

KNάΨ τ Ετ'ΗέΖθ ηΐτ υ̇κζθΖβη KχϷΣΓ άΨ ἤΩΖ Κθ̇υε ὙνάτΗ
Η Ινάίε άΟΖάά ΚΩ ΩΜηέΓ ΒΙΞη ΓΩΓ Ὑς άΨ έΙΙ/ΙΙ θ ΟΑΦ
ΎΦεέε ΚΩ Οβκη ΩΜηέΓ ΕΤΓή Η ΤΨ .ΩΖὙΓ ΛάΙΦ έὙΨ ΚΩΪ ή
(ΗΙΗΗΐ)ΨΟη ΗhminH ἰhḥ °C

ὙΗέὙΓ ΠΘΑΕ Η άήΓβΩΝ
άΨ ἤΨΙΕΖβη ΨάΟΓ άἰΛΒγθ̇τ̇ά̇ΗέὙΓ ΩΖά Η άήΓβΩΝ ΔΜΝ
ΚΩ ΙΜΞΓ Ἰ/Ἰ L ὙνέJE ΒΞΡ ΚΩ άΟΖάά Ὑν ή ε ΛΗΤς ΚΥη
ρῡέΖ άΨ Η ΒΙΔΡ άΨ ἤΩΖ Κθ̇υε ΕΤέν Δη̇έΩ ΔΜΝ ΣΔς
ρῡέΖ Ε- άΨ Κū ωσΛΓ ΕΤέν τ Η̇h±h °C ΤΥΠΨ ΔΨ
ΕΨΟΔς ές ή ας .ΩΨεὙ ἤΨΙΕΖβη ΨΟη ἤΩΖ ΒΛέΓ ὙΦγὙὐ-
άΨ άέλἰι άΟϷΟΒ ἠΟ̇έὙ ή ἤΨΙΕΖβη τ άΟΖάά ὙΑΦΨ άἰοΓ
ΚΠΦΚϷΕ λE άήἠΟΛΤ ΒΞΙΛ ή ὙΖη̇έΩ ΚΞἸ Ἰ-Ἰ mm άἰσἸ
άΟΖάά ΚΩ (ΕἰέME ἡέέϷΖΟὙ) ΕἰέV ΔΖΟὙ ωΨκ ὈΒΞΓ
.ΩΖ ΚΓΙΞἸ

ἸhH hḥmg·NO₃⁻-N/Ι Δχά άΨ ΓἠέΖθ άΟΖάά ΚΩ Ε- έΩ ἠΗΒἰ
έVΙΕVέΖθΨ άἰΛἠέΖτΩ ΩΖά ήτθ ΨάΟΓ Ὑκ1λΖΦἸ άἰἢΕΓ ΨΟΓ
g ἡKH₂PO₄=h/Ἰ g ἡK₂HPO₄=Hg (έΖθ έΛ άΨ) ὙΤΙΖ
mgἸh·Na₂HPO₄=H/h g ἡMgSO₄=h/H g ἡNH₄Cl=h/Ἰ
mg/L (έΖθ έΛ άΨ) ὙΤΙΖ ὈΤθἸ ΨΟΓ h mg/L Η FeCl₃=
ἡMnCl₂ = Ἰh mg/L ἡCaCl₂ =ἸἸ mg/L ἡZnSO₄ =Ἰh
= mg/L hḥ ἡCuSO₄ = hḥ mg/L ἡ(NH₄)₆Mo₇O₂₄ = hḥ
ας .(ΗἸΗh)ΩΨεὙ ΚΓΙΞἸ EDTA = Ἰhḥ mg/L Η CoCl₂
άἰΛΒγθ̇τ̇ά̇ΗέὙΓ ρΒΟE ΓἠέΖθ έΓἸ ḘΨP Η ήHά ἰἸ ή
Η ΛάΙΦ άΟΖάά ή ἠέλἰι ΨέὙὐ ἠἰΛἠΟ̇έὙ ἡΚΖΤV ΩΖά
άΨ τ'ΟΕVέΖβ ἠἰὙΖΨ ή ἤΨΙΕΖβη τ Ε- ΚΩ ἤΦἰγτ ΒΑΦΟΦ
ἤΩΖ ἠΩΝ Ἰhḥrpm ε Φέτ Δἰέβ Η Ηhmin ΕΠή ΓΩΓ
.ΔἰέὙ άἠέἸ ἤΨΙΕΖβη ΨάΟΓ ΩὙ ΚΑΡέΓ άΨ Η

