the molecular weight of chitosan, and it is clear that it decreased the molecular weight faster at the first 15 minutes of reaction time. Therefore, the molar concentration of chitosan in the solution increased with temperature and reaction time. The reaction order was determined from the molar changes of chitosan on reaction time and found followed -0.1 reaction order to the molar concentration of chitosan. The Arrhenius equation was used to study the correspondence influence of reaction temperature on the degradation reaction rate constant. The results suggest that the values of degradation rate constant increased with higher reaction temperature. The value of activation energy was determined under the experimental operating conditions examined to be 99.8 kJ/mol. The FT-IR spectra demonstrated that there was no change in the chemical structure of chitosan before and after the degradation reaction.

1. Introduction

Chitosan is generally accepted as a product derivative of chitin that ordinarily acquired from crustacean shell through partial deacetylation reaction using base or enzyme [1]. Chitosan has a different structure compared to chitin concerning some acetyl groups present in chitin which have been replaced by atoms H. Hence, chitosan will have a varying degree of deacetylation (DD) with a chemical name as (1→4)-2-amino-2-deoxy-β-D-glucan.

As amino-polysaccharides, chitosan is extensively utilised for some purposes with great features regarding biocompatible, antibacterial, biodegradable, nontoxic, and environmentally friendly. Accordingly, chitosan is utilised in numerous applications, for example, in foods, biomaterials, medicine, cosmetics, and pharmaceutical products [2-6]. However, low solubility in water is the characteristic of original chitosan derived from the shell of shrimps as it has high molecular weight. These properties make the original chitosan have a limited utilisation in particular for medical applications. Therefore, it is necessary to obtain a chitosan product through the degradation process that accomplishes its higher solubility and preserves its biological properties. Oligomer chitosan with high solubility in solvents can be achieved through degradation reactions via several techniques. The degradation can be carried out by a chemical method using acids [7-10], high impact energy [11-13], and enzymatic [14-15].



Recently, acetic acid has been widely implemented in oxidative degradation using hydrogen peroxide as an oxygen carrier. However, there is little attention to the exploitation of formic acid as an acid solvent in the chitosan degradation with the utilisation of hydrogen peroxide. Formic acid may show better performance than acetic acid as a solvent when combined with hydrogen peroxide. The utilisation of hydrogen peroxide and synergised with formic acid has been widely employed, as shown in another type of oxidation reaction called epoxidation reaction [16-17]. Hence, this work aims to study the influence of reaction temperature and time on chitosan degradation and determine the kinetics of chitosan degradation in the formic acid solution with the presence of H₂O₂.

2. Materials and methods

2.1. Materials

The feedstock of chitosan with an average molecular weight of approximately 3300 kDa and a degree of deacetylation of 96.31% was used in this research. This chitosan was obtained from Xi' An Lukee Bio-Tech Co. Ltd. Hydrogen peroxide, formic acid, acetic acid, sodium hydroxide, and ethanol absolute were supplied by Chem-supply as laboratory reagent grade.

2.2. Feedstock preparation of chitosan solution

The starting of chitosan solutions was prepared in a glass reactor with dissolving chitosan to obtain 10 g/L chitosan in 1% formic acid solution. A calculated amount of formic acid solution was dissolved in the water to obtain 800 mL 1% formic acid solution. Following this, 8 grams chitosan dissolved in this acid solution and stirred with low rotation speed overnight to ensure chitosan has been soluble thoroughly.

2.3. Experimental setup and procedure

The chitosan degradation was carried out in a 1-L glass reactor equipped with a magnetic stirrer, condenser and thermocouple. The reactor was located on a heating plate and connected with temperature control, whose temperature could be maintained $\pm 1^\circ\text{C}$. The reaction temperature was set by adjusting the temperature controller connected to the heating plate, and a calculated amount of hydrogen peroxide was added when the desired reaction temperature was reached with a final concentration 1% (w/v) in the mixture. The degradation reactions were run at several isothermal conditions and samples were taken at certain reaction times. After the degradation reaction, the samples were collected and cooled to terminate the reaction. It was then neutralised with 2 M NaOH solution to pH 8-9. The neutralised solution was then filtered off to separate solid phase (low molecular weight of chitosan) and liquid phase (oligomer chitosan soluble in the water). After that, the solid phase was washed with water until the remaining washing water was neutral. Next, the remaining impurities in the solid phase was removed using ethanol. Finally, the solid was vacuumed and then dried at 60°C to remove the water content. The solid product was analysed to determine its molecular weight using the viscometric method, and FT-IR was performed to monitor the formation and disappearance of functional groups of original and low molecular weight of chitosan.

2.4. Analytical methods

The viscosity-average molecular weight of chitosan (M_v) was measured using an Ubbelohde viscometer with a capillary diameter of 0.36 mm at 30°C. The several dilute solutions of chitosan in 1% acetic acid solution (C) were measured its flowing time (t_s) and the solvent acetic acid (t_0) in duplicate for each. The specific viscosity of the dilute chitosan solutions (η_{sp}) was calculated from relative viscosity (η_r) according to the following equation (1):

$$\eta_r = \frac{t_s}{t_0}, \quad \eta_{sp} = \eta_r - 1 \quad (1)$$

Huggins equation (2) was performed to determine the intrinsic viscosity (η) from the known value of specific viscosity (η_{sp}):

$$\frac{\eta_{sp}}{C} = [\eta] + k[\eta]^2 C \quad (2)$$

by plotting $\frac{\eta_{sp}}{C}$ vs C , the intercept at $C = 0$ was obtained as the intrinsic viscosity (η) [8]. The M_v value was determined through the Marck-Houwink equation (3):

$$[\eta] = K.M_v^a \quad (3)$$

The value of K and a for chitosan in 1% acetic acid solution are 0.0474 mL/g and 0.723, respectively [18]. Those values of K and a are constant and defined as the Mark-Houwink constants.

