BULK ETCH RATE MEASUREMENT OF CR-39 DETECTOR AT CONSTANT NORMALITY USING THE DIAMETERS AND THE LENGTHS OF THE TRACKS OF α-PARTICLES

Hussein **A. A**hmed
Dept. of Physics, Faculty of Science, University of Zakho, Kurdistan Region – Iraq.
(Accepted for publication: December 21, 2014)

Abstract

The aim of this paper is to determine the bulk etch rate of Nuclear Track Detector (type CR-39) using the track's diameter-length (Le-D) measurement method by irradiating the detector with different energies of alpha particles from ^{241}Am source. Constant normality (6.25) N of the chemical solution NaoH at a temperature of (70±1) ^{o}C is used in etching the detectors to measure the track's lengths and it's diameter at different etching times corresponding to the energy of the incident's particles. The bulk etch rate V_B values of CR-39 detector have been found by using Le-D method are (1.4228, 1.2563, 1.5098, 1.438) µm.hr^{-1} and they showed good agreement with the values measured by the removed layer method which were (0.944-1.831) µm.hr^{-1}.

Key words: Bulk etch rate. CR-39, Track length, Nuclear Track Detector (NTD).

Introduction

A heavy charged particle leads to intensive ionization when it passes through matter. Along the path of the particle, a zone called the *latent track* is created, which is enriched with free chemical radicals and other chemical species. If a piece of material containing the latent track is exposed to some chemically aggressive solution (such as aqueous NaOH or KOH solution) the chemical reaction would be more intensive in the latent track. Such a solution is called the etchant. Through the etching, the latent track becomes visible as a particle "track" which may be seen under an optical microscope. The effect itself has been known for long time, which is called the "track effect" (Nikezic and Yu, 2006), The technique has been extensively investigated in the literature, and has been widely applied in many fields of science and technology (Nikezic and Yu, 2003). The main use of CR-39 plastic detector is in the field of health physics, such as for detection of proton, helium and heavy charged particle, radon monitoring and neutron dosimetry (Jain, et al., 2013)

Two main parameters that govern the track formation are the bulk etch rate V_B and the track etch rate Vt. These two important variables were introduced by Fleischer et al. (Fleischer et al. 1975). The bulk etch rate V_B is the rate of removing of the undamaged surface of the detector. Due to the chemical reaction between the etching solution (etchant) and the detector material, some molecules of the detectors are removed. The final track is the removal of the material from the detector surface.

During etching, the material is removed, layer by layer, and the thickness of the detector becomes smaller and smaller.

The bulk etch rate has been the subject of many measurements in the past, and it is probably the most frequently measured quantity concerning track detectors. It has been determined in a variety of materials, irradiated by different ions and etched under various etching conditions. There are several V_B, determination methods broadly categorized into indirect and direct methods.

One of these methods is the determination of V_B from the diameter of tracks of fission fragments; this is one of the oldest and most frequently used methods for determination of V_B. Fission fragments are easily obtained from a ^{252}Cf radioactive source. Since the ranges of fission products are relatively small, the track etch rates can be considered constant during etching. Under this condition, the following simple approach can be applied. When the incidence is normal and Vt = constant, the diameter of the track opening is given by (Nikezic and Yu, 2004):

$$D = 2h\sqrt{\frac{V-1}{V+1}} \qquad (1)$$

where V = (V_t/V_B), and h is the thickness of the removed layer during etching.

The bulk etch rate could be determined from the change in the mass of the detector Δm and the density of the detector material, V_B could be calculated as (Durrani and bull, 1987) and it is based on Eq. (2):

$$\mathbf{V_B} = \frac{\Delta m}{2A\rho t} \quad (2)$$

where Δm is mass difference, A the etched surface area, ρ the density of the detector and t is the etching time.

Nikezic and Janicijevic proposed a "peel-off" method to directly measure the bulk etch rate for the LR-115 detector based on surface profile measurements using an instrument called (Taylor Hobson, Leicester, England).(Nikezic and Janicijevic, 2002).

From the other methods of measurement V_B the track of high gamma dose on the response of PADC detector (CR-39). The bulk etch rate V_B, alpha track etch rate Vt and the sensitivity or etch rate ratio-V = V_t/V_B were measured based on measurements of the track diameters for normally incident fission fragments and alpha particles according to the equation(Salman, 2010):

$$V_B = \frac{D_f}{2t} \quad (3)$$

Where D_f is the diameter of tracks resulting from the fission fragments.