ΨέὙὐ ή ΓἠέΖθ ḘΨP ὙἠἠέΕΟEη Κθηθς άἰΛΒΖγθβ άΨ
ΕἠΟἠἰ ΚΩ Βγθ̇τ̇ά̇ΗέὙ ΩΖά ήτθ ΨάΟΓ ἠέέη ΚθΓΕ έΩ ἠΗΒἰ ἠέλἰι
ΚἠΤΠΡάΨ .(Ηh)Δβη ἤΩΖ ἤΨΙΕΖβη ΒΑΦΟΦΩ ΩΖά ΔΜΝ ἠέΖγἸ
ὙAs έΦχἸ ὙβἠΓ ἠἰΛέΖγἸ έὙΨ ή ἤΨΙΕΖβη ΓἠἠἠΓ έὙΨ άΨ
ΨΙΞV ὙΦΨ ΚΩΗ ἠἠἠἠ ΚὙέὙ ἡΖΖ ἡὙἠέβ ἡὙἠ ὙἠVH
ἡἸ)Δβη ΚΖἰέὙ άἠέἸ ΚΝΟE ΨάΟΓ ἠάΨέὙἠέΜΩ ὙβἠΓ ρῡέΖ
ΕΨΟη ḠΤ ὙΦΨ ΚΩ ΚἠΟ̇έὙ ἠἠἠἠ ΚὙέὙ ΕΤθ ΚVη άΨ .(ΗἸH ἠἸ
ὙVVέΖτΩ ὈὙN Δἠέφ ΕΨΟη ḠΤ Η ΕΨΟη Εἠήά ἠἠVH Πσβ
Ἰ) Δβη ΚΖἰέὙ άἠέἸ ἤΨΙΕΖβη ΨάΟΓ έὙΨ ΨΟΓ έVἡ ή ε Φ
ωἠΓ ΕἠΟἠἰ ΚΩ ἠέλἰι ΨέὙὐ ή ΒἠΟE ἤΨΙΕΖβη άΟχἠΓ ΚΩ .(ΗἸH
ἠέΖγἸ ΕἠΟἠἰ ΚΩ ἠἠἠἠ ΚὙέὙ Η ὙVVέΖτΩ ΩΖά ΔΜΝ ἠέέη
Ο- ὙὙVἠἠἠ ὙVἠἠ ΓἠέΖθ άΨ ΒΑΦΟΦΩ Ὑἠἠ ΔΜΝ ὙβἠΓ
ΚVἠὙVN ΕἠΟἠἰ ΚΩ ΩἠΟEὙΨ ΨέὙὐ τ ἤΩΖ ΟβκἸ ἠἠἠἠ ΚὙέὙ
έΞIP ἠIP άΨ ΚἸΖἠἠ. ΨέὙ ἠἠέἸ ΚΝΟE ΨάΟΓ Κθηθς άἰΛ δ Hά
άἰΛΩΡἠH ή ἠΟΦN ḘΨP ΔΜΝ ΩVΩN ἠΨΓ ΚVη ή ἤΨΙΕΖβη
Εἠἠἠ ε ΛΗΤς ΚVη άΨ .(ΗἸ ΗΗἸ)ΨΟΖὙἸ ἤΨΙΕΖβη Ὑἠἠἠἠ
ḘHέΕΟEη ἠἠἠἠἠἠ ή ἤΨΙΕΖβη τ Ὑἠἠἠἠἠ Ὀ- ὙVἠἠ ΓἠέΖθ
τ ἤΩΖ ΟβκἸ ἠἠἠἠ ΚὙέὙ έΖγἸ ἠIP ἠἠἠἠ έΖγἸ τ άΟΖάά άΨ
.Δβη ἤΩΖ ΚΖἰέὙ άἠέἸ ΚὙἠΓ ΨάΟΓ ἠέλἰι ΨέὙὐ

