ISSN : 0974 - 7451 Volume 8 Issue 11

Environmental Science

An Indian Journal

Current Research Paper

ESAIJ, 8(11), 2013 [436-441]

Theoretical and experimental study of radon separation from water by bubbling system

Hossein Noorinezhad[1], Hassan Hashemipour Rafsanjani[1]*, Maryam Mirzaie[1], Ali Negarestani[2]
[1]Department of Chemical engineering, College of Engineering, ShahidBahonarUniversity of Kerman, Kerman, (IRAN)
[2]Radon research laboratory, International Center of Science, High Technology &
Environmental Sciences (ICST), Kerman, (IRAN)
E-mail : Ha-hashemipour@mail.uk.ac.ir

ABSTRACT

To pay attention to importance of earthquake prediction, many of researchers try to predict this natural disaster by means of events and precursors that take place before earthquake. Change of radon concentration in thermal waters about active faults is one of these precursors. Radon in water (especially in continues monitoring) can be determined by measuring radon in an air circuit coupled to the water. In this research used bubbling System for coupling of air and water, theoretical and empirical study are done on this system. Time constant parameter as an indictor of separation rate was lesser than 20 minutes in most of experimental conditions. In other to determine of bubbling system's optimum working point, mathematical modeling of this system was presented, too.

KEYWORDS

Separation;
Bubble column;
Radon;
Mathematical modeling.

INTRODUCTION

Annually, in all over the world natural disasters such as floods, hurricanes, earthquakes, etc. cause irreparable losses of life and property. Most of these events are predictable and human takes necessary actions before that they take place. Unfortunately, against the improvement of science and technology, one of these natural disasters that human cannot predict that, is earthquake. Earthquake from the viewpoint of losses of life has first place among the natural disasters and it is on second place from the viewpoint of losses property. Therefore, more studying and researching on this field is vital.

Researchers indicated that there are many earthquake precursors. One of these precursors is changing of radon concentration in thermal waters about of active faults. In 2007, Erees et al. studied radon concentration in thermal waters and indicated that radon concentration in thermal waters changes before or after of earthquake[1]. Therefore, radon concentration in thermal waters about active faults should be measure continually. Most of radon monitors cannot detect radon concentration in water directly, and they can detect radon concentration in air bond wit. Therefore radon molecules should be separated from water and transferred to air. Aeration and membrane separation methods are usual methods. Aeration method is faster than membrane separation but air humidity in this method is too high. When radon concentration in water changes, its concentration should change in air. Most important factor for select separation method is quickness of this process.

Here, time constant parameter is defined as required time that concentration of radon receives to 63% of its final concentration. In 1996, Surbek used membrane contact method to transfer radon from water into air. He provided a pipe membrane from polypropylene and put it in ccontinous flow of water. Air inter aside of pipe membrane and out from another side, then inter to detector of radon concentration. Exhausting air from detector return to membrane so that air has closed couple cycle. Time constant that he achieved from his system, was about 72 minutes[2].

In this research, with contact of water and air in a bubbling system, how changing of radon concentration is studied and time constant of this system is measured. The used air system in this study is a bubble column. This system is selected since the rate of mass transfer between two phases water and air is appropriate and diffusion of water into air phase increase so consumption of desiccant increase. Also, in this study in order to determine optimum performance point, appropriate mathematical model is given. In the must experimental conditions, time constant is less than 20 minutes. At optimum performance point this constant is about 11 minute.

TIME CONSTANT DETERMINATION METHOD

Surbeck showed in figure 1, if radon concentration in water has a step change then radon concentration in air will change exponentially with time (equation (1)).

$$C_a(t) = C_a(\infty)\times(1-\exp(-\frac{t}{\tau})) \quad (1)$$

In this equation τ is time constant. By fitting experimental data and mathematical modeling results on this relation, we can determine experimental and modeling time constant respectively. It is clear that if separation is fast then τ is small.