2.5. Kinetics model

Kinetic model of chitosan degradation has been developed according to the rate of chemical reaction definition. The degradation rate is expressed as the number of moles of cutting off the glycosidic linkage in the chitosan chain to yield the two pieces [19] according to the following equation (4):

$$R = \frac{d[M]}{dt} = kM^n \quad (4)$$

M is known as the molar concentration of chitosan (mol/L). The properties k and n represent the reaction rate constant and reaction order, respectively. In this case, the reaction order (n) typically has a negative value as with the increasing of chitosan solution concentration, the degradation rate will decrease. The molar concentration of chitosan can be calculated through equation (5):

$$M = \frac{C}{M_n} \quad (5)$$

Then, the solution of the differential equation (4) is described in equation (6):

$$M_t^{1-n} - M_0^{1-n} = (1-n)kt \quad (6)$$

where M_t is chitosan concentration at a certain reaction time (t) and M_0 is the initial concentration of chitosan. It is obvious that the value of C as the solution concentration remains constant (g/L), but the molar concentration (molarity in mol/L) each time increases with the reducing number of molecular weight through the degradation process. The M_n value is the number-average molecular weight can be calculated from the M_v value through equation (7) below:

$$M_v = \left[(1+a)\Gamma(1+a) \right]^{\frac{1}{a}} M_n \quad (7)$$

where $\Gamma(1+a) = \int_0^{\infty} e^{-t} t^a dt$ and the value of M_v is obtained from equation (3) above.

3. Results and discussions

3.1. The influence of reaction temperature and time on the molecular weight of chitosan

The reaction temperatures of degradation were varied at 40, 50 and 60°C for 120 min reaction time to study the influence of reaction temperature on the chitosan degradation. The corresponding of viscosity-average molecular weight (M_v) was plotted on a logarithmic scale in correlation with reaction time t at the different reaction temperatures, as depicted in figure 1. The results indicated that the M_v value decreased with the addition reaction time. The reaction temperature similarly demonstrated a substantial effect on chitosan degradation indicated by a significant reducing the molecular weight of chitosan. The corresponding rate of decrease for M_v value of chitosan in percentage was 98.26, 99.40, and 99.83% respectively for 120 reaction time from the initial M_v value of chitosan of 3300 kDa. The M_v value of

chitosan dropped to 57.4, 19.8, 5.6 kDa for 120 min, respectively. Interestingly, the most significant reduction of M_v value was achieved at the first 15 minutes of reaction time with the corresponding rate of decline in percentage for M_v value was 94.33, 96.58, 98.47% respectively.

Figure 2 shows the correlation between the molar concentration of chitosan (M_t) vs reaction time (t) and the result indicated that the molar concentration of chitosan increased with the rise of reaction time. This finding implies that a random scission of glycosidic linkage occurred and results in a lower number-average molecular weight of chitosan. Therefore, it will increase the molar concentration of chitosan with additional reaction time.

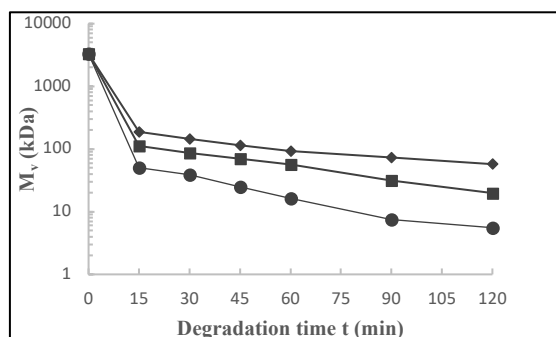


Figure 1. The influence of reaction temperature on the viscosity-average molecular weight of chitosan (M_v) for different temperatures: (◆) 40°C; (■) 50°C; (●) 60°C.

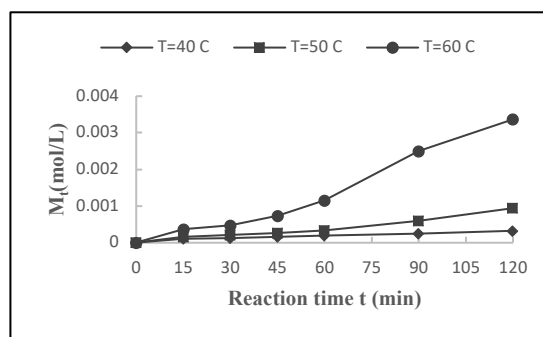


Figure 2. The molar concentration of chitosan vs time.

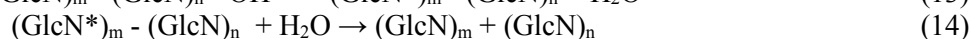
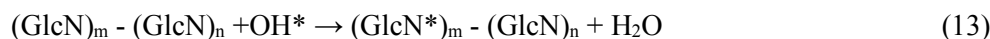
These results confirm a previous finding stated that reaction temperature plays an essential role for chitosan degradation [20]. The experimental results conclude that hydrogen peroxide in the formic acid solution may accelerate chitosan degradation during the degradation reaction. The reaction mechanism of chitosan degradation is mainly under the attack of powerful oxidant, namely, hydroxyl radical [21]. The reaction step is illustrated as follows, R-NH₂ first produces R-NH₃⁺ in acid solution and decomposition of H₂O₂ also occurred as shown in equation (8) and (9) then summarised as a total reaction in equation (10). The reaction mechanism of chitosan degradation with hydrogen peroxide in the acid solution is as follows [21]:



The hydroxyl radical (HO*) is easily produced from the decomposition of hydroperoxide anion as it is not stable, and the reactions in equation (11) and (12) take place.



Eventually, the hydroxyl radical (OH*) attacks the glycosidic linkage in chitosan to produce oligomer chitosan according to the reactions in equation (13) and (14).



3.2. Kinetics degradation of chitosan

Some different rate models have been suggested regarding polymer degradation [19, 22, 23]. However, in this paper, the reaction rate was modelled as a function of molar concentration with a negative order n according to equation (4) [19]. Utilising equation (6) as the solution of the differential equation (4), the reaction order (n) can be determined by performing trial and error of the n value on plotting $[M_t^{1-n} - M_0^{1-n}]$ vs t . The n value of -0.1 showed the best fit of the curve with the kinetic model. The

finding of this study indicated that chitosan degradation followed -0.1 reaction order corresponding to the chitosan concentration.