ἰΛ δ Hά Η ΨἠΟΓ

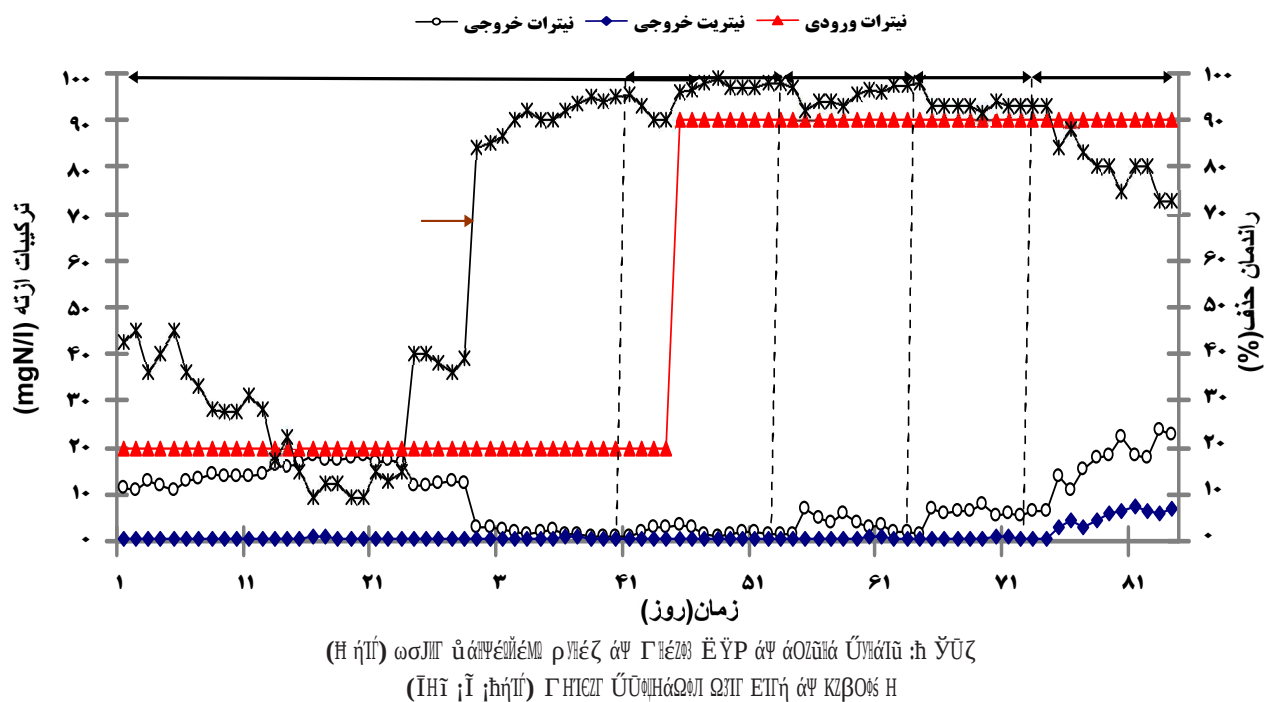
ἠέλἰι ΨέὙὐ τ ἤΩΖ ΟβκἸ ἠἠἠἠ ΚὙέὙ ΚΦME
ἠέάἠἠ ἠἠΚἠΟΖβη KχϷΣΓ ὙV ἠἠἠἠ ΚὙέὙ ΟβκἸ άΟχἠΓ ΚΩ
ήἠ ΛHέΦ Η ΨHάH ΒΖγθβ ΚΩ ΙΜΞΓ ΓάἠΡ έἠέἠ άΨ ΒΗΛΓ
ἤΨΙΕΖβη ΨάΟΓ Η ΔΦἡ ἡἠἠἠ ἠἠἠmL ὙνέJE ΒΞΡ ΚΩ
ἠέλἰι ΨέὙὐ Η ἠἠἠἠ ἠἠἠἠ ἠἠἠἠ ἠἠἠἠ ἠἠἠἠ ἠἠἠἠ ἠἠἠἠ
τ ΗἸ-ἸἸ ἠἠ ε Γ άΨ ὙΦεέε ΚΩ ΨάἠΩΖβη Ὑἠ ή ἤΨΙΕΖβη τ
έσἰ ΚΩ ἠἠΚἠἠHά τ Ηhḥ-hḥḥ Η H-h/Ἰ mLέσἰ ΚΩ ἠἠΚἠἠHά
ΚΩ Η ΚΩH Ὑἠἠ ΔἰγἸ άΨ SOἸ ἠΨΓ ΗΨ ή ὙςΟAXΓ ἡἸ-HἸἠμ
ὙὙVέΖὙἠ ἠάὐ ἠΨ Ὑἠἠ ΓάΟκ ΚΩ Η ΚΓΙΞἸ ἠέάἠἠ KχϷΣΓ
ΚΩΪ ὙV ΙVές ή ὙΦ ΕΨΟΔς ΒΛἠέἠ άΟχἠΓ ΚΩ .ΩΖ ἠΨἠ ἠἠέἸ