Also V_B could be measured by another method; and it is by measuring the cone base diameter D, and the height Le, this method requires selecting only tracks for which precise measurements of the cone height and diameter could be performed (for example we cannot measure the track cone heights for low energies, for which the microscope image may be affected by shadow tracks).(Manzoor, 2006; Balestra et. al., 2007).

$$V_B = \frac{D^2}{4tL_e}\left[1 + \sqrt{1 + \frac{4L_e^2}{D^2}}\right] \quad (4)$$

Since V_B is one of the most important parameters that control the formation and development of tracks, there has been a large literature debate discussing V_B. Here, an incomplete survey of works on V_B was given. It has been shown that V_B depends on many factors like the purity of the basic substances, the molecular structures of polymers, conditions of polymerization, environmental conditions during the irradiation and finally the etching conditions. In this way, there are different topics related to V_B, which included the following:

_ Dependence of V_B on the chemical composition and preparation of the detector;

_ Dependence of V_B on the etching conditions (temperature and concentration of etching solution as well as the presence of stirring);

_ Dependence of V_B on the irradiation of the detector before etching with different kinds of ionizing or non-ionizing radiations(Nikezic and Yu, 2004).

Experiment

The CR-39 detectors used in the present work were irradiated with alpha particles with energies (2.0, 2.9, 3.6 and 4.3) MeV. An ^{241}Am alpha-particle source (main initial energy E_o =5.48 MeV) was employed, and the stopping medium between the source and the detectors was air. The irradiated detectors were etched in an aqueous 6.25 N NaOH solution at a temperature of 70 ◦C for different duration times of etching process. The lengths and the diameters of the tracks were measured by using a digital camera of type MDCE-5A fixed directly on the light microscope and connected to the computer by using Image Driving Software which is provided with the camera for picturing the lengths and the diameters of the tracks.

Results and discussion

There are two methods to find the bulk etch rate for the used detector; it can be found either by irradiating it with charged particles or without irradiating it with those particles in the methods of measuring the V_B. There is a modern method to measure V_B, by measuring the length - diameter of the track. This method (Le-D) requires irradiating the detector with charged particles and photographing the form of etching tracks that were formed in the detector due to the etching solution, and measure the length and the diameter experimentally. While it requires the other known methods - including the method of measuring the thickness of the removed layer from the surface of the detector - to measure the thickness of the detector after etching operations for successive periods of time without the need to irradiate it with charged particles.

Figure (1) shows the relationship between multiplying etching period in along the formed track and the square of the track diameter (t*Le & D^2) at different energies of alpha particles.

Figure (2) shows the relationship between the square of the track diameter and the square of the track length (D^2 & Le^2) through different periods of time with energies of alpha particles (α) (2.0 , 2.9, 3.6, 4.3) MeV. It can be observed from the figures that the relationship between (t*Le & D^2) and (D^2 & Le^2) are almost a linear relationships in stage of cone regular track , and that the relationship does not continue to change linearly with the increasing of etching hours over this stage , because the length of the track increases through etching time and up to permanence or saturation at the end of the first stage when it reaches the top of the etching track to end over the particle in the detector , while the diameter of the track continues to increasing with the progress of etching at the stage of over-etching that extent outside the range of the particle in the detector. Thus, our measurements must be within the regular phase of the cone shape of the track, where we have performed measurements for different times of etching.

The stoppage of etching at the times that shown in the figure 1 and figure 2 is attributable to the lengths of the formed tracks do not continue to increase with the increasing of the tracks diameters with the progress of etching; R' should not have a negative value when etching solution reaches a depth greater than the extent of the particle inside the detector and after over-etched of the detector.

To measure V_B in a method of the removed layer thickness from the detector by etching without irradiating it with alpha particles (by etching the detector in a background), just by etching CR-39 detector by using the etchant solution itself NaOH at temperature (70 ± 1) °C at the same normality.

Figure 3 shows the relationship between the bulk etch rate(V_B) using the method of Le-D and energies of alpha particles were used to irradiate the detector CR-39. It could be seen from the figure that the bulk etch rate V_B is independent on energies of α-particles (i.e. the relation is constant). The values of V_B are around 1.4 µm /hr.

