

## Diffusivity of water in Unplasticised PVC

Dr. Awham M.H.\* & Zaid Ghanem M. Salih\*

Received on:8/11/2009

Accepted on:16/2/2010

### Abstract

The current study concerns an investigation of diffusion mechanism of different kinds of water into thermoplastic material (typeunplasticised PVC, (UPVC)) that is often used as pipes for healthy draining purposes and other services.

After preparation of samples from this material, they were immersed in glass containers which contain (sea water, river water, rain water, distilled water, and tap water), the weights of these samples are measured at periodic time of soaking.

The aim of this work is introducing an idea about the diffusion behavior and the penetration of water through the material under study, then, the values of diffusion coefficient ( $D_x$ ) are evaluated for each type of water mentioned above.

After comparing the obtained results from these tests, it is found that the distilled water has the higher value of ( $D_x$ ) into the (UPVC) material, it is followed by the sea water and then the rainwater, while each of the river and tap water record the lowest values.

**Keywords:** Diffusion coefficient, Thermoplastic material, weight gain, Fick's law.

### أنتشارية الماء في مادة (UPVC)

#### الخلاصة

يختص البحث الحالي بدراسة آلية الانتشار لنماذج مختلفة من المياه في مادة مطاوعة للحرارة من نوع (UPVC) التي غالباً ما تستعمل كأنابيب لأغراض الصرف الصحي والخدمات الأخرى، حيث تم غمر نماذج من تلك المادة في حاويات زجاجية تحتوي على (ماء البحر، ماء النهر، ماء المطر، الماء المقطر، الماء العادي)، ومن ثم قيست اوزان تلك النماذج بعد فترات زمنية دورية من الغمر. الهدف من هذه الدراسة هو إعطاء فكرة عن السلوك الانتشاري وآلية تغلغل الماء خلال المادة قيد الدراسة ومن ثم تحديد قيم معامل الانتشار ( $D_x$ ) لكل نوع من المياه المذكورة آنفاً.

وبعد مقارنة النتائج المستحصلة من الاختبار، وجد بان الماء المقطريمتلك اعلى قيمة لمعامل الانتشار ( $D_x$ ) الى داخل مادة (UPVC) ويليه ماء البحر ثم ماء المطر في حين يسجل كل من ماء النهر والماء العادي القيم الاوطأ.

### Introduction

Polyvinyl Chloride Polymers (PVCs), is generally referred to as vinyl resins, are prepared by the polymerization of vinyl chloride in a free radical addition polymerization reaction. This polymer can be made

by suspension, emulsion, solution, or bulk polymerization methods [1].

The vinyl chlorides are formed from hydrochloric acid, limestone and natural gas or coal. The forms of vinyl chloride are almost unlimited [2].

PVC can be manufactured in expanded or cellular form. It is available in two forms, namely flexible and rigid. It can be extruded easily and molded into the desired form[2]. The flexible types are strong, tear resistant, and have good aging properties, while the rigid types have good dimensional stability and water resistance. They are resistant to acids and alkalies.

#### **Diffusion studies**

When a rigid polymer is brought into contact with water, water diffuses into the polymer structure, thus causing it to swell. Analysis of the mechanism of water diffusion into a polymeric material has recently been of increasing interest because of important application of swellable polymers in biomedical, pharmaceutical, agricultural, and engineering fields.[3]

Water diffusion behavior of the polymer depends on the nature of the polymer (i.e. the charge, ion content, and the cross linking agent content) and environmental conditions such as ionic strength, pH, and temperature of the solution [3].

Seon and others [4] studied the water sorption behavior of the IPNs at various temperatures and humidity levels. They noticed that equilibrium water uptake increases as humidity increases and the increase is more noticeable at high humidity.

Tejraj and others [5] investigated the sorption diffusion and swelling characteristic of Sodium alginate and its blend membranes with Poly (vinyl alcohol) in water-acetic acid mixtures by using gravimetric method at 30-40 and 50 °C. The membranes were characterized by X-ray diffraction and Fourier transforms technique.

Gabriel and Pearl [6] studied the behavior of cured FM300 epoxy - a

structural film adhesive subjected to partial and full moisture saturation. The mechanical response of the epoxy due to increasing moisture contained was dependent on the testing method. In stress relaxation testing, they noticed that the epoxy was plasticized when partially saturated with the moisture, but it became more rigid when fully saturated.

Keh et al[7] estimated the diffusion coefficients and solubility for organic solvents permeation through high density polyethylene

. They found that the diffusion coefficients and solubility of these solvents correlated well with their molecular weights and dipole moment, respectively.