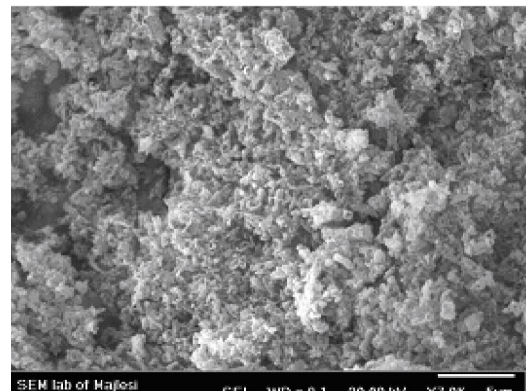
ἸΛΚΖΊΤΥ

ὙΨή Γ' ΕΖΘ ΕΐΘ

ρῡέζ τ ἀΟΖñά άψ Γ'έζΘ ΔχΑώ ε λιü κÜ πΟλέ MYIZ
ΨάΟΓ üΠlüέZüTÜ ûήτβΩN άOXΠf KÜ Kü ωσJΠ üάΨέÜÉΜÜ
ñΩZ ñΨΨ EINj HήIΓ hÛÜZ άΨ ΨOÜ ñΩZ KZÍëù έχj άΨ έχj
BTΞH ήñ hĩ d ΔZÛü T Kû ΔγJ ήñ ÜüTP MYIZ .Δβñ
ñΩZñ άΨ ÜNHÉF ñΩZ KθλE O- άΨ Γ'έζΘ ΔχΑώ Γ'InYITΓ-
SOΓ ETΓή Üç ήñ ας Πñ .Δβñ KZÍY ε Vñíñ αß ε λιü
EHíΘ H KZÍëù ΓάOk ÜMNOE Ÿññ áΩJΓ KÜ Γ'έζΘ ÈÛP
ήñ ε ΘÜ KÜ üάΨéÜ ñÉMO BHΨ ήIΓ ψHéz ήñ Ÿñ Γ'έζΘ ÈÛP
ΓάOk KÜ áOZñá üήñΩZñ ññá Tü H E- ήñ ας .Δβñ ñΩθβá èÍh
YγP éÜ Íh mg/L üΨHάH Γ'έζΘ KφIH ΔχΑώ Tü H BHIΩΓ
Kü h/~ H h~I ; I/Iñ h ΓHICZ ÜÜφHάΩφL ΩJΠ üIIEΠή άΨ Γññ
ñΩZ ñΨΨ EINj h ŸÜZ άΨ iH Ī ;ñ üIΛήIΓ άΨ YΘÉE KÜ
ézDü ññáOΔI áOZñá ήñ ÜNHÉF O- άΨ Γ'έζΘ ΔχΑώ Δβñ
èÍh ήñ ε ΘÜ íθ E- ÈÛP ETΓΩñά H LάΨ Γññ Hñ mg ήñ
άΩJΓ KÜ ÜÜφHάΩφL ΩJΠ ETΓή ε λιü Tü Ωñt él .Δβñ ñΨOÜ
άΨ JΘñtBL .Δβñ KZÍá ÉBñTÜ ÜNHÉF Γ'έζΘ ΔχΑώ üíθtZ

H B1E3H K3hHá ΓάOk Kú áOZúá ÚNHÉΦ ήí úáΨÉOKOΔ3
άέΩJΓ ЖΦΦυE ЎŶŶ ú1L δHά ú1Bíέú έχ3 ΨάOΓ ú1LέZTúA1S
úέZTOZúOZúSβH δHά ήí ņΨIEZβH TÚ ÚNHÉΦ ΓíέZú ΔχAó .ΩZ
ŊOς άΨ TŪVÉΓH HACH ΔúέZ ΔΦIβ (DR, 5000) UV
δHά ήí ΔVέZú úέΦúņņHΩ3H úíέú H έZTO3T3 hŶŶ ŌYN ΛOΓ
ήí ŶŶŶ .ΩZ ņΨIEZβH NitriVer3 ĒέúΓ ήí ņΨIEZβH TÚ ÚΞIβŬ3ά
άOZúá ήí ÚNHÉΦ K3OΔ3 ΔVέZú H ΓíέZú ΔχAó úέΦúņņHΩ3H
pH .ΩZ ņΨΨ άOŭŭ čŶŶŶ μ ŶŶŶΓ έOŶ TÚ ЖΔEHH ŬŶŶK ήí
úέZTOΦγTZS δHά ήí ņΨIEZβH TÚ ŶΨέE Kú ŬZXBH ΓάHΩú
ΩZΓΨάHΩ3TβH ú1ΨOΔŶLά ú1Bíέú ÚΞIβŬ3ά H ÚΞIβΓάHΩú
άΨ ŬŶΨ ΨOΓ Ŷú úέΦúņņHΩ3H ΔMN .(hņ)ΩZ άέΩJΓ ЖΦΦυE
TOC- ņΩΓ έZΓ TOC ņŶúZβΨ ήí άOZúá ήí ÚNHÉΦH úΨHÁH
ЖΦŶtBL .ΩZ ņΨIEZβH ЖSŭt Shimatzu ΔúέZ ΔΦIβV_{esh}
άΨ ΨέúŌH H έZγú úHά KŶŶŶ ΩZά BάŶOΦŌ EΨΨ EŶŶ3 ΔMN
ŬŶŶHά Ŭ3HέZŬŶ ŶŶŶŶHέŬŶŶ ņŶúZβΨ ήí ņŶŶŶ Жέú Πoβ
ņέú άOŶŭ ΔΦIβ AIS2100 Seron ņΩΓ SEM-EDX
.ΩΨέú ņΨIEZβH ŬŶŶŶŶ