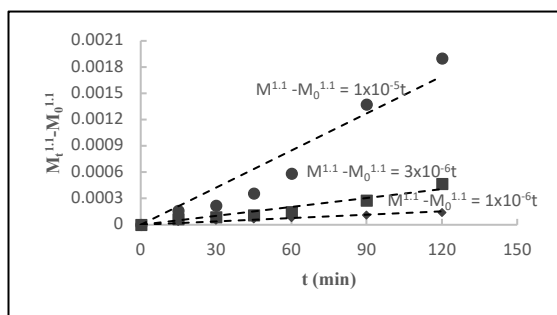


Figure 3. The changes of the molar concentration of chitosan fitted with -0.1 reaction order for different temperatures: (◆) 40°C; (■) 50°C; (●) 60°C.

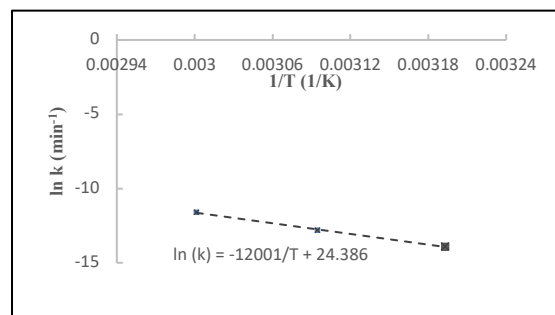


Figure 4. Plot Arrhenius to determine the rate constant

The changing for the molar concentration of chitosan was modelled according to -0.1 reaction order indicated a good fit with a coefficient of correlation $R^2 \geq 0.921$ (figure 3). The value of rate constants (k) for different temperatures: 9.1×10^{-7} (40°C), 2.7×10^{-6} (50°C), 9.1×10^{-6} (60°C) (mol/L)^{1.1}/min. These rate constants are higher than compared to using sonolysis method with additional of Fe(III)/H₂O₂ in acetic acid solution with the value of k is in the range $1.538 - 4.923 \times 10^{-9}$ mol^{1.7}L^{-1.7}.min⁻¹ for additional H₂O₂ between 0.0 – 1.2 mL [23]. They also reported that the reaction order was -0.7 using the same model used in this paper. This results showed that the chitosan degradation rate increased with reaction temperature indicated by the higher value of k as the temperature increase (figure 4). From the plot between $\ln(k)$ and $1/T$, the value of activation energy (E_a) was obtained to be 99.8 kJ/mol. This activation energy value is considerably higher than that for degradation using electrochemical with electrode Ti/Sb-SnO₂ ($E_a = 43.61$ kJ/mol) and close to the value stated for acetic acid and H₂O₂ ($E_a = 88.5$ kJ/mol) [20, 24].

3.3. FT-IR spectra of degradation products

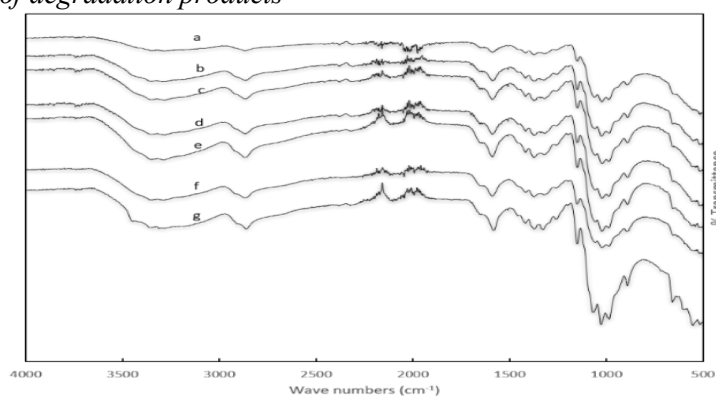


Figure 5. FT-IR spectra of chitosan for degradation at 60°C with reaction time 0 min (a), 15 min (b), 30 min (c), 45 min (d), 60 min (e), 90 min (f), 120 min (g).

The FT-IR spectra of chitosans for different reaction times at a reaction temperature of 60°C is described in figure 5. The peak which appeared at around 3368 cm⁻¹ was referred to as the stretching vibration of N-H and O-H [25]. The peaks at 1648 cm⁻¹ and 1324 cm⁻¹ were assigned as amide I and amide III, respectively [26]. The peaks, as indicated at about 1597, 1156 and 1079 cm⁻¹ were amide II, C-O-C, and C-O, respectively [25]. The β-D-(1→4) glycosidic bond shown at the peak in the range 1158-895 cm⁻¹ [27]. The results of FT-IR spectra confirmed that there is no formation of a carboxylic group during the degradation reaction as there was no peak appeared at 1735 cm⁻¹ attributed to the

carboxylic group [28]. The results suggest that the chemical structure of initial chitosan and depolymerised chitosan remained the same and there was no significant difference with the increasing of the reaction time of degradation. Hence, it can be concluded that with the utilisation of H₂O₂ in 1% formic acid, there is a primary reaction occurred with the cutting off the β -glycosidic linkage, and no side reaction occurred with the formation of the carboxylic group during the chitosan degradation.

4. Conclusions

Oxidative degradation of chitosan in formic acid solution utilising hydrogen peroxide as an oxidising agent had been done and resulted in lower molecular weight of chitosan. The reaction time and temperature have a significant effect on the degradation reaction and the faster decrease occurring at the first 15 minutes. The degradation followed -0.1 reaction order to the molar concentration of chitosan and the activation energy is 99.8 kJ/mol. The chemical structure of chitosan remained identical during the degradation reaction and indicated only primary reaction occurring with the cutting off the β -glycosidic linkage to produce lower molecular weight of chitosan.

Acknowledgments

Mr Edy Purwanto would like to thank the Indonesia Endowment Fund for Education (LPDP), Ministry of Finance; collaborated with the Directorate General of Higher Education (DIKTI), Ministry of Research, Technology and Higher Education, the Republic of Indonesia for financial support.

