# CALCULATION OF RADON DIFFUSION COFFICIENT AND DIFFUSION LENGTH IN SOME SOILS TYPES

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**ABSTRACT**

**In this study, the effect of humidity on the diffusion coefficient of radon gas and the diffusion length was studied in different soils .We have used a modern device( SARAD German-made)was used to calculate the concentration of radon in different degrees of humidity and temperature. After linking it to the exposure system for radon, which was made by the researchers ,results obtained for soil indicated to a great agreement between the theoretical(predicted) and practical (measured) values of the results of this study. The study also indicated that diffusion coefficient decreased at slightly increasing of humidity by (10% -60%) of the diffusion coefficient results in the low humidity levels, which are less than 40% with a significant increase of more than(10%-60%)for humidity levels greater than 40% .Also for the diffusion length, it decreases with increasing of humidity.**

**Keywords: humidity, exposure system, radioactive.**
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## حساب معامل انتشار الرادون و طول انتشاره في بعض انواع الترب

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**المستخلص**

تم في هذا البحث دراسة تأثير الرطوبة في معامل وطول انتشار غاز الرادون خلال ترب مختلفة ،حيث تم استعمال جهاز حديث SARAD الماني الصنع في حساب تركيز غاز الرادون عند درجات رطوبة وحرارة مختلفة بعد ان يتم ربطه مع منظومة التعريض لغاز الرادون التي تم تصنيعها من قبل الباحثين .اشارت النتائج المستحصلة للتربة الى تقارب كبير بين القيم النظرية (المتنبأ عنها) والعملية(المقاسة) لنتائج هذه الدراسة مما ادى الى اعتمادها في حساب معامل الانتشار وطول الانتشار لمواد اخرى لم تتم دراستها عمليا أو نظريا.كما اشارت الدراسة الى تناقص قيم معامل الانتشار بزيادة الرطوبة وبشكل قليل بنسبة (10% – 60%) من نتائج معامل الانتشار عند درجات الرطوبة القليلة اقل من 40% وبنسبة كبيرة تصل بحدود ( 60% – 10%) عند درجات رطوبة اكثر من 40% وكذلك الحال لطول الانتشار حيث يتناقص الطول مع زيادة الرطوبة .

كلمات مفتاحيه: الرطوبه، منظومة التعريض، نشاط اشعاعي.
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## INTRODUCTION

Radon was discovered in 1899 by the two scientists R.B.Ownes and E.Rutherford (10). $^{222}_{86}$Rn is radioactive gas, single-atom, chemically inertin nature, very toxic, in the case of condensation turned into transparent liquid and then turns into a solidmaterial. Radon has three isotopes: Actinon$^{219}$Rn, Thoron$^{220}$Rn, and radon$^{222}$Rn(19). It has an atomic number of about 86 and amelting point(-71$^o$c) and a boiling point (-61.8$^o$c) with a density of (9.73kg.m$^{-3}$) and an atomic radius of about 1.34$^o$ A (5).The main source of radon is radium $^{226}$Ra (11). The rate of radon generation varies with environmental conditions, most importantly humidity and pressure, this is due to the effect of humidity and pressure on the bounce of radon atom that is generated from Radiation dissolution of radium (14).Depleted uranium munitions are used during military operations where uranium causes soil pollution (6). The effect of pollution reaches water, rocks, and enters the food chain of humans, animals and plants (1). The productivity of the soil reflects the state of overlap between the chemical, physical and properties of the soil (2). The addition of Lime to the soil as an improvement to some of the physical and mechanical properties of the soil has improved the soil's ability to retain water and increase its humidity content ( 16 ).Radon is one of the sources of lung cancer at long exposure to high concentrations (17 ). The International Agency for Cancer Research has concluded that there is sufficient evidence to consider radon as a carcinogen for humans (4 ).Some factors affect the concentration of radon gas, its diffusion coefficient and the length of its diffusion, including permeability and porosity in the soil and building materials, The diffusion coefficient of radon is the ability of the gas to spread through the materials. When the porosity and the permeability of the medium are increased, the ability of radon to move within the soil increases. The diffusion coefficient also depends on the water content in the soil, granular size and pressure. as well as temperature that plays a significant role (9).The method used to measure radon is the active way that external energy is needed to investigate(3,8).The objective of this study is to the effect of humidity on calculating the diffusion coefficient of radon gas and the diffusion length during the various materials (soil, loam, sand) and compare the results with theoretical and practical results.