#### **Experimental part**

The diffusion experiments on (UPVC) material were performed in different types of water. Five types of water were used for this study that included: (sea water, river water, rainwater, distilled water and tap water). Sea water was brought from Mediterranean Sea from Lattakia beaches –Syria. River water was brought from Tigris River. According to the standard specification (ASTM-D570), the samples were cut in rectangular shapes of certain dimensions (10, 10) mm<sup>2</sup> from (UPVC) pipes, made in K.S.A. by the national factory for plastic industries in Jeddah city. Initial masses of these samples were obtained by using sensitive electronic balance type (Mettler, model AE160, 4digits).

The dry samples were immersed into containers that contain (100 ml) of each type of the five above – mentioned types of water. At intervals about (2 weeks) during the immersion periods, these specimens were weighted. Before weighing, the specimens' surfaces were wiped by a

soft tissue, and the samples were allowed to stand free at ambient conditions for one minute.

In this study, the weight gain (%) was measured as a function of soaking time for (UPVC) material that submerged in different types of water at room temperature. The rate at which a polymer material absorbs water is expressed by the diffusion coefficient (DX).

The percentage weight change of the samples after each period of immersion was calculated from the expr+

$$\text{(weight gain)\%} = \frac{\text{Weight of wet specimen} - \text{Weight of dry specimen}}{\text{Weight of dry specimen}} \times 100 \quad \dots (1)$$

The diffusion coefficient was evaluated from the relationship: [8,9]

$$D_x = \pi \left( \frac{Kt}{4Mm} \right)^2 \quad \dots (2)$$

Where (K) is the slope of straight line curves which represent the relations between weight gain (%) and (time) 1/2

(t) is the thickness of the specimen.

(Mm) is the apparent maximum water content.

It is worth mentioning to show that the total dissolved salts (ppm) units and the (pH) measurements of each type of water were measured and the data are listed in Table (1).

**Results and discussion**

The kinematics of water penetration into the polymer material varies with the nature of polymer system that is being considered and the exposure conditions [6].

In the simplest case, water molecules enter the polymer without interacting with the molecular segment network. This case can be represented by Fick's Law, which assumes that the absorption is a diffusion process only

driven by moisture concentration gradient. Frequently, however, the Fickian model does not adequately represent the absorption process. Such case is called non-Fickian, or anomalous diffusion [6].

In the present work, experiments were performed on (UPVC) material, to analyze the mechanism of water transport into the material, to study the influence of water transport on the nature of polymer. The diffusivity tests were continued for about (5months) of socking in water.

To study the water-absorption Kinetic, water-uptake or weight gain(%) curves were obtained as a function of square root of immersion time in water.

Figs.(1,2,3,4 and 5) represent this relation of each sort of water under study. From these figures, it can be recognized that there are two regions in the curve, the initial part of the curves is linear and rate of water uptake (the initial gradient of the curve) increased with (t)1/2 and then the behavior becomes non linear in the second region of the curve as shown in the Figures (1) to (5).

Although initial absorption is similar to that predicted by Fick's law, it can be seen from these figures that behavior depended greatly on the nature of water [10].

Apicella et al [11,12] proposed that there are three modes of sorption(i) bulk dissolution of water in the polymer network;(ii) moisture absorption onto the surface of holes that define the excess free volume of the glassy structure; and (iii) hydrogen bonding between hydrophilic groups of the polymer and water.

From the results obtained from curves in figures (1-5), it appears the water absorption behavior into the (UPVC)

samples can be predicted well by a Fickian sorption model. It can be noticed from the relation (weight gain% -  $\sqrt{t}$ ) has some similarity in the behavior of diffusivity curves between the distilled water and tap water and between river water with rainwater.

The values of diffusion coefficient (DX) are listed in Table (1). It can be noted from this data that the order of magnitude of (DX) was  $10^{-5}$ (m<sup>2</sup>/sec-1) at room temperature. It is also shown in Table (1) that the values of (DX) are approximately in the range  $(1-12) \times 10^{-5}$  m<sup>2</sup>.sec-1 of the different kinds of water under investigation. This value is comparable with previous reported results [13, 14].

#### Conclusions

- 1- The results obtained with this method show that water diffuses into the polymer material in accordance with Fick's law to reach saturation at room temperature.
- 2- Water diffuses into the (UPVC) polymer between about (0.06 to 0.17) weight % of the specimens under test and the diffusion coefficient is about  $(1-12) \times 10^{-5}$  m<sup>2</sup>.sec-1 which is close to the results obtained in other investigations.
- 3- The behavior of water diffusion through the polymer was found to be affected by the type of water depending on the (pH) value and the percentage of total dissolved salts (TDS) in each type of water.
- 4- There are no effects observed on the shapes, dimensions or color of (UPVC) material after the immersion in water for more than (5months)
- 5- The existence of microcracks, voids or any other inhomogeneity in the polymeric

material would enhance the process of water penetration into material.