References

- [1] Struszczyk M H 2006 *12. Global Requirements for Medial Applications of Chitin and its Derivatives (Polish Chitin Society) Monograph* **11** 95 – 102.
- [2] Shahidi F, Arachchi J K V and Jeon Y 1999 *Trends in Food Sci. & Technol.* **10** 37-51.
- [3] Khor E and Lim L Y 2003 *Biomater.* **24** 2339-2349.
- [4] Suh J K and Matthew H W 2000 *Biomater.* **21** 2589-2598.
- [5] George M and Abraham T E 2006 *J. Controlled Release* **114** 1-14.
- [6] Rinaudo M 2006 *Prog. Polym. Sci.* **31** 603-632.
- [7] Hasegawa M, Isogai A and Onabe F 1993 *Carbohydr. Polym.* **20** 279-283.
- [8] Jia Z and Shen D 2002 *Carbohydr. Polym.* **49** 393-396.
- [9] Zamani A and Taherzadeh M J 2010 *BioResour.* **5** 1554-1564.
- [10] Tsao C T, Chang C H, Lin Y Y, Wu M F, Han J L and Hsieh K H 2011 *Carbohydr. Res.* **346** 94-102.
- [11] Choi W S, Ahn K J, Lee D W, Byun M W and Park H J 2002 *Polym. Degrad. Stab.* **78** 533-538.
- [12] Li K, Xing R, Liu S, Qin Y, Meng X and Li P 2012 *Int. J. Biol. Macromol.* **51** 767-773.
- [13] Hai L, Diep T B, Nagasawa N, Yoshii F and Kume T 2003 *Nucl. Instrum. Methods Phys. Res. B* **208** 466-470.
- [14] Lin H, Wang H, Xue C and Ye M 2002 *Enzyme Microb. Technol.* **31** 588-592.
- [15] Lee D X, Xia W S and Zhang J L 2008 *Food Chem.* **111** 291-295.
- [16] Goud V V, Patwardhan A V, Dinda S and Pradhan NC 2007 *Chem. Eng. Sci.* **62** 4065-4076.
- [17] Campanella A, Fontanini C and Baltanas M A 2008 *Chem. Eng. J.* **144** 466-475.
- [18] Knaul J Z, Kasaai M R, Bui V T and Creber K A M 1998 *Chem. Eng. J.* **76** 1699-1706.
- [19] Taghizadeh M T and Abdollahi R 2011 *Ultrason. Sonochem.* **18** 149-157.
- [20] Chang K L B, Tai M C and Cheng F H 2001 *J. Agric. Food. Chem.* **49** 4845-4851.
- [21] Tian F, Liu Y, Hu K and Zhao B 2004 *Carbohydr. Polym.* **57** 31-37.
- [22] Cai Q, Gu Z, Fu T, Liu Y, Song H and Li F 2011 *Polym. Bull.* **67** 571-582.
- [23] Taghizadeh M T, Abdollahi R and Orang N S 2012 *J. Polym. Environ.* **20** 208-216.
- [24] Gu Z, Cai Q, Liu Y and Li F 2013 *J. Polym. Environ.* **21** 479-486.
- [25] Huang Y, Wu Y, Huang W, Yang F and Ren X 2013 *Polym. Degrad. Stab.* **98** 37-43.
- [26] Wang W, Du Y, Qiu Y, Wang X, Hu Y, Yang J, Cai J and Kennedy J F 2008 *Carbohydr. Polym.* **74** 127-132.
- [27] Ma F, Wang Z, Zhao H and Tian S 2012 *Int. J. Mol. Sci.* **13** 7788-7797.
- [28] Li K, Xing R, Liu S, Qin Y, Meng X and Li P 2012 *Int. J. Biol. Macromol.* **51** 767-773

ISSN 1757-8931

IOP Conference Series

Materials Science and Engineering

2nd International Conference
on Robotics and Mechantronics

517

VOLUME 517 – 2019

8–11 November 2018
Singapore

EDITOR
Meng Joe Er

The open access journal for conference proceedings

iopscience.org/jpc

IOP Publishing

PAPER • OPEN ACCESS

Editorial Board

To cite this article: 2017 *J. Phys.: Conf. Ser.* **817** 011002

View the [article online](#) for updates and enhancements.

You may also like

- [The influence of sintering temperature on characteristic of ceramics based on bentonite, glass bead and alumina](#)
P Sebayang, D H Simbolon, R R Zulwita et al.
- [Water evaporation rate of RSG-GAS spent fuel storage pool](#)
Titik Sundari, Mukhsinun Hadi Kusuma, Budiyo et al.
- [Characterization, risk assessment, and potential utilization of fly ash from PLTSA Merah Putih at Bantargebang, Bekasi, Indonesia](#)
M H Robbani, A Shoiful, P A Hendrayanto et al.

Editorial Board

Chief Editor

Febty Febriani (febty.febriani@lipi.go.id)

Indonesian Institute of Sciences (LIPI)

Research Center for Physics

Komplek PUSPIPTEK Serpong,

Tangerang Selatan 15314,

Indonesia

Keisuke Takahashi (Keisuke.takahashi@eng.hokudai.ac.jp)

Hokkaido University

Graduate School of Engineering

North 13, West 8

Sapporo, 060-8628

Japan

Peng Han (hanpeng407@gmail.com)

Institute of Statistical Mathematics

Risk Analysis Research Center (Statistical Seismological Research Project)

10-3 Midori-cho, Tachikawa

Tokyo 190-8562

Japan

Siwei Chen (chen-sw@criepi.denken.or.jp)

Central Research Institute of Electric Power Industry

Materials Science Research Laboratory

2-11-1 Iwadokita, Komae-shi

Tokyo 201-8511

Japan

Xinhong Qiu (qxinhong@gmail.com)

Wuhan Institute of Technology

School of chemistry environmental engineering

No.693, Xionghu Avenue, Hongshan District Wuhan, Hubei Province, P.R.