## MATERIALS AND METHOD

**Radon monitor:** The concentrations of radon gas have been measured .Its diffusion coefficient and length coefficient in materials like (soil, loam, sand) were measured using radon monitor type (**SARAD RTM 1688)** Fig.1 and with the exposure system as shown in Fig 2. The radon gas $^{\mathbf{222}}$**Rn** is collected for the purpose of measuring its concentration by this device . The short half-life of radon progeny is produced because of radon decay in the measurement chamber directly. After $^{218}$ Po nuclei decay, it remains and becomes a positive charge for a short time, because some electrons spread away by alpha particles that emitted. The number of collected ions of Po-218 corresponds to the concentration of radon inside the chamber. Po-218 nuclei have auto-dissolve at half-life (3.05 minutes) and about 50% of the particles emitted to the surface of the detector decay and were recorded by the device (18).

**Fig. 1. Radon monitor type SARAD (18 )**

**Fig. 2. Exposure system and radon monitor**

The exposure system that was designed and implemented by the researcher, as shown in figure 2, connecting to the radon monitor (**SARAD RTM 1688**). It was consisting of a chamber of size (725 $cm^3$) in which the radioactive source ($^{226}$**Ra**) with half life of 1600 years has **5µci** activity was put in , and then a cylinder was installed above the chamber with a size of 100 $cm^3$ and then pierced down to allow radon gas go through the chamber to the cylinder. The cylinder was closed by a stopper pierced and connected by a rubber tube with the radon monitor. The materials under study were dried in an electric oven at $80^0$C for an hour.

**Measurement method**

**A** / The system has been left closed for 24 hours. After this period, the material (soil) were put in cylinder to calculate the radon diffusion coefficient into different sizes for each measurement (20, 40, 60) $cm^3$ by connecting the system with the radon monitor. The measurement period was (5 minutes)and with10 attempts .By measuring the concentration of radon gas with volume (20$cm^3$), before($x_1$=0) and after placing the materials( $x_2$=2.8) cm, the radon diffusion coefficient was calculated by the following equation (12, 13).

$D = \lambda \, [(x_2 - x_1) / \ln (N_1 / N_2)]^2$ **...........** (1)

$N_1$ and $N_2$ represent the concentration of radon at distance $x_1$ and $x_2$ respectively from the source (at certain which degree of saturation recorded by the device).

λ: decay constant of radon (= 2.1X$10^{-6}$ $sec^{-1}$)

Same procedure for volumes 40 and 60 $cm^3$ with $x_3$=5.6 and $x_4$=8.4 respectively. That can we choose Δx between them at the same humidity that measure by SARAD.

The length of radon gas is calculated from the following equation (12,13).

$L = \sqrt{D} / \lambda$ **.............** (2)

D: radon diffusion coefficient.

L: radon diffusion length.

The same procedure made by increasing degree of saturation in steps by adding drops of water (15) .the results shown in table (1), then recording $N_1$ and $N_2$ at $X_1$ and $X_2$

**B** / The soil is changed with another material , then the same steps of calculation made for soil types (loam and sand) as shown in table 2 and 3. That also show the theoretical value recorded according to Roger's equation as following:- (15).

$De = De_{(Air)} p \exp(-6mp - 6m^{14p})$ **…………..**(3)

Where De $_{(Air)}$ is the radon diffusion coefficient in air ($1.2\times 10^{-5}$ $m^2$ $s^{-1}$)

*p* is the porosity of matter which change with degree of saturation and calculated as in reference (7).

m is the water saturation.