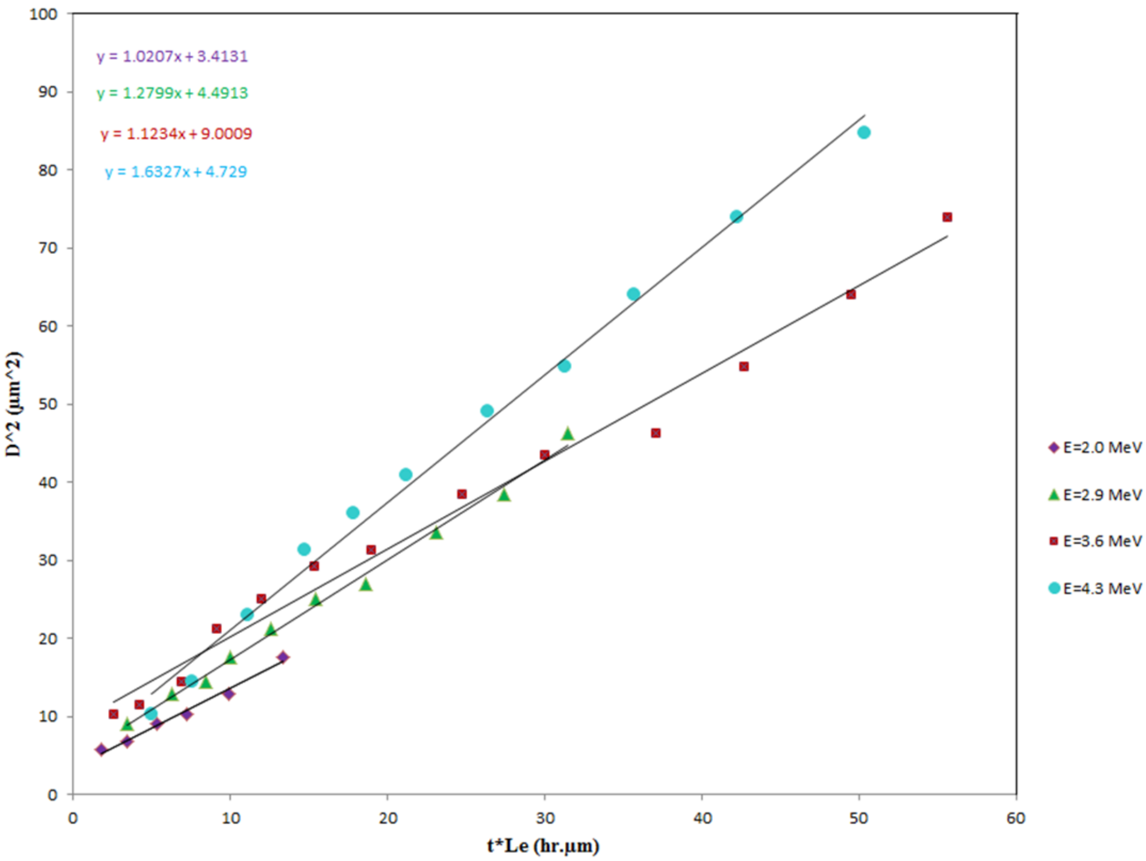

Fig. (1): The relationship between the square of the track diameter (D^2) and the product of etching time (t) and height (Le) at different energies of alpha particles.