China

Mohsen Farahat (mohsen105@hotmail.com)

Central Metallurgical Research and Development Institute (CMRDI)

Mineral Processing and Agglomeration

P.O. Box 87 Helwan, Cairo

Egypt

Young-Ho Ko (yhko@etri.re.kr)

Electronic and Telecommunications Research Institute (ETRI)

Photonic/Wireless Convergence Components Research Department

218 Gajeong-ro, Yuseong-gu, Daejeon, 34129

Korea



Eni Sugiarti (eni.sugiarti@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Titi Anggono (titi.anggono@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Isnaeni (isnaeni@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Yuliati Herbani (yuliati.herbani@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Ferensa Oemry (ferensa.oemry@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Hubby Izzuddin (hubby.izzuddin@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Widi Astuti (widi.astuti@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research and Development Division for Mineral Technology
Jl. Ir Sutami Km.15 Tanjung Bintang, Lampung Selatan
Lampung. 35361
Indonesia

Wahyu Bambang Widayatno (wahyu.bambang.widayatno@lipi.go.id)
Indonesian Institute of Sciences (LIPI)

Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Deni Shidqi Khaerudini (deni.shidqi.khaerudini@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Kirana Yuniati Putri (kirana.yuniati.putri@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Fredina Destyorini (fredina.destyorini@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Nurfina Yudasari (nurfina.yudasari@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Qolby Sabrina (qolby.sabrina@lipi.go.id)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Risma Sundawa (risma.sundawa@gmail.com)
Indonesian Institute of Sciences (LIPI)
Research Center for Physics
Komplek PUSPIPTEK Serpong,
Tangerang Selatan 15314,
Indonesia

Table of contents for issue 1, volume 703, IOP Conference Series: Materials Science and Engineering

Volume 703

2019

[← Previous issue](#) [Next issue →](#)

International Conference on Informatics, Technology and Engineering 22–23 August 2019, Bali, Indonesia

Accepted papers received: 06 November 2019

Published online: 05 December 2019

[Open all abstracts](#)

Preface

OPEN ACCESS 011001

Preface

[View article](#) [PDF](#)

OPEN ACCESS 011002

Peer review statement

[View article](#) [PDF](#)

Papers

Green Manufacturing and Green Processes

OPEN ACCESS 012001

The use of blockchain to support sustainable supply chain strategy

J Parung

[View article](#) [PDF](#)

OPEN ACCESS 012002

Green chemical engineering: challenges in chemical industrial processes for a better life

L Riadi

[View article](#) [PDF](#)

OPEN ACCESS 012003

Xylanase production from combined *Reutealis trisperma* with potato dextrose broth by *Tricoderma reesei*: the effect of pretreatment

Y E Agustin, L Riadi and T P Utami

[View article](#) [PDF](#)

OPEN ACCESS 012004

Regulatory performance of two different tuning methods for milk cooling control system

R Agustriyanto

[View article](#) [PDF](#)

OPEN ACCESS 012005

The solubility correlation of azobenzene derivatives in supercritical carbon dioxide: a short review

D S Alwi and A S Jusri

R S Aji and A S Iyahi

[View article](#) [PDF](#)**OPEN ACCESS**

012006

Container storage tariff policy analysis using combining game theory and system dynamics approach

A G Budianto and B Wirjodirdjo

[View article](#) [PDF](#)**OPEN ACCESS**

012007

Effect of NR-g-cellulose coupling agent into NR-cellulose composite dispersibility and its physical properties

H Handayani, A Cifriadi, A S Handayani, M Chalid, S Savetlana and M Christwardana

[View article](#) [PDF](#)**OPEN ACCESS**

012008

Formulation and characterization of chitosan-alginate freeze dried matrices loaded with oleoresin extract of red ginger

E A Krisanti, A Safiya and K Mulia

[View article](#) [PDF](#)**OPEN ACCESS**

012009

The effects of electroculture on shoot proliferation of garlic (*Allium sativum* L.)

Von Louie R Manguiam, Ashley Marie N. Margate, Rose Danielle G Hilahan, Harold Gian L Lucin, Kristopher Ray S Pamintuan and Adonis P Adornado

[View article](#) [PDF](#)**OPEN ACCESS**

012010

Preparation and characterization of polyvinyl alcohol-chitosan-tripolyphosphate hydrogel for extended release of anti-tuberculosis drugs

K Mulia, S A Chadarwati, A J Rahyussalim and E A Krisanti

[View article](#) [PDF](#)**OPEN ACCESS**

012011

The surface roughness analysis using sound signal in turning of mild steel

Anayet U Patwari, A A Zamee, M H Bhuiyan and S M Sakib

[View article](#) [PDF](#)**OPEN ACCESS**

012012

A review of a machine design of chocolate extrusion based co-rotating twin screw extruder

P Pitayachaval and P Watcharamaisakul

[View article](#) [PDF](#)**OPEN ACCESS**

012013

Tofu wastewater treatment through a combined process of coagulation-flocculation and ultrafiltration

P Prawati, A Oktariany, S S Putri, I Aditya and S Kartohardjono

[View article](#) [PDF](#)**OPEN ACCESS**



012014



Carbon emission modelling in container terminal operations planning using a system dynamics approach



D N Prayogo



[View article](#) [PDF](#)