## RESULTS AND DISCUSSION

Table 1 shows that the values of radon diffusion coefficient, in soil at different saturation levels(water content) , are slightly similar to Rogers' theoretical values. They can also be slightly similar to the practical results that were measured in the first method (15), and were similar to our present study. figure 3. shows the relationship between the radon diffusion coefficient and degree of saturation in soil, which is in a decreasing curve. Because the ability of radon diffusion decreases with increasing degree of saturation .

**Table 1 . Theoretical results of diffusion coefficient by Rogers (15), first method (15)and present work for soil with degree of saturation .**

| water saturation | Rogers value($m^2s^{-1}$) | Method 1 ($m^2s^{-1}$) | present work ($m^2s^{-1}$) | L (m) |
|---|---|---|---|---|
| 0 | $0.82x10^{-5}$ | $8.15x10^{-6}$ | ….. | ….. |
| 0.16 | $0.432x10^{-5}$ | ….. | ….. | ….. |
| 0.2 | $0.3644x10^{-5}$ | ….. | $5.83x10^{-6}$ | 1.6662 |
| 0.25 | $0.2929x10^{-5}$ | ….. | $3.92x10^{-6}$ | 1.3663 |
| 0.29 | $0.2449x10^{-5}$ | ….. | $3.05x10^{-6}$ | 1.2051 |
| 0.34 | $0.1947x10^{-5}$ | ….. | $1.32x10^{-6}$ | 0.7928 |
| 0.38 | $0.1613x10^{-5}$ | ….. | $2.50x10^{-6}$ | 1.0911 |
| 0.4 | $0.1466x10^{-5}$ | $6.52x10^{-6}$ | $1.73x10^{-6}$ | 0.9076 |
| 0.45 | $0.1149x10^{-5}$ | ….. | $1.21x10^{-6}$ | 0.7591 |
| 0.5 | $0.0894x10^{-5}$ | $2.72x10^{-6}$ | $1.06x10^{-6}$ | 0.7105 |
| 0.55 | $0.0689x10^{-5}$ | ….. | ….. | ….. |
| 0.6 | $0.0525x10^{-5}$ | $1.12x10^{-6}$ | ….. | ….. |
| 0.63 | $0.0441x10^{-5}$ | ….. | $7.60x10^{-7}$ | 0.6016 |
| 0.7 | $0.0282x10^{-5}$ | $5.14x10^{-7}$ | ….. | ….. |
| 0.71 | $0.0262x10^{-5}$ | ….. | $3.61x10^{-7}$ | 0.4146 |
| 0.82 | $0.0089x10^{-5}$ | $1.99x10^{-7}$ | ….. | ….. |
| 0.83 | $0.0077x10^{-5}$ | …… | $0.358x10^{-6}$ | 0.4129 |
| 0.84 | $0.0066x10^{-5}$ | ….. | $0.269x10^{-6}$ | 0.3579 |
| 0.86 | $0.0046x10^{-5}$ | ….. | $0.301x10^{-6}$ | 0.3786 |
| 0.9 | $0.0018x10^{-5}$ | ….. | ….. | ….. |

**Table 2. Theoretical results of diffusion coefficient by Rogers(15)and present work for loam with degree of saturation.**