#### References

- [1]. Charles A. Harper, "Handbook of Plastic, Elastomer and Composites", (ch.1), Thermoplastic, Mc Graw Hill Companies, (2004).
- [2]. R.K. Rajput, "Engineering materials", revised edition, S. Chand and Company LTD, New Delhi, (2008).
- [3]. Belma I. and Banu D., "J. of App. Poly. Sci.", Vol.96, No.5, June, PP.(1783-1788),(2005).
- [4]. Seon J.Kim, Ki. J. Lee, Sun I. Kim, Kyu. B. Lee, Yong D. Park, "J. of App. Poly". Sci, Vol.90, No.1, Oct.3, PP.(86-90),(2003)
- [5]. Tejraj M. A., Lakshmi C. S., B. Vijaya K. N., and others, J. of App. Pol. Sci., Vol.94, N0.3, Nov.5, PP.(1139-1150), (2004).
- [6]. Gabriel L., Pearl L., "J. of App. Poly. Sci.", Vol.95, No.5, March.5, PP.(1285-1294),(2005)
- [7]. Keh P., Ping W. and Chia H. "J. of Environmental engineering", ASCE, Vol.132, No.5, May1, PP.(519-526), (2006).
- [8]. Han and J. Koutsky, Composites, Vol.14, No.1, Jan., PP. (67-70), (1983).
- [9]. B. Dewimille and A.R. Bunsell "Composites", Vol.14, No.1, Jan., PP. (35-40), (1983).
- [10]. Susham M.,Jaya B., A.k. Bajpai, "J. of App. Poly. Sci ", Vol. 94, No. 4, Nov. 15, PP. (1815-1826), (2004).
- [11]. Apicell A., Nicolais L. and de Catudis, "Adv. Poly. Sci ", Vol.66, No. 189,(1985).
- [12]. Myung C. L.and Nikolaos A.p., "J. of App. Poly. Sci ", vol.47, PP. (1349-1359), (1993).

[13]. Jacobs P.M., Jones F.R., "J. of Materials Sci", Vol.24, No.7, July, PP. (2331-2336), (1989).

[14]. Marc T. a, Shoshana N., Gad M., " J. of Materials Sci.", Vol.22, PP. (2435-2446), (1987).

Table (1) The values of (TDS), (pH) and ( $D_x$ ) of each type of water.

Type of water	TDS(ppm)	pH	$D_x * 10^{-5} m^2.s^{-1}$
Sea water	more than 600 *	7.05	9.71
River water	580	6.9	1.09
Rainwater	103	7.3	6.13
Distilled water	121	7	11.93
Tap water	426	8.1	1.46

\*exceed the limit of measurement of instrument.

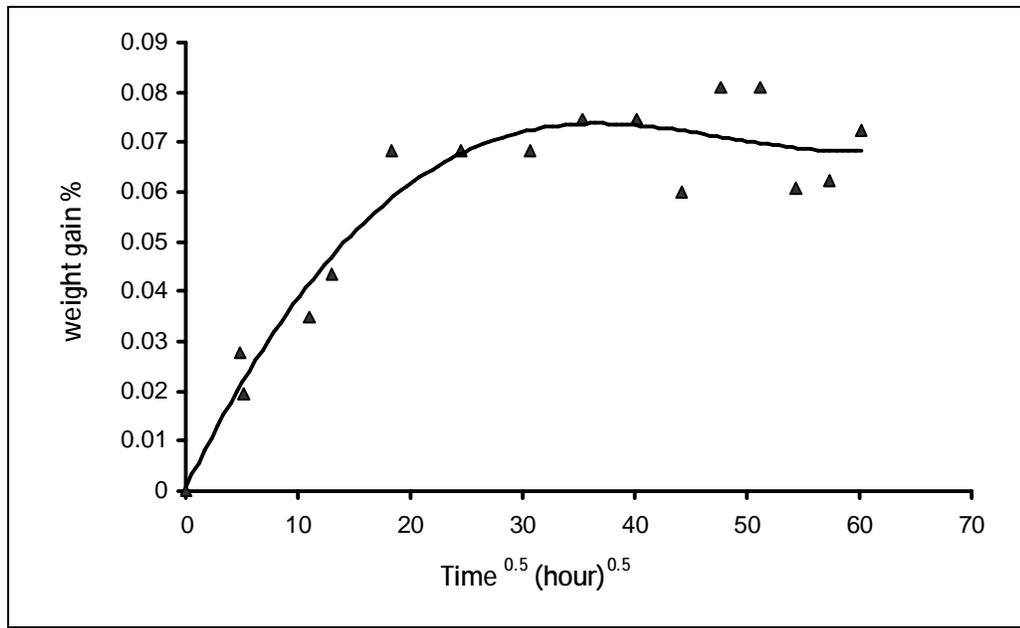


Figure (1) Weight gain (%) of (UPVC) in the sea water as a function of square root of immersion time.