-
- OPEN ACCESS** 012015
Effects of initial concentration, adsorbent mass, pH and temperature to personal care products waste removal with activated carbon as adsorbent
H R Priyantini, L Riadi, C Effendi, F Effendi and A Mitayani
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012016
The integration of social responsibility into business operation: case study of Indonesian manufacturing industry
E D Rinawiyanti, C Huang and S As-Saber
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012017
A kinetic study of oil-in-water emulsion formation stabilized by rice husk ash and lecithin
L Sapei, S W Kurniawan and A P Siantoro
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012018
A systematic literature review for developing sustainability assessment tool: formulating the state of the art and future direction
Y Sari, A Hidayatno, A Suzianti and M Hartono
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012019
Controlled release fertilizer based on starch chitosan encapsulation
E Savitri, E Purwanto, A N Kodrat and E Yonathan
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012020
Price and inventory policy strategy model in a price sensitive dual channel supply chain structure considering product substitution
R Y H Silitonga and N Christina
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012021
Assessing materials from hoarded mobile phones: hidden e-waste subject for reverse logistics
R Siringo, H Herdiyansyah, R D Kusumastuti and A E Lucianto
[View article](#) [PDF](#)
-
- OPEN ACCESS** 012022
Optimisation of subtractive rapid prototyping process parameters using response surface methodology
T J Suteja and M A Hadiyat
[View article](#) [PDF](#)
-
- Green Design and Innovation**
-
- OPEN ACCESS** 012023
Green dynamic capability for enhancing green innovations performance in a manufacturing company: a conceptual framework
R Ambaranti, R Govindaraju and D Irianto
[View article](#) [PDF](#)



OPEN ACCESS	012024
Combined structural equation modelling – artificial neural networks model for predicting customer loyalty	
M A Hadiyat	
 View article	 PDF



OPEN ACCESS	012025
The use of consumer behavior to identify the flow mapping of waste cooking oil: A finding from Semarang, Indonesia	
S Hartini, D P Sari and A A Utami	
 View article	 PDF



OPEN ACCESS	012026
Perceived kansei and performance-based usability impact on satisfaction for web-based applications	
M Hartono	
 View article	 PDF



OPEN ACCESS	012027
Measurement of student satisfaction and loyalty using service quality model for higher education (HedQual) at industrial engineering department University of Pelita Harapan	
N Hartono, Laurence and B F Tjahjadi	
 View article	 PDF

OPEN ACCESS	012028
Expertise-based decision makers' importance weights for solving group decision making problems under fuzzy preference relations	
E Herowati	
 View article	 PDF

OPEN ACCESS	012029
Organic-inorganic nanocomposite membranes for molecular separation and bioapplications	
J Hou, P D Sutrisna, L Li and V Chen	
 View article	 PDF

OPEN ACCESS	012030
Tensile Properties of Kenaf Fiber by Alkalinization Treatment: Effect of different concentration	
Ismojo, K A Zahidah, E Yuanita, E Kustiyah and M Chalid	
 View article	 PDF

OPEN ACCESS	012031
How do the Indonesian ecologically conscious millennials value upcycled clothing?	
C A Parung	
 View article	 PDF

OPEN ACCESS	012032
Passive design implementation as sustainable development approach on vertical housing case study: Sentra Timur Residence	
T Riotama and H Herdiansyah	
 View article	 PDF

OPEN ACCESS	012033
Development and usability evaluation of virtual guide using augmented reality for Candi Gunung Geopir in	

Development and usability evaluation of virtual guide using augmented reality for Canal Gunung Gangsir in East Java

I M Ronyastra, I Hapsari and F P Pani

[View article](#) [PDF](#)

OPEN ACCESS

012034

The Role of Ergonomics in Supporting Supply Chain Performance in Manufacturing Companies: a Literature review

N Sampouw and M Hartono

[View article](#) [PDF](#)

OPEN ACCESS

012035

Fluazinam Potential as a Fungicide in Liquid Culture System for the Growth of *Haematococcus pluvialis* Microalgae

J R Witono, V Novianty, H Santoso, A Miryanti and A J Kumalaputri

[View article](#) [PDF](#)

Power System and Green Energy Management

OPEN ACCESS

012036

The use of pyrolusite to remove Pb and Cd in aqueous solutions: isotherm and thermodynamic

Y Fransiscus, M W B Kembie and N M Tanusaputra

[View article](#) [PDF](#)

OPEN ACCESS

012037

Power generation in a plant-microbial fuel cell assembly with graphite and stainless steel electrodes growing *Vigna Radiata*

K R S Pamintuan and K M Sanchez

[View article](#) [PDF](#)

OPEN ACCESS

012038

Gas sensitive properties of ZnO nanorods formed on silicon and glass substrates

V V Petrov, A P Starnikova, Y N Varzarev, K A Abdullin and D P Makarenko

[View article](#) [PDF](#)

OPEN ACCESS

012039

The study of the properties of lead zirconate-titanate films on silicon substrate after halogen lamps rapid thermal annealing

V V Petrov, A S Kamentsev, V V Polyakov and Y N Varzarev

[View article](#) [PDF](#)

OPEN ACCESS

012040

Temperature Dependence of Electrical Properties of ZnO Nanorods Array

V V Petrov, Y N Varzarev and K A Abdullin

[View article](#) [PDF](#)

OPEN ACCESS

012041

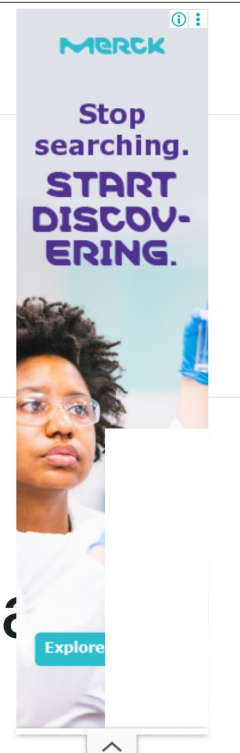
The kinetics oxidative degradation of chitosan in formic acid with the presence of hydrogen peroxide

E Purwanto, J Connor and Y Ngothai

[View article](#) [PDF](#)

OPEN ACCESS

012042



Discover more

- Open access journals
- Journal submission guidance
- scientific

IOP Conference Series: Materials Science and Engineering

United Kingdom | Universities and research institutions | Media Ranking

Discontinued in Scopus as of 2021

Country

United Kingdom



Subject Area and Category

Engineering
 Engineering (miscellaneous)
 Materials Science
 Materials Science (miscellaneous)

Publisher

IOP Publishing Ltd.