| water saturation | Rogers value($m^2s^{-1}$) | present work($m^2s^{-1}$) | L (m) |
|---|---|---|---|
| 0 | $1.709x10^{-5}$ | ….. | ….. |
| 0.15 | $5.8835x10^{-6}$ | $5.582x10^{-6}$ | 1.6301 |
| 0.2 | $4.7591x10^{-6}$ | ….. | ….. |
| 0.28 | $3.3460x10^{-6}$ | $2.847x10^{-6}$ | 1.165 |
| 0.32 | $2.789x10^{-6}$ | $2.639x10^{-6}$ | 1.1212 |
| 0.45 | $1.5006x10^{-6}$ | ….. | ….. |
| 0.46 | $1.4275x10^{-6}$ | $1.155x10^{-6}$ | 0.7432 |
| 0.49 | $1.227x10^{-6}$ | $1.046x10^{-6}$ | 0.7071 |
| 0.5 | $1.1676x10^{-6}$ | ….. | ….. |
| 0.55 | $8.9983x10^{-7}$ | ….. | ….. |
| 0.56 | $8.5282x10^{-7}$ | $0.978x10^{-6}$ | 0.6824 |
| 0.62 | $6.1121x10^{-7}$ | ….. | …. |
| 0.63 | $5.7595x10^{-7}$ | $0.608x10^{-6}$ | 0.5381 |
| 0.7 | $3.6829x10^{-7}$ | …… | ….. |
| 0.71 | $3.4217x10^{-7}$ | $0.575x10^{-6}$ | 0.5233 |
| 0.76 | $2.2724x10^{-7}$ | ….. | ….. |
| 0.77 | $2.0765x10^{-7}$ | $0.513x10^{-6}$ | 0.4943 |
| 0.82 | $1.1623x10^{-7}$ | …… | ….. |
| 0.85 | $7.3136x10^{-8}$ | $0.608x10^{-6}$ | 0.5381 |
| 0.88 | $3.9180x10^{-8}$ | $0.415x10^{-6}$ | 0.4445 |

**Table 3. Theoretical results of diffusion coefficient by Rogers (15)and present work for sand with degree of saturation.**

| water saturation | Rogers value($m^2s^{-1}$) | present work($m^2s^{-1}$) | L (m) |
|---|---|---|---|
| 0 | $1.3235x10^{-5}$ | ….. | …. |
| 0.18 | $6.4060x10^{-6}$ | $5.552x10^{-6}$ | 1.626 |
| 0.25 | $4.7274x10^{-6}$ | ….. | …. |
| 0.26 | $4.5224x10^{-6}$ | $4.971x10^{-6}$ | 1.5386 |
| 0.3 | $3.7768x10^{-6}$ | ….. | ….. |
| 0.33 | $3.2909x10^{-6}$ | $3.809x10^{-6}$ | 1.3468 |
| 0.34 | $3.1425x10^{-6}$ | $2.954x10^{-6}$ | 1.186 |
| 0.36 | $2.8616x10^{-6}$ | $2.001x10^{-6}$ | 0.9761 |
| 0.4 | $2.3661x10^{-6}$ | $1.711x10^{-6}$ | 0.9026 |
| 0.45 | $1.8545x10^{-6}$ | ….. | …. |
| 0.5 | $1.4429x10^{-6}$ | ….. | ….. |
| 0.52 | $1.3009x10^{-6}$ | $1.695x10^{-6}$ | 0.8984 |
| 0.6 | $8.4735x10^{-7}$ | ….. | ….. |
| 0.61 | $8.0054x10^{-7}$ | $1.002x10^{-7}$ | 0.2184 |
| 0.65 | $6.3107x10^{-7}$ | ….. | ….. |
| 0.7 | $4.5515x10^{-7}$ | $0.449x10^{-7}$ | 0.1462 |
| 0.75 | $3.0827x10^{-7}$ | ….. | ….. |
| 0.77 | $2.5663x10^{-7}$ | $1.11x10^{-6}$ | 0.727 |
| 0.8 | $1.8561x10^{-7}$ | $1.43x10^{-6}$ | 0.8252 |
| 0.82 | $1.4365x10^{-7}$ | $0.893x10^{-7}$ | 0.2062 |