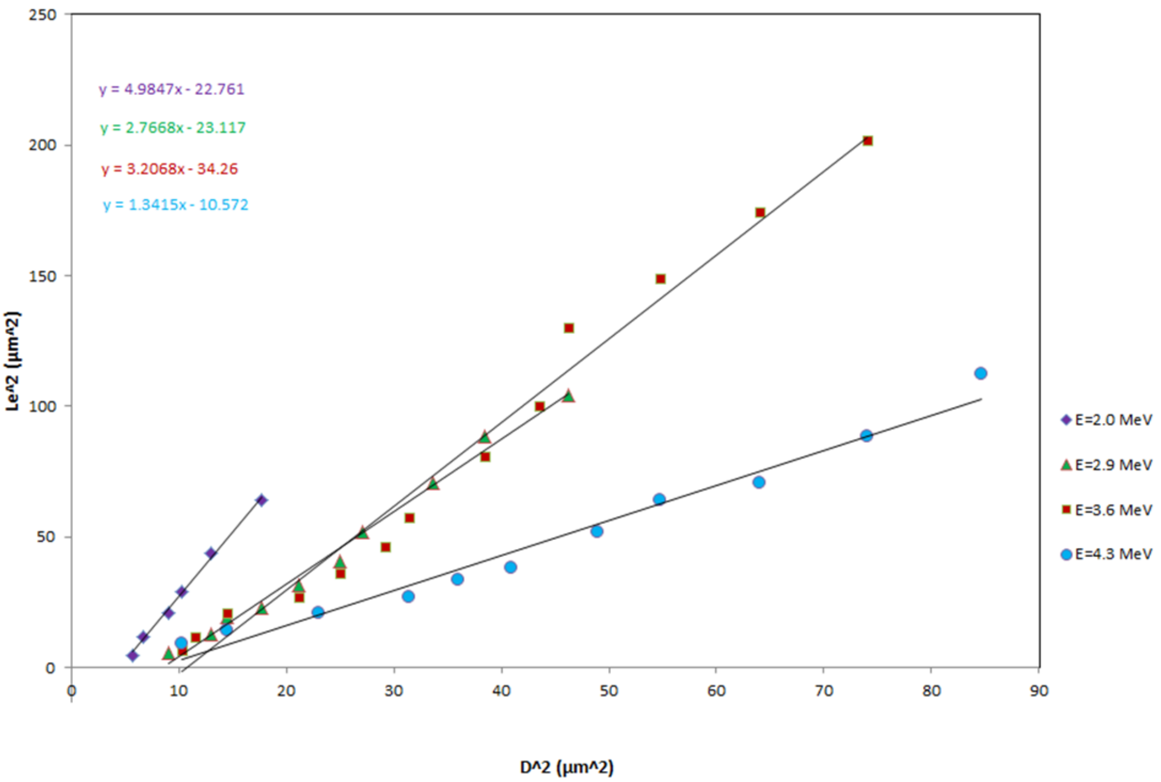

Fig. (2): The relationship between the square of the track diameter (D^2) and square of height (Le) at different energies of alpha particles.