H-Index

82

Publication type

Conferences and Proceedings

ISSN

17578981, 1757899X

Coverage

2009-2021, 2024

Information

[Home](#)

[How to publish in this journal](#)

mse@iop.org

Scope

Th
pr
ph

Close

Ads by **clickiQ**

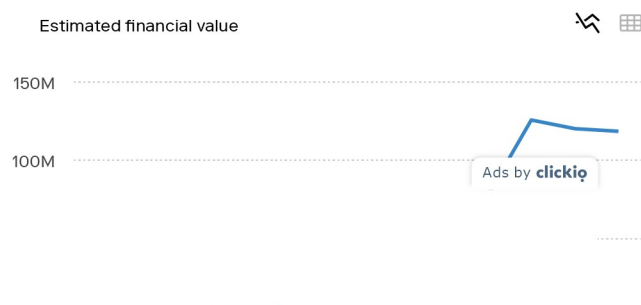
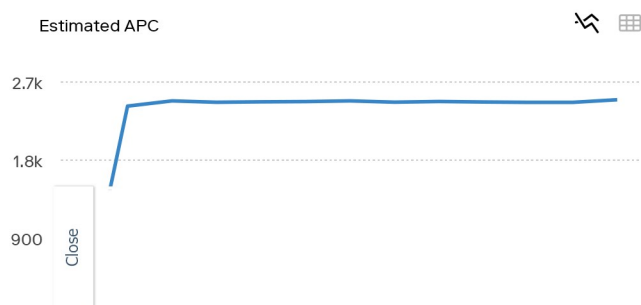
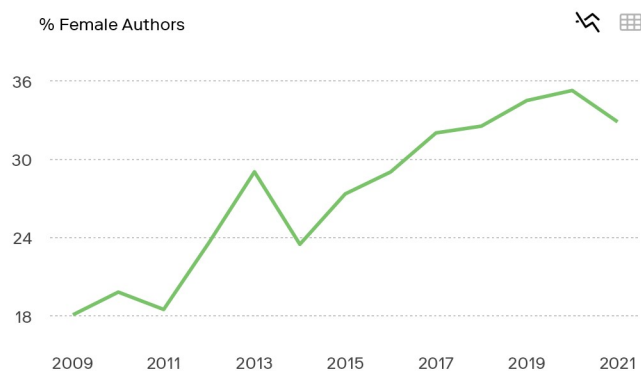
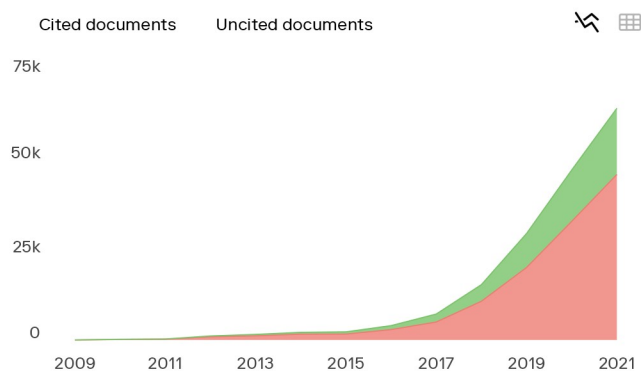
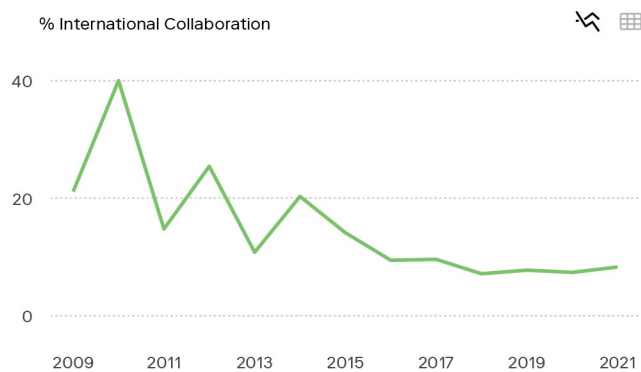
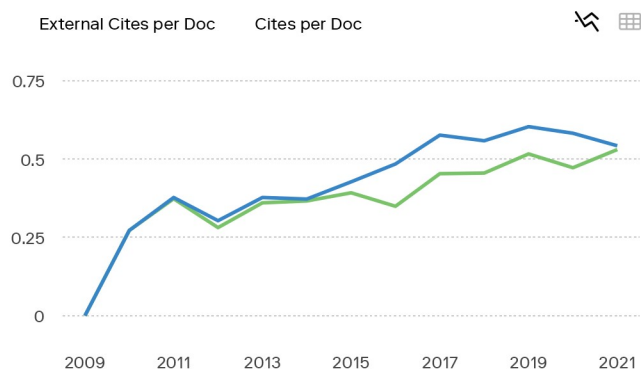
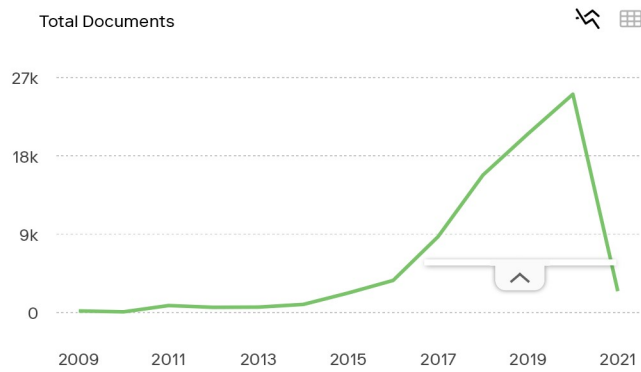
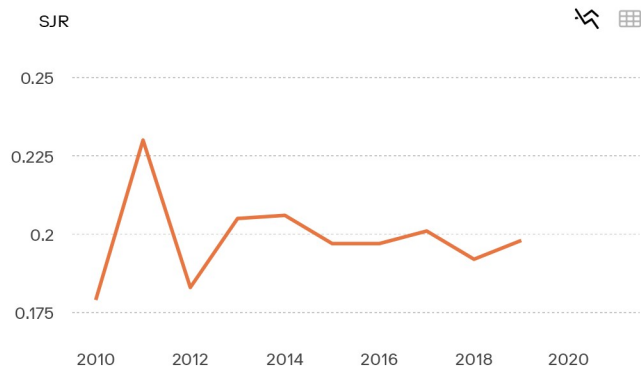
science and mathematics.