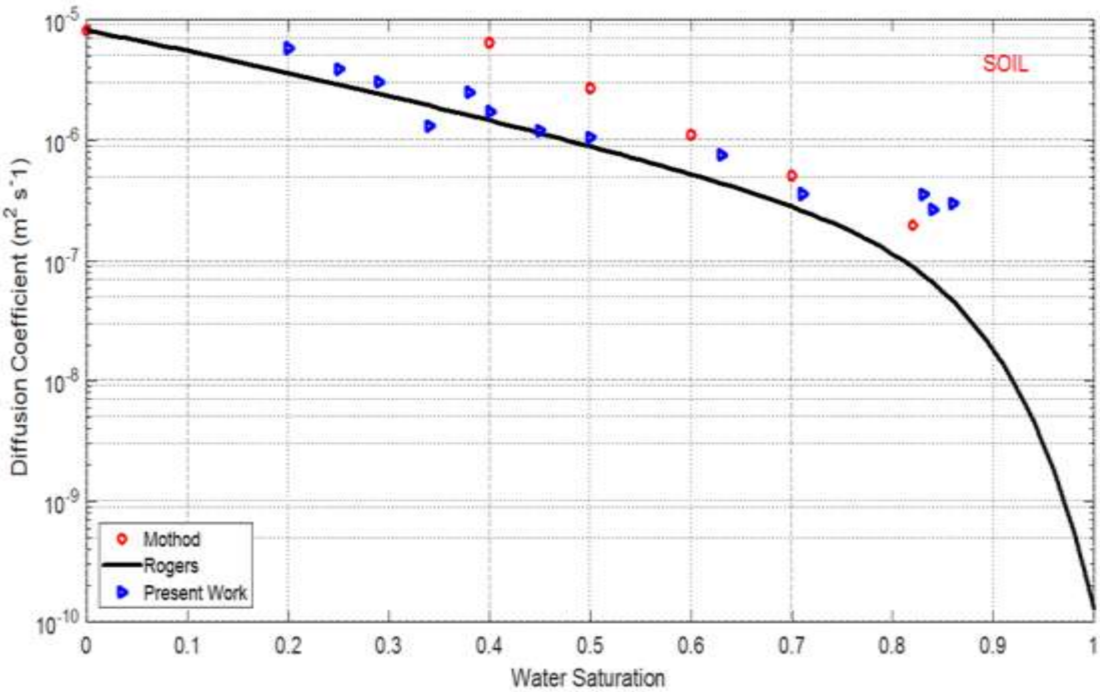


**Fig. 3 . Relation between the radon diffusion coefficient and degree of saturation in soil**

figure 4. shows the relationship between the radon diffusion length and degree of saturation in soil, which is in a decreasing curve with increasing degree of saturation