MATERIALS AND METHODS

In this research, for radon separation from water and transport it to air, bubbling system was used. Bubbling system composed of cylindrical bubble column by 10 cm diameter and 32 cm height. Material of column was glass and perforated tube was used for making bubble in bottom of column. There are two holes on top of column. One of these holes for entering water and other for exhausting air. Also there are two holes in bottom for water discharging and air entering to column. Water rate was controlled by valve 1 and 2 (figure 1). In order to consideration of water temperature on time constant, a heater was used on water path before inter in column. Water temperature was detected by thermometer 1 and 2 (figure 1). A pump was used for circulation of air in couple cycle. Also air flow rate was measured by a rotameter. Water flow rate was measured by scaled glass and chronometer. In this research, RAD7 continues monitor was used for detection of radon concentration in air. This detector made by DURRIDGE Company. Some desiccant was used on air cycle path because of RAD7 is sensitive about humidity. At whole of experiments in this research, holdup to hold on 30 cm. there is schematic of this system in figure 1.

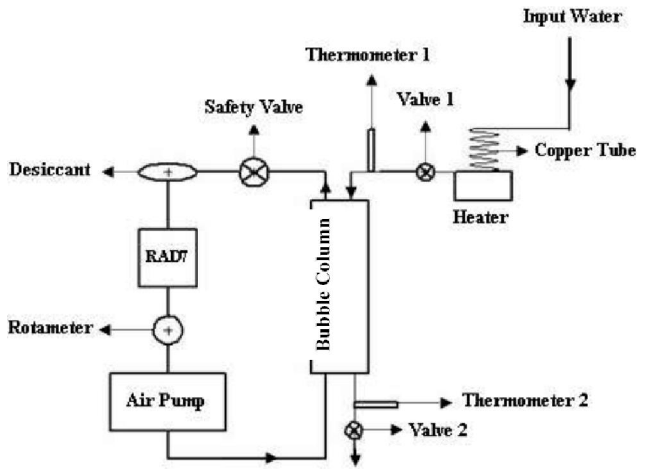

Figure 1 : Radon concentration changing in water detector

MATHEMATICAL MODELING

Experimental data showed satisfactory of this setup (TABLE 2). Mathematical modeling of this setup was presented. By this modeling optimum performance point of system was determined. Bubble column is most important to modeling this set-up. In this research, axial dispersion model that is a usual model for bubble columns[3], was used for both phase (water and air).

An element with dx width was supposed in axial direction of bubble column (figure 2). Mass balances in two phases were written on radon.

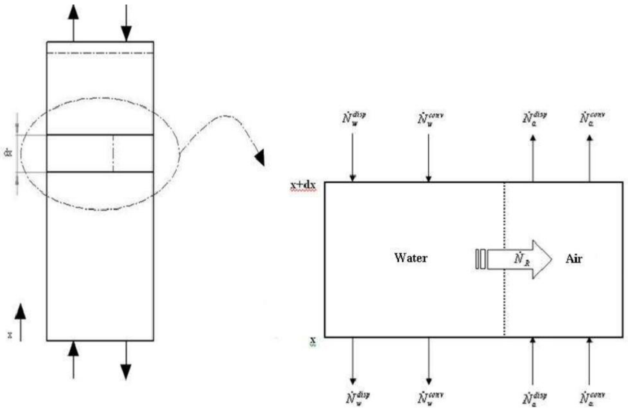

Figure 2 : Element of bubble column

In figure 2, $\dot N_w^{disp}$ and $\dot N_a^{disp}$ are radon mass transfer rates in water and air due to dispersion, respectively. $\dot N_w^{conv}$ and $\dot N_a^{conv}$ also are radon mass transfer rates in water and air due to convection, respectively[4]. These parameters are defined as follows:

$$\dot N_w^{disp} = +\varepsilon_w E_w A \frac{\partial C_w}{\partial x} \quad (2)$$

$$\dot N_w^{conv} = u_w A C_w \quad (3)$$

$$\dot N_a^{disp} = -\varepsilon_a E_a A \frac{\partial C_a}{\partial x} \quad (4)$$

$$\dot N_a^{conv} = u_a A C_a \quad (5)$$

In figure 2, $\dot N_R$ is mass transfer rateof radon per unit volumeof bubble column from water to air. Usuallythe overall mass transfer rate per unit volume of a bubble column is governed by the liquid-sidemass transfer coefficient. Therefore:

$$\dot N_R = K_L a (C_w - C_w^*) \quad (6)$$

In this relation C_w^* is radon concentration in interface of two phases. It was supposed at equilibrium with radon concentration in air bulk:

$$C_w^* = k C_a \quad (7)$$

In equation (7), *k* is radon water solubility (Ostwald coefficient), defined asthe steady state ratio C_w/C_a.*k* is the temperature dependent (see figure 3).