Discover more

Impact factor analysis >

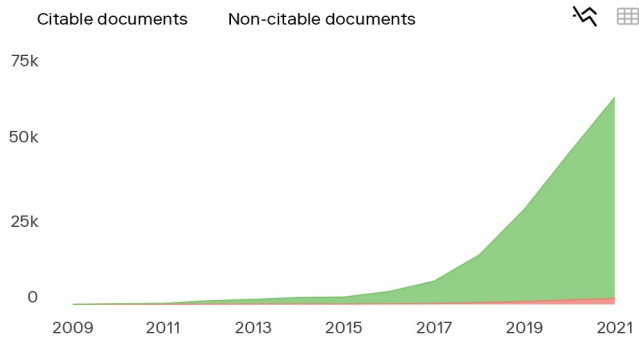
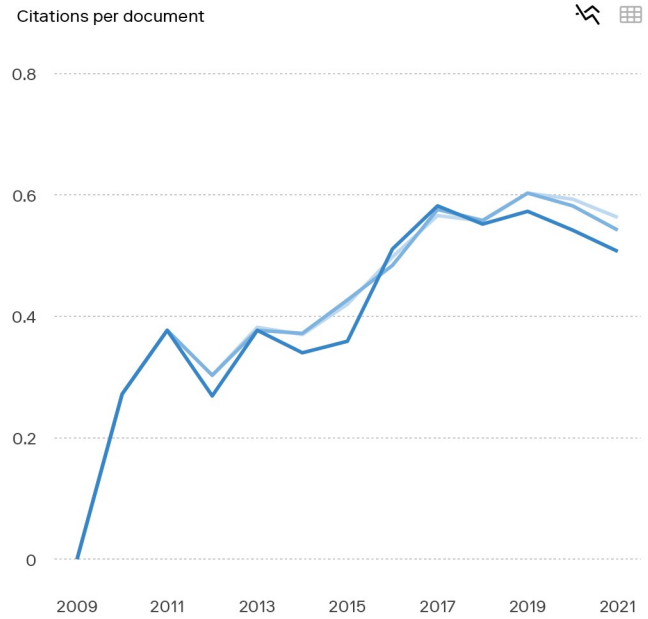
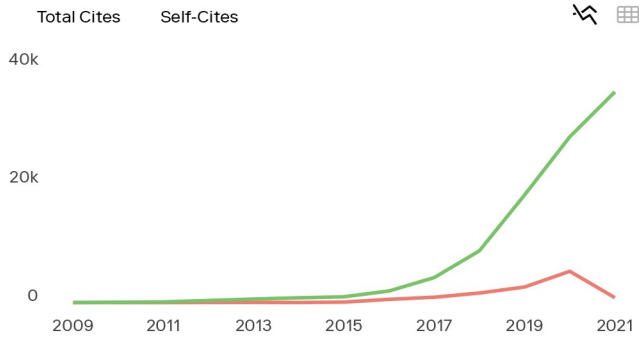
Economics >

Computer Science >



Year	Est. APC (USD)
2010	2424

Year	Est. value (USD)
2009	



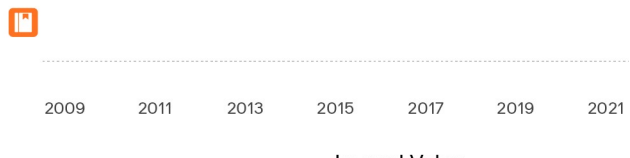
- Cites / Doc. (4 years)
- Cites / Doc. (3 years)
- Cites / Doc. (2 years)

Documents cited by public policy (Overton)

Documents related to SDGs (UN)



Coming soon



IOP Conference Series: Materials Science and...

Not yet assigned quartile

SJR 2025

powered by scimagojr.com

← Show this widget in your own website

Just copy the code below and paste within your html code:

```
<a href="https://www.scimag
```

SCImago Graphica

Explore, visually communicate and make sense of data with our **new data visualization tool.**

Powered by: Scopus®

Close



Source details

IOP Conference Series: Materials Science and Engineering

Years currently covered by Scopus: from 2009 to 2021

(coverage discontinued in Scopus)

Publisher: Institute of Physics Publishing

ISSN: 1757-8981 E-ISSN: 1757-899X

Subject area: [Engineering: General Engineering](#) [Materials Science: General Materials Science](#)

Source type: Conference Proceeding

CiteScore 2021

1.1



SJR 2021

0.249



SNIP 2024

0.622



[View all documents >](#)

[Set document alert](#)

[Save to source list](#)

[CiteScore](#) [CiteScore rank & trend](#) [Scopus content coverage](#)

CiteScore 2021

$$1.1 = \frac{68.488 \text{ Citations 2018 - 2021}}{62.140 \text{ Documents 2018 - 2021}}$$

Calculated on 05 May, 2022

CiteScore rank 2021

Category	Rank	Percentile
Engineering		
General Engineering	#194/300	35th
Materials Science		
General Materials Science	#362/455	20th

[View CiteScore methodology >](#) [CiteScore FAQ >](#) [Add CiteScore to your site](#)

About Scopus

[What is Scopus](#)

[Content coverage](#)

[Scopus blog](#)

[Scopus API](#)

[Privacy matters](#)

Language

[日本語版を表示する](#)

[查看简体中文版本](#)

[查看繁體中文版本](#)

[Просмотр версии на русском языке](#)

Customer Service

[Help](#)

[Tutorials](#)

[Contact us](#)

ELSEVIER

[Terms and conditions](#) ↗ [Privacy policy](#) ↗ [Cookies settings](#)

All content on this site: Copyright © 2026 Elsevier B.V. ↗, its licensors, and contributors. All rights are reserved, including those for text and data mining, AI training, and similar technologies. For all open access content, the relevant licensing terms apply.