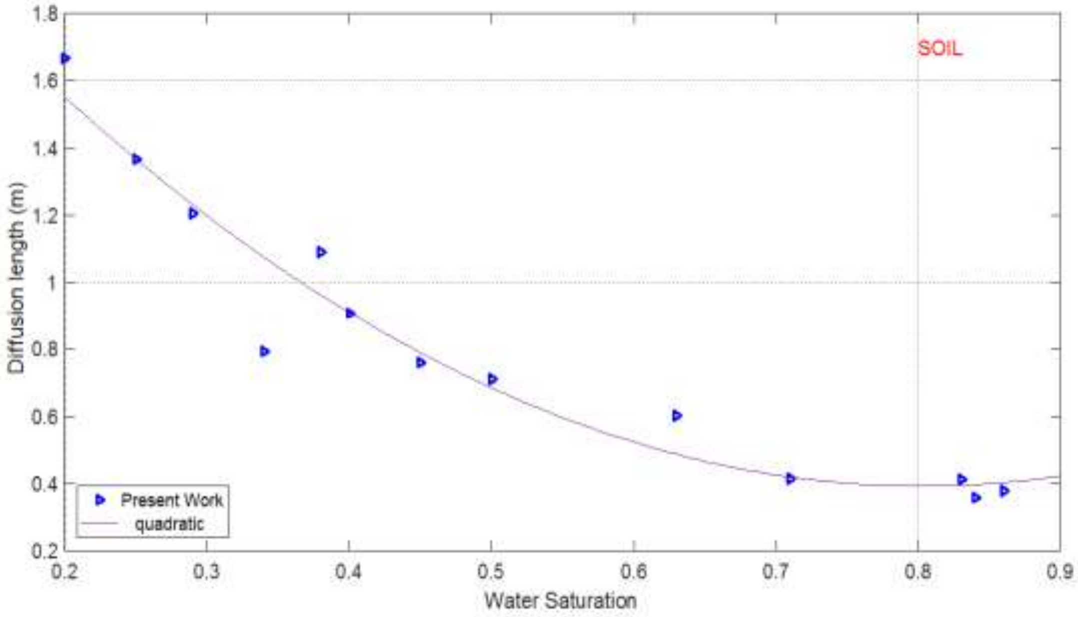


**Fig. 4 . Relation between the radon diffusion length and degree of saturation in soil**

Table 2. shows the values of the radon diffusion coefficient in loam at different degree of saturation values, which were close to Rogers' theoretical results. The relationship between the radon diffusion coefficient and degree of saturation in the loam was also shown in Fig. 5. Because there was no previous practical study on this matter, we compared only the theoretical results.

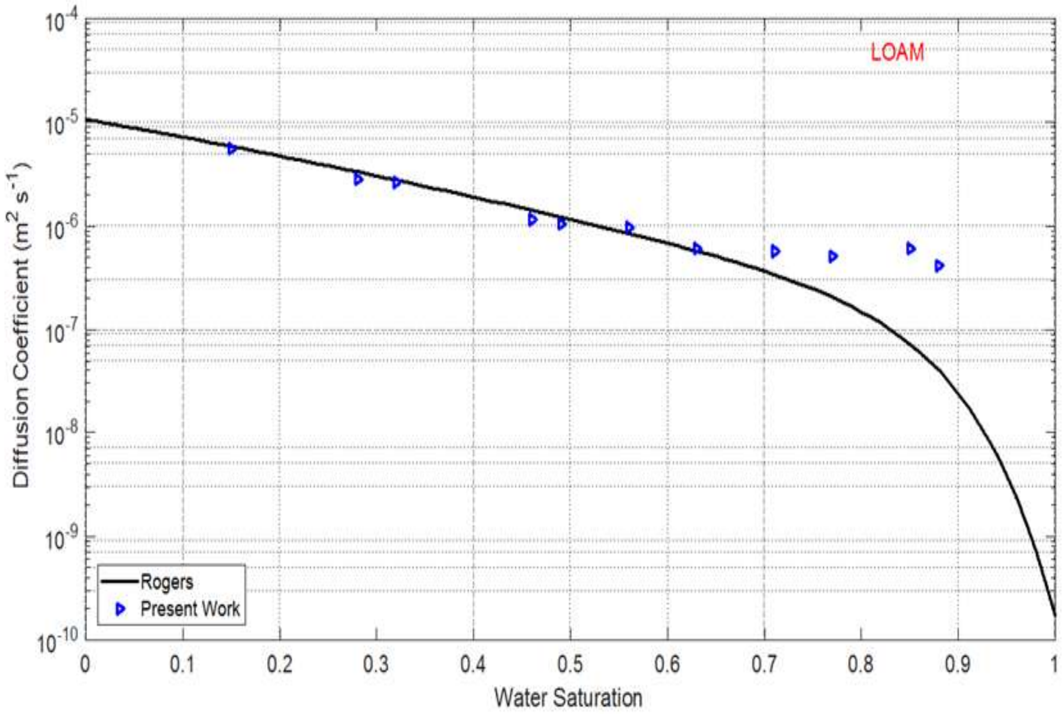


**Fig. 5 . Relation between the radon diffusion coefficient and degree of saturation in loam**

The relationship between the radon diffusion length and degree of saturation in loam was also shows in Fig.6, which in decreasing curve.