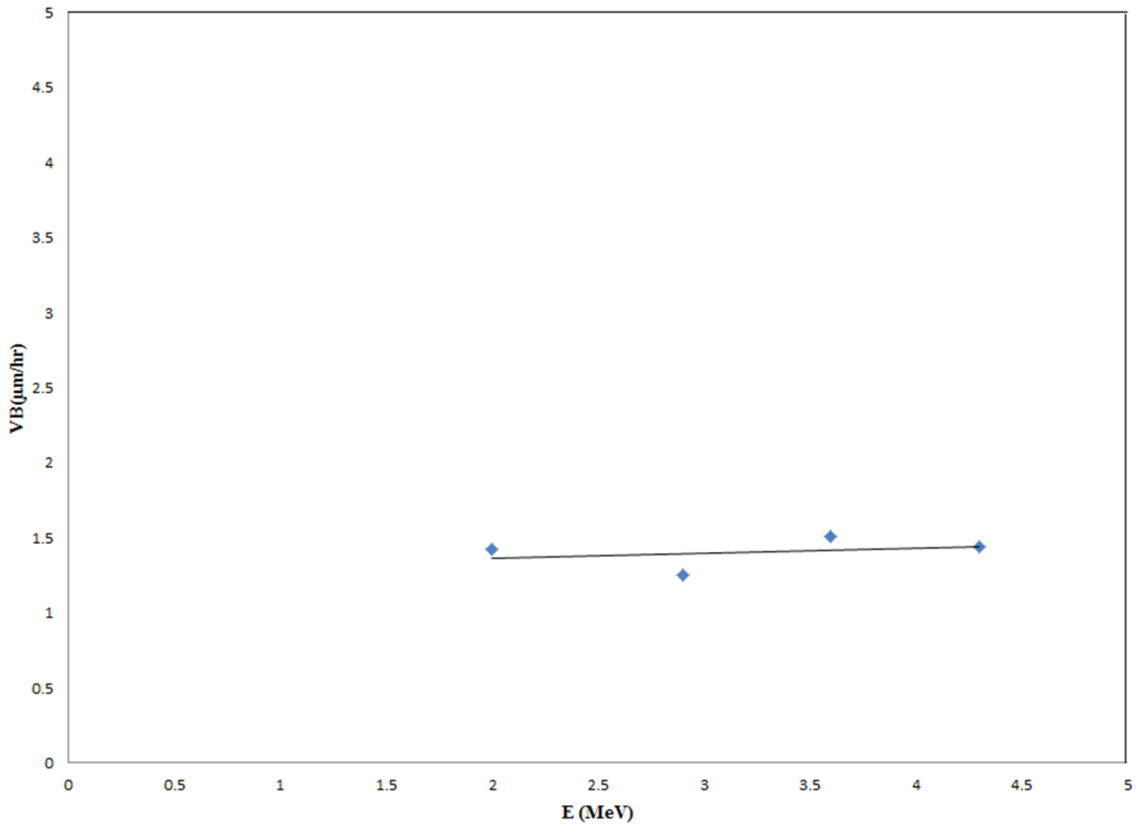

Fig. (3): The relationship between the bulk etch rate (V_B) and the energies of alpha particles at constant normality.

This value is rather consistent with the value of V_B obtained by the method of Le-D and the method of measuring the thickness of the removed layer as shown in Figure 4 which has been proved by (Al-Nia'emi and Kasim., 2013) and the value of V_B is 1.23 µm /hr (Ho et al., 2003) and the value of V_B is 1.45 µm /hr (Ahmed, 2010) and the value of V_B is 1.7 µm /hr (Yu et al., 2005) by using NaOH at the same normality (6.25 N).