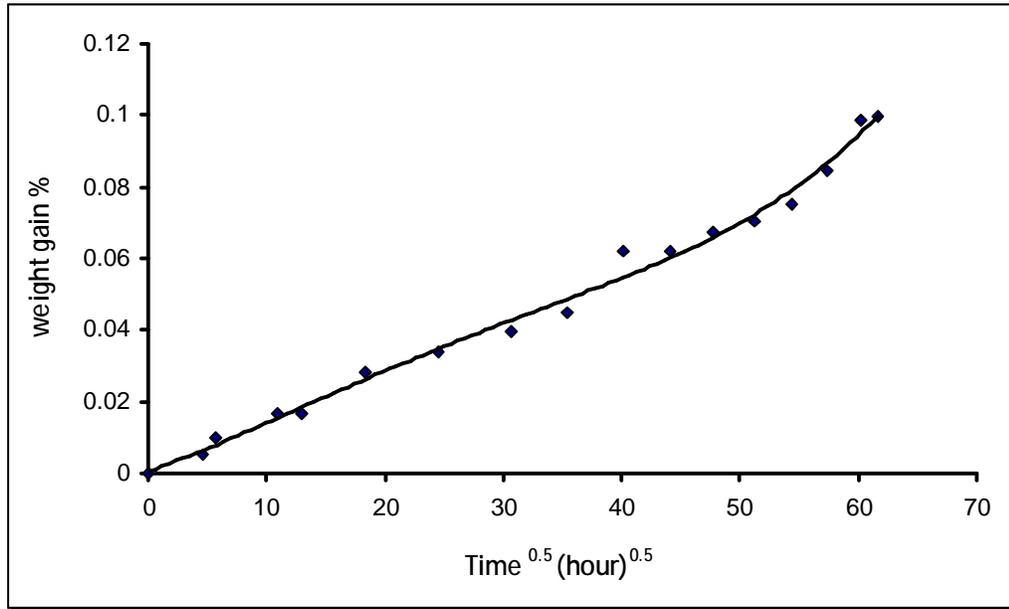


Figure (2) Weight gain (%) of (UPVC) in the river water as a function of square root of immersion time.

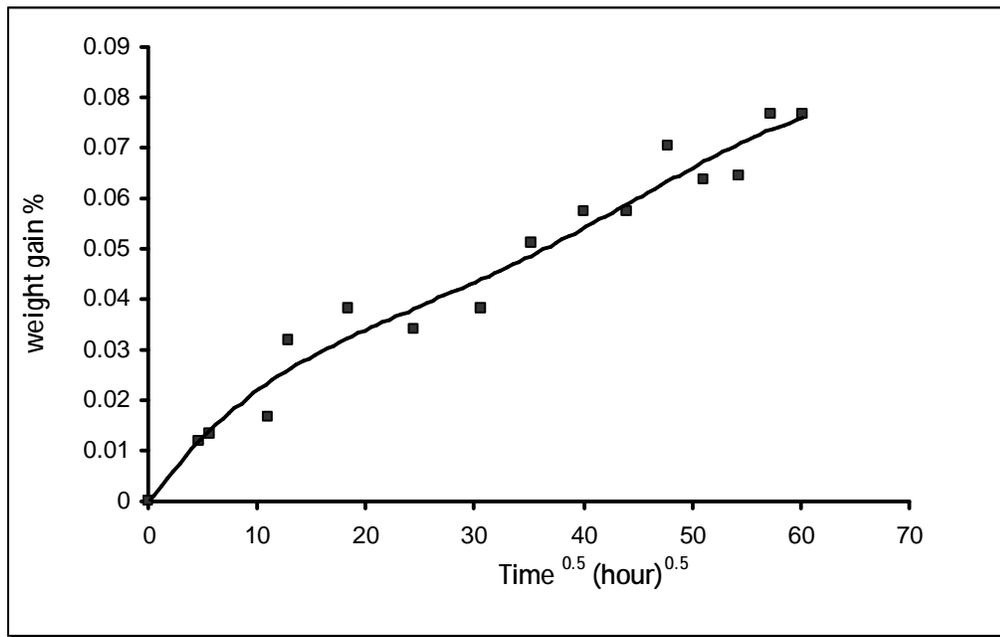


Figure (3) Weight gain (%) of (UPVC) in the rainwater as a function of square root of immersion time.