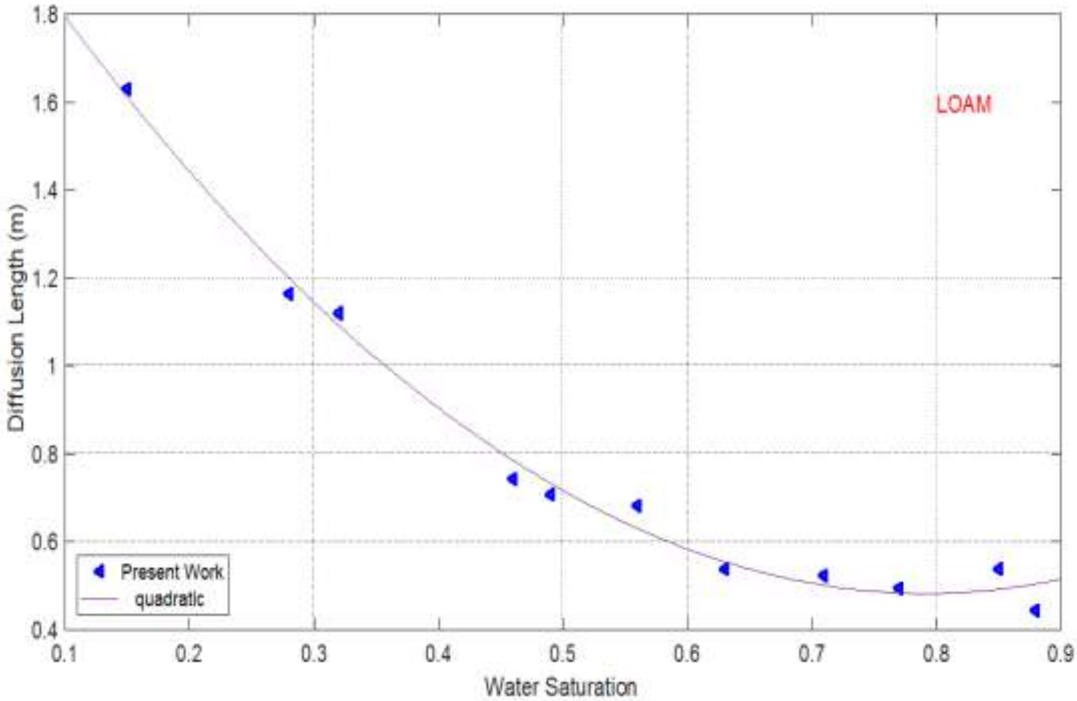


**Fig. 6 .Relation between the radon diffusion length and degree of saturation in loam**

Table 3. shows the values of the radon diffusion coefficient in sand at different degree of saturation values. It was close to Rogers' theoretical results. The relationship between radon diffusion coefficient and degree of saturation in sand was shown in Fig. 7. The relationship between radon diffusion length and degree of saturation in sand was shown in Fig.8.