 $\Theta \Sigma^0$

ΘΡΠΉ η̇ ὙΰΥ ΕΗΟΗ̇ ΚΩ ὉΈΞ Ὁ- ὙΰΥτ'ΟΙΟΦΩ ΚΘΕΛΕ
 ἄΟΧΠΓ ΚΩ ὙσφΣΓ Δγ'ή ἡτ'ΟΙΟΠῪΕΟΦΩ ΩΞἄ ΚΩ Ηἄ Η ΩΩΝΩΝ
 Η ЖП- ;Δ'έζθ3 ;Γ'έζθ3 ΚΑΔΝ η̇ Ὁ- ἡΠΤΛΠΦΩ ḘŸΡ
 ΚΩ ἐΦΦ ΕΠΦΠΒ ὙΣ ὙΰΥτ'ΟΙΟΦΩ ΚΥΞΕ ὙΠΪ ὙΠ- ΨΗΓ Η ἡΠῪΠ
 .(hH)ΔβΪ ΚΖ'εῦ ἄἔΪ ЖΘЈΣΓ ΚΝΟΕ ΨἄΟΓ ἡ̇ ἸΨέλγῡ ἄΟς
 ἡΠΒγφ3ῡἄἡ η̇ ἸΨΙεζβΪ τῒ Γ'έζθ3 ḘŸΡ ΕΙῪΓΗ̇ ΚῡΠσΓ ЖΥἡ ἄΨ
 Η ἄΗΠΠΞ ἐλγῡ τῒ ὙΰΥτ'ΟΙΟΦΩ Βλγφβ ρβΟΕ Ὁ- η̇ ḘΗΕΕΟΕ
 ΚῡΠσΓ ΨἄΟΓ ἡἔλἡἡ ΨεῡΟῦ τῒ ἸΩΞ ΟΒκἡ ἸΠσΓ Жῡἔῡ ἐλγῡ
 ḘΗΕΕΟΕ ἡΠΒγφ3ῡἄἡ ἡήΠβΩΝ ἄΟΧΠΓ ΚΩ .ΔβΪ ΚΖ'εῦ ἄἔΪ
 Γη̇ ἡἡῡ ΩΦΟΕ Η ΕΗέΖῪΠῡ ἸΩΞῡἔῡ ΕΗΟΗ̇ ΚΩ Γ'έζθ3 СΠΦРἡ τῒ Κῡ
 ὙΣΟΑΧΓ ;Κλγῡ ἄΟΖῡἄ ὙΥ ἄΨ ΔβΪ ἄῡῡἔῡΠΠΕ εἡἡἡ ЖΥἡ ἄΨ
 Η ὙΥΥἡἔῡτῒ ΩΞἄ ΔΜΝ ὙΚτλλΖΦἡ ὙΥῡῡΨ ΨΗΓ ; Γ'έζθ3 η̇
 αἡβΟβ ωΠΠκ ΚΠΦΚΘΕΛΕ ἡήΟΠΠτῒ ἄΟΖῡἄ η̇ ὙΚΠР ЖΞἡ
 Γ'έζθ3 ΔΧἈῶ ΕΨΟἡ βΠῒ Δἡἡ ΚΩ (ΕΗέΦΖΟῡ) Εἡἔγἡ ὅ τῡΠῡ
 ἡἔῡἡἡἡΩΞἡ ΓῡΠῡΠῡἡ- Κῡἡἡἄ ΓἄΟκ ΚΩ Η ΚΖΧῡἄ Ε- ΚΩ ἡΨἡἄἡ
 ἸΩΞ ἸΨΨϣ ΕΠῡ3 Η ἡΠῡ ḣ ὙῪΞ ἄΨ Ε- ΜΥΠΖ3 Κῡ ΩΞ ΒΠΞἡ Γ'έζθ3
 ἡἔῡΠἡἄ ἡἡῡ- η̇ ḣἡ d ΕΠῡἡ ΓΩΓ ὙΣ ὅ Πβἡ ЖΥἡ εἡ .ΔβΪ
 Ω3ἡἄ Ε- η̇ αἡ ἡ εἡΠῡ ḣΩΞἡ ἄΟΖῡἄἄ ἄΨ Γ'έζθ3 ΔΧἈῶ ἄΟΖῡἄἄ
 ἄΟοР ὙφΨ ΚΩ βΠДЗРἡ Γ'έῡῡἔἡ ЖΥἡ .ΔβΪ ΚΖΞΨ Ὑἡῡἡἡἡ
 ἸΨΠΓ ἄΟοР Η ЖΞἡ ΚΩД3 ἄΨ ΨΟΝΟΓ ḘΗΕἡἔῡἔῡ ἡΠΒγφ3ῡἄἡ
 ΕΨΟἡ ΒΠἔἡ Η ὙῪ- ἸΨΠΓ ΒΠДἡ η̇ αἡ ἡ .ΔβΪ ἸΨΠΖῡἡ STEH ὙῪ-