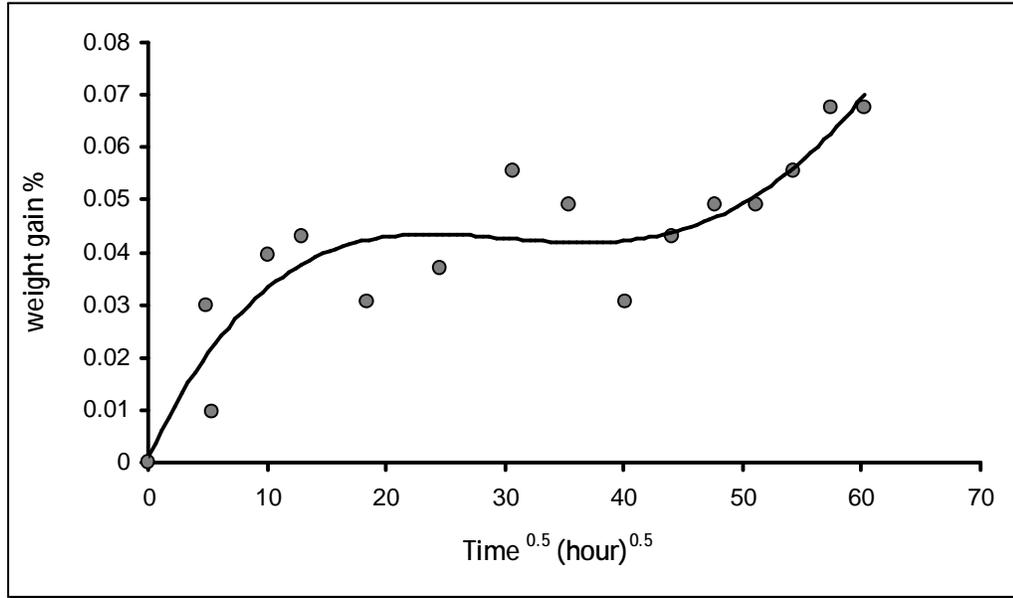


Figure (4) Weight gain (%) of (UPVC) in the distilled water as a function of square root of immersion time.

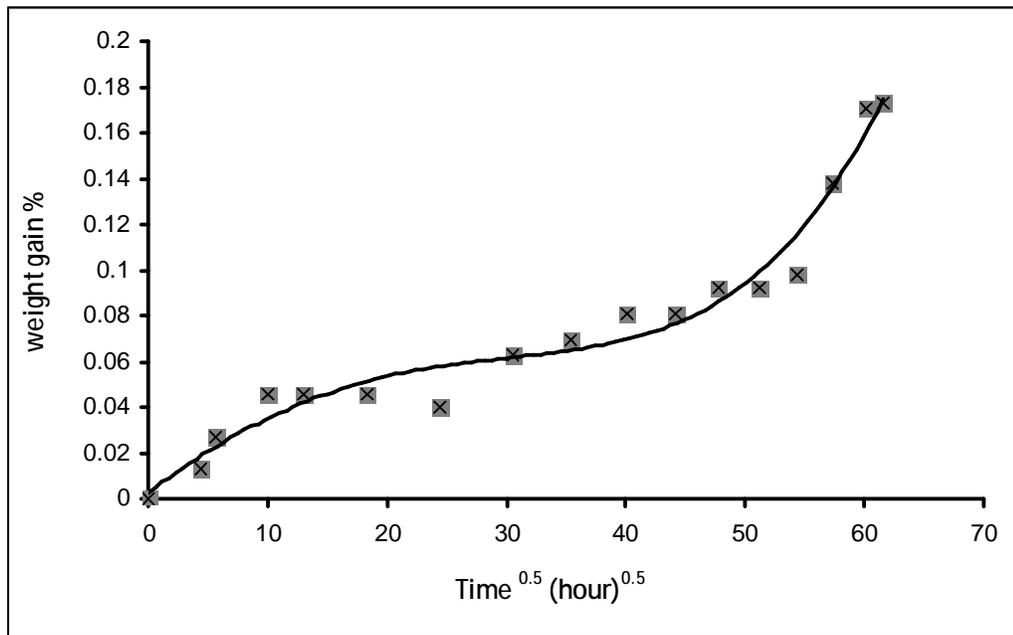


Figure (5) Weight gain (%) of (UPVC) in the normal water as a function of square root of immersion time.