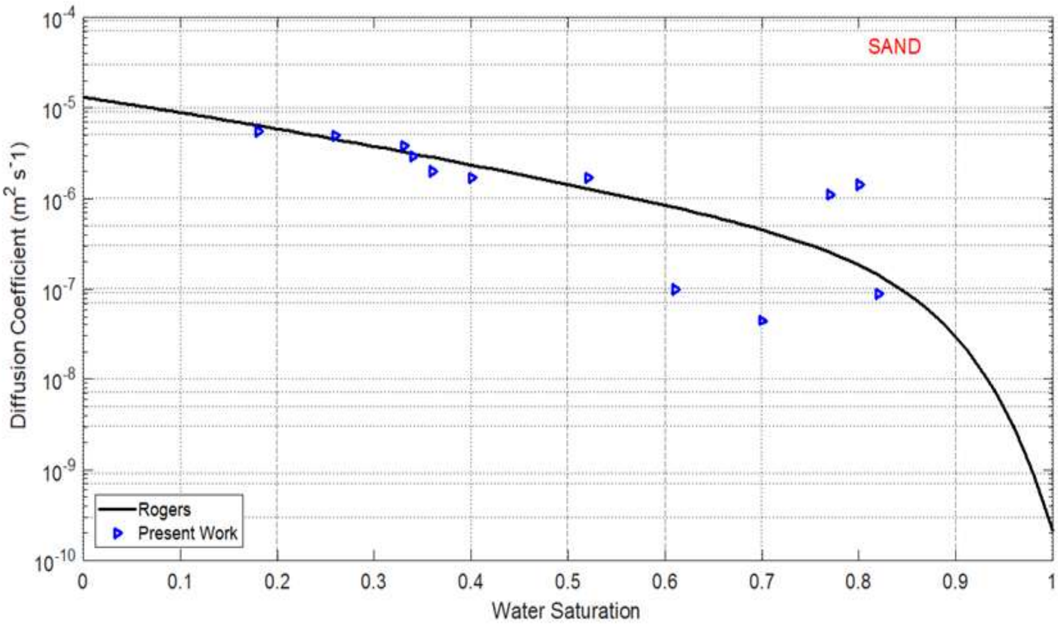


**Fig. 7 . Relation between the radon diffusion coefficient and degree of saturation in sand**

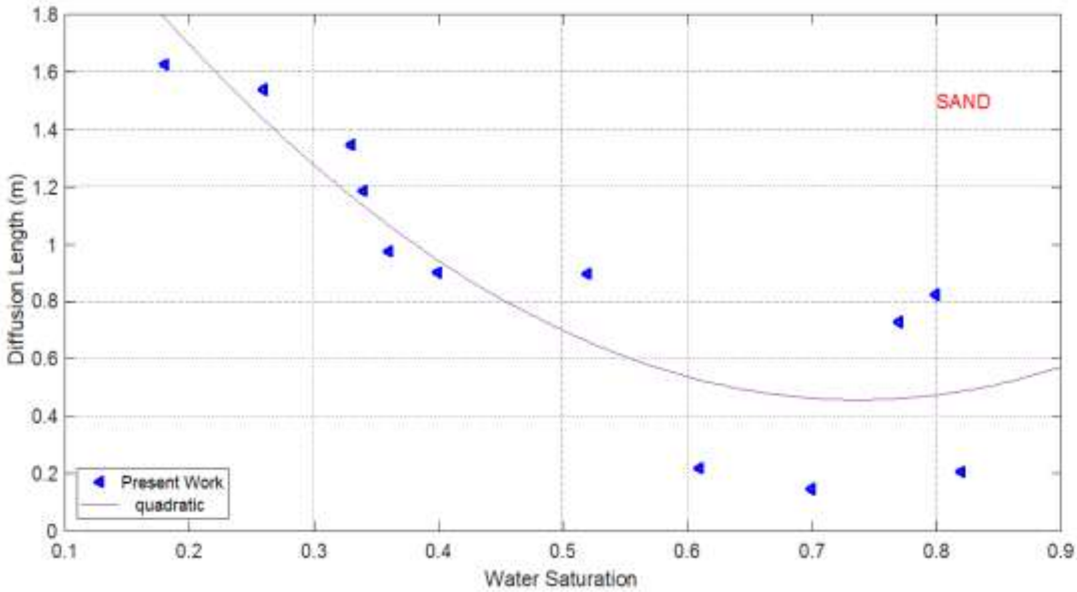


**Fig. 8 . Relation between the radon diffusion length and degree of saturation in sand**

From this work, we can conclude that radon diffusion coefficient decreases with increasing water content (water saturation) in soil and other types of soils .By using a new SARAD device which give us the ability to measure radon diffusion coefficient with changing in water saturation like many work (15) ,the results shown agreement with theoretical results by reference (15) .The same thing was for other types of soils loam and sand(which there was little studies about them) and for diffusion length ,so we can correct any result about radon diffusion coefficient and diffusion length and its risk.

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