h h h i i t b a p e a t u d l h m a p b o e n o z b i e h g t u p o f
 g o g a p k u u a o s k o d b e i p p e t n h a u m i n g m y z z i o
 h i u n h e f a p p h e i o g o m n e i b i e h h i h a h i h e t g h
 a p . (h i) d b e i p o o i i - i i k i n p a p i p i e z b e p a o g a o z u a
 p p e t n h h h h h i t b a p s o a r e s g t u p o f k e f z k o a h j y
 b z g b a p p h e l i u u l u b e p o d k i t x j k o p a p k u
 i o s a p e g e f e e t i i p i z i t s i e e u t h e i o e u y p h g i i o
 . (h i) d b e i p e u e x j e e k y i i h b u u a p e u i e m g o g
 u n h e f a p p h e f e e e i o h h h i i t b a p e a t u d l h k i m
 e i o g h k z g p u l u b t u i d e e i o g t p e e i a a o z u a
 a o o p . (h h) o m p o d b e i i o p h h / h - h / i h a e l i u
 o m e u t u u n o i o o k e l e u l a o z u a h i u n h e f a p g a h o u
 . (h h) o z t a o z u a h i u n h e f a p l u e z u a o o p i p i z
 e t n i i y u z a p k u e f o k u p o f a p g a h o u g e f e e m y z z
 u n h e f a p g a h o u e i o g k z i a b t u h i u i p d b e i n o z i p p
 i i i h u u o h a o o l o z t e t g h a p k o i t b l . p a o a o z u a h i
 d b e i n o z i n o l i g a o z u a u n h e f a p g a h o u a o j g k n e z d u
 g a h o u e i o g h / i h h / i j h / i a o j g k u e l i u t p i
 e p o a h i n i z k u e o e u t h a a i . d b e i p o o d u i u n h e f
 i n o u h d i a k o i t b l h l i k z p i n a l h e f h e z g u d p
 p p d i y a o z u a h i e l h e f h (s l o u g h i n g) b a o f o o e o z
 . d b e i k z g p e i i i o m n e i h i u a p e u i e m h a p e i i i t k u
 d u i e z g t o k z i e u b i e h g t u p o f e i b a p k u d y o i p a p j y
 a p o m e u t y i t j y h i p o o b u i z i u n h e f g a h o u e i o g
 a e i k n o e p a o g a h i n i z e z g t u u f y o i o o u l b z g b o t x z h
 i p i e z b e p a o g u u n o i o o u l b z g b i n o d i o m t e l . (h h) p e u
 u a o d u e k e l e h i p i e z b e o m i t o o u t o u o i o i o e o o t s i t a p
 . (h h) o m z y l u i z u l u i t k e f z

y i t i o m e u d b g a h o u h i a o j g j y e i i i j y e u i u
 i y u z a p i n o z k n a m y z z u t b e o . o u o i y p k u i n o m u p h o z g
 u z x b k u d i y a o z u a h i u n h e f o u z x b a o j g a p u e f e e
 g t u e u t u h i p i e z b e d a i . d b e i n o z i n o l i g u p h a h o