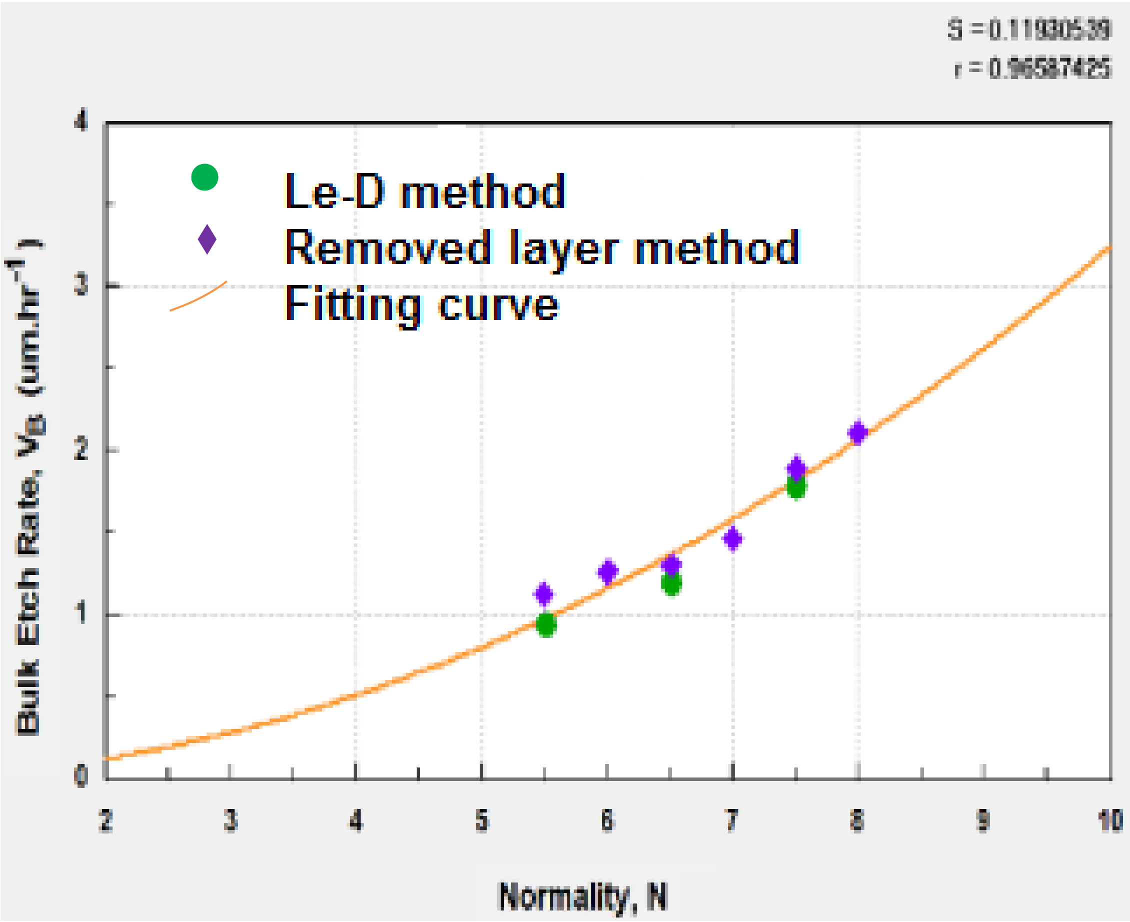

Fig. (4): Rates of the bulk etch using the method of the removed layer thickness and the method Le-D with different normality (Al-Nia'emi and Kasim, 2013).

Conclusions

From the obtained results we conclude that the method Le-D gives good results to measure the bulk etch rate (V_B), but it's not a simple method because it requires to get photos of the tracks in the detector, measurement of the lengths and the diameters accurately. Also the bulk etch rate does not depend on energy of the particles that is used to irradiate the detector. It was found that the results of V_B that were measured by using the thickness of the removed layer are rather compatible with the results of V_B that were measured by using Le-D method that requires irradiating the detector with the particle charged with different energies.

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پێوانەیی بارستاییی ڕێژە هەڵدەکوڵی CR-39 دۆزەرەوە لە نۆمالەتیی نەگۆڕ لەلایەن بەکار هێنانی تیرەی بازنەیەکە و درێژیەکەی ڕێیەکە

کورتي

ئامانجێ ئەڤ کاخەزە دا ڕێژە یێ بارستایی هەڵدەکوڵی دۆزەرەوەێ ڕێ ناووکی دیاری بکە (جوور CR-39) تیرەی بازنە-درێژی ێ ڕێ بەکار دهێنە (Le-D) ڕێگەێ پێوانە ب یرراداتینگێ دۆزەرەوە ب وزەی جیاوازێ تەنۆچکەێ ئەلفا ددە ^{241}Am ژێدەر ب نۆمالەتیی نەگۆڕ (6.25 N) ئێنێ ناوە ێ ل کیمیاوی چارەسەری NaOH پلەی گەرمیەکێ (70±1) ^{o}C ئۆك هات بەکار هێنان د ناڤ هەڵدەکوڵیێ دۆزەرەوە دا درێژی ێ ڕێ بپێوە ئوو وی تیرەی بازنە ل هەڵدەکوڵیی جیاواز حەیام نامە دگۆڕنەوە بۆ وزەیێ تەنۆچکە ێ ڕوواو .بەها یێ CR-39 بارستاییێ ڤب هەڵدەکوڵی ڕێژە دۆزەرەوە بوویە دۆزییەوە ب بەکار هێنان ڕێگەێ –دیە (1.4228, 1.2563, 1.5098, 1.438) $\mu m.hr^{-1}$ ئوو وان ڕێککەوتنی باش شان دا ب بەها پێوا ب ڕێگەێ چین لا برد کۆ بوو (0.944-1.831) $\mu m.hr^{-1}$.

حساب معدل القشط العام للكاشف CR-39 عند عيارية ثابتة باستخدام اقطار واطوال الاثار

خلاصة:

الهدف من هذا البحث هو لتحديد معدل القشط العام لكاشف الاثر النووي (نوع CR-39) باستخدام طريقة قياس طول–قطر الاثر (Le-D) عن طريق تشعيع الكاشف بطاقات مختلفة لجسيمات الفا من المصدر 241Am بعيارية ثابتة (6.25N) للمحلول الكيميائي NaOH عند درجة حرارة ^{o}C (70±1) لقشط الكواشف لغرض قياس اطوال الاثار واقطارها عند فترات قشط مختلفة تبعا لطاقة الجسيمات الساقطة. وكانت قيم معدل القشط العام VB للكاشف CR-39 التي وجدت باستخدام طريقة Le-D هي (1.4228, 1.2563, 1.5098, 1.438) $\mu m.hr^{-1}$ واظهرت توافق جيد مع النتائج المستحصلة باستخدام طريقة الطبقة المزالة والتي هي (0.944-1.831) $\mu m.hr^{-1}$.