e o z i b a t h k z i t y e i i i u o p t e a o z u a h i u n h e f i n o z
 e t g i a t s h p j y d x a o h / i h p h o p k u u u o h a o o l o z t e t g
 e i i i h h i m g / l h i e o k u y e e i k u o b m g t y i d o z
 u l p a o z i z b e i i e g o p h i e o k u d b e i n o z b a g h i y y p
 p b o e i n o z k n a m m y z z . (h h h i) p o o o m o f u z o m i z o u d e u
 u u o h a o o l o z t e t g k u d y o i h i u i p i o j o j s g e i b
 t h k z i y u e o t e u u n o i o o k e l e b z g b u y a i u e i
 e t g k o i t b l . d b e i k z i t y e l i u b z g b e i g o h a e l i u
 y j y g b t u o m e u t b z g b e l a p k i o m u u o h a o o l o z t
 u u p h u u o h a o o l o z t e t g e i m h b i . (h h h i i j i) o z t
 u l e i n e h p e u a d i e o b m g t y i d o z o u y i o u l a o z u a i h i e u p
 u u n o i o o k e l e u l o m n e i a p u o a b u l p h t h t y i d o z o o
 i y u i e z u u u d y i z d o i u t e i o e i y e s h i y t i j y . d b e i
 i o a b e h a p k u p o g i n j z h y o m y e h t y i d o z p o g e o f b i o y
 k i o m p h i z b a j y a p . (i) d b e i a i y u e o p e b z g b p e u a d i e o
 k o o u e i i - i i k i n p a p e i y e z o p u l l c e z u o z a d m n
 u l o m n e i a p h k p i u g i i s e i m h b i . (h i h h h) d b e i n o z
 u u n e o i k u e t h a o o l e o u u o h e o e i e i y e z o p u u n o i o o
 p o s g p h e l i u y i b k u p e u u t o o o e i n e g y o l a s g h i
 y i p a p j y e u i u . p o z u t u n e u o p e u a d i a p i b z o p i e y h
 o u e i t d o f e f b o x i e d m n u l u b u l b z g b k o i t
 . p e u u t a e i i p i e z b e p a o g

(H)
 1.1 S⁰ + No₃⁻ + 0.76 H₂O + 0.4 Co₂ + 0.08 NH₄⁺ →
 1.1 So₄²⁻ + 0.08 C₅H₇No₂ + 1.28 H⁺ + 0.5 N₂
 u p h a h o p h e i i i d m n a h i o b p o b h i k u p o f j y a p
 u t b e o . d b e i n o z i p i e z b e p h d i e e i n a o x i g k u a o z u a k u
 e i o g k u a o z u a h i u n h e f p h i i y u z a p i n o z k n a m m y z z
 i n o z b a i i ± h / h k o u z i o g k u h k z i t y e l i u o p h h / i t e h / i
 b u m h b i k u d b e i u z o m i z o u u l p a o z i z b e o p a p k u d b e i
 . d b e i k z i o z e e f e e e i u e o p e i o u u o h a o o l o z t e t g e o z
 e p o d k i t x j h i e o e u t i k u u p h a h p h b o x i e t h a j y h i
 . (h i) p o d b o m z n h a o z u a k u u l u b

دوره پنجم / شماره چهارم / زمستان ۱۳۹۱

1. Zhang TC, Lamp DG. Sulfur: limestone autotrophic denitrification processes for treatment of nitrate contaminated water: batch experiment. *Water Res.* 1999; 33(3):599-608.
2. Sierra-Alvarez R, Beristain-Cardoso R, Salazar M, Gomez J, Razo-Flores E, Field JA. Chemolithotrophic denitrification with elemental sulfur for groundwater treatment. *Water Res.* 2007;41 : 1253 –62.
3. Kimura K, Nakamura M, Watanabe Y. Nitrate removal by a combination of elemental sulfur-based denitrification and membrane filtration. *Water Res.* 2002; 36: 1758–66.
4. WHO .Guidelines for drinking-water quality. [electronic resource]: 3rd ed. Geneva, Switzerland. Vol. 1: Recommendations. World Health Organization; 2006.
5. Pekdemir T, Kacmazoglu EM, Keskinler B, Algur OF. Drinking Water Denitrification in a Fixed Bed Packed Biofilm Reactor. *Tr. J. of Engineering and Environmental Sciences.* 1998; 22: 39-45.
6. Wang Q, Feng C, Zhao Y, Hao C. Denitrification of nitrate contaminated groundwater with a fiber-based biofilm reactor. *Bioresour Technol.* 2009; 100: 2223–7.
7. Godini H, Rezaee A, Beranvand F. Hydrogenotrophic Denitrification of Water Using Zero Valent Iron Nano Particles. *Iran. J. Health & Environ.* 2010; 3(2): 143-152
8. Weisenburger DD. Potential health consequences of groundwater contamination by nitrate in Nebraska. In: Bogardi I, Kuzelka RD, editors. *Nitrate contamination*, NATO ASI Ser., vol. G30. Germany: Springer, 1991.
9. Bitton G. *Wastewater Microbiology* 3ed. Florida: John Wiley & Sons Inc Publication; 2005.
10. Wang H, Qu J. Combined bioelectrochemical and sulfur autotrophic denitrification for drinking water treatment. *Water Res.* 2003; 37:3767–75.
11. Wan D, Liu H, Qu J, Lei P, Xiao S, Hou Y. Using the combined bioelectrochemical and sulfur autotrophic denitrification system for groundwater denitrification. *Bioresour Technol.* 2009; 100: 142–8.
12. Kim HR, Lee LS, Bae JH. Performance of a sulphur-utilizing fluidized bed reactor for post-denitrification. *Process Biochem.* 2004; 39(11): 1591-7.
13. Zhang Z, Lei Z, He X, Zhang Z, Yang Y, Sugiura N. Nitrate removal by *Thiobacillus denitrificans* immobilized on poly (vinyl alcohol) carriers. *J Hazard Mater.* 2009; 163: 1090–5.
14. Liu LH, Koenig A. Use of limestone for pH control in autotrophic denitrification: continuous flow experiments in pilot-scale packed bed reactors. *J Biotechnology.* 2002; 99: 161-171.
15. Zeng H, Zhang TC. Evaluation of kinetic parameters of a sulfur–limestone autotrophic denitrification biofilm process. *Water Res.* 2005; 39: 4941-52.
16. Soares MIM. Denitrification of groundwater with elemental sulfur. *Water Res.* 2002; 36:1392–5.
17. Ma LU, Yang BL, Zhao JL. Removal of H₂S by *Thiobacillus denitrificans* immobilized on different matrices. *Bioresour Technol.* 2006; 97: 2041- 6.
18. Liu W, Vidic RD, Brown TD. Optimization of high temperature sulfur impregnation on activated carbon for permanent sequestration of elemental mercury vapors. *Environ. Sci. Technol.* 2009; 34(3):483-8.
19. Vidic RD, Liu W, Brown TD. Development of novel activated carbon-based adsorbents for control of mercury emissions from coal-fired power plants. *Proceedings of the Aadvanced Coal-Based Power and Environmental Systems Conference*; 1997 July 22-24; Pittsburgh, Pennsylvania.
20. APHA, AWWA, WPCF. *Standard Methods for the Examination of Water and Wastewater.* 18th ed. Washington DC: APHA; 1992.
21. Rittmann BE, McCarty PL. *Environmental Biotechnology: Principles and Applications.* Boston: McGraw Hill; 2001.
22. USEPA. *Guidelines for Drinking Water Quality.* United State Environmental Protection Agency. 1999.
23. Liu H, Jiang W, Wan D, Qu J. Study of a combined heterotrophic and sulfur autotrophic denitrification technology for removal of nitrate in water. *J Hazard Mater.* 2009; 169(3):23-8.

Drinking Water Denitrification using Autotrophic Denitrifying Bacteria in a Fluidized Bed Bioreactor

Abdolmotaleb Seid-mohammadi¹, Hossein Movahedian Attar², *Mahnaz Nikaeen²

¹Department of Environmental Health, Faculty of Health, Hamadan University of Medical Sciences, Hamadan, Iran

²Department of Environmental Health, Environment Research Center, Isfahan University of Medical Sciences, Isfahan, Iran

Received: 23 April 2011 ; Accepted: 23 July 2011

ABSTRACT

Background and Objectives: Contamination of drinking water sources with nitrate may cause adverse effects on human health. Due to operational and maintenance problems of physicochemical nitrate removal processes, using biological denitrification processes have been performed. The aim of this study is to evaluate nitrate removal efficiency from drinking water using autotrophic denitrifying bacteria immobilized on sulfur impregnated activated carbon in a fluidized bed bioreactor.

Materials and Methods: After impregnating activated carbon by sulfur as a microorganism carriers and enrichment and inoculation of denitrifying bacteria, a laboratory-scale fluidized bed bioreactor was operated. Nitrate removal efficiency, nitrite, turbidity, hardness and TOC in the effluent were examined during the whole experiment under various conditions including constant influent nitrate concentration as 90 mg NO₃--N/l corresponding to different HRT ranging from 5.53 to 1.5 hr.

Results: We found that the denitrification rates was depended on the hydraulic retention time and the nitrate removal efficiency was up to 98% and nitrite concentration was lower than 1mg/l at optimum HRT=2.4 hr respectively. Moreover, there was no difference in hardness between influent and effluent due to supplying sodium bicarbonate as carbon source for denitrifying bacteria. However pH, TOC, hardness, and turbidity of the effluent met the W.H.O guidelines for drinking water.

Conclusion: This study demonstrated that an innovative carrier as sulfur impregnated activated carbon could be used as both the biofilm carrier and energy source for treating nitrate contaminated drinking water in the lab-scale fluidized bed bioreactor.

Keywords: Denitrification, Impregnated activated carbon, Autotrophic bacteria, Fluidized bed bioreactor

*Corresponding Author: nikaeen@hlth.mui.ac.ir

Tel: +98 311 7922660 , Fax: +98 311 6682509