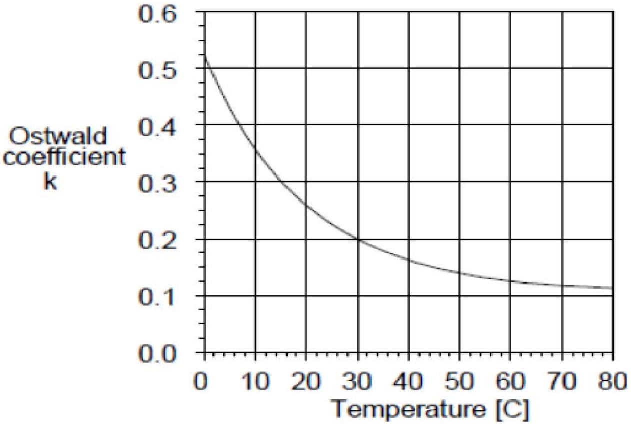

Figure 3 : Radon water solubility vs. temperature (Ostwald coefficient *k*)

With substation (7) into (6):

$$\dot N_R = K_L a (C_w - kC_a) \quad (8)$$

After writing balances on radon in water and air, then substation relations 2, 3, 4, 5, 8 in these balances, governing equations on radon concentration in water and air will be obtaining. These governing equations are couple and depend on time (*t*) and location (*x*). It is necessary to remind that time of experiment is negligible against radon half time ($T_{1/2}$= 3.82 Days), then radon consumption in air and water by decay reaction was neglected[5].

For water phase:

$$\varepsilon_w E_w \frac{\partial^2 C_w}{\partial x^2} + u_w \frac{\partial C_w}{\partial x} - K_L a (C_w - kC_a) = \varepsilon_w \frac{\partial C_w}{\partial t} \quad (9)$$

Boundary and initial conditions of this equation are:

$$C_w(x,0) = C_{w0} \quad (10)$$

$$\frac{\partial C_w(0,t)}{\partial x} = 0 \quad (11)$$

$$C_w(L,t) = C_{w0} \quad (12)$$

In these relations, C_{w0} is radon concentration in inlet water to column. This concentration is measured by batch method. It is standard way of RAD7 detector for measuring of radon concentration in water.

For air phase:

$$\varepsilon_a E_a \frac{\partial^2 C_a}{\partial x^2} - u_a \frac{\partial C_a}{\partial x} + K_L a (C_w - kC_a) = \varepsilon_a \frac{\partial C_a}{\partial t} \quad (13)$$

Boundary and initial conditions of this equation are:

$$C_a(x,0) = 0 \quad (14)$$

$$\frac{\partial C_a(L,t)}{\partial x} = 0 \qquad \textbf{(15)}$$

In other to obtain second boundary condition of equation 14, it is necessary to model air out of column. In other words, this modeling result relation between radon concentration in air at inlet and outlet of column. Constituents out of column were supposed mix tank. Therefore:

$$Q_a(C_a(L,t) - C_a(0,t)) = V_m \frac{dC_a(0,t)}{dt} \qquad \textbf{(16)}$$

V_m is volume of mix tank equivalent with volume of parts in air cycle (exception bubble column). For this setup, V_m is about 6 liters.

Experimental correlations for estimating of parameters

Correlations were used for estimating of parameters listed in TABLE 1:

TABLE 1 : Correlations were used for estimating parameters in the model

Parameter	Symbol	correlation	ref
Water dispersion coefficient	E_w	$E_w = 2.7 d_c^{1.4} u_a$	[3]
Air dispersion coefficient	E_a	$E_a = 5\times 10^{-4}\left(\frac{u_a}{\varepsilon_a}\right)^3 d_c^{1.5}$	[3]
Air hold-up	ε_a	$\frac{\varepsilon_a}{1+\varepsilon_a} = 0.0625\left(\frac{u_a}{\upsilon_w g}\right)^{\frac{1}{4}}$	[6]
volumetric mass transfer coefficient	$K_L a$	$\frac{K_L a\, d_c^2}{D_{R,w}} = 0.452\left(\frac{\nu_w}{D_{R,w}}\right)^{\frac{1}{2}} \left(\frac{d_c u_a}{\nu_w}\right)^{\frac{3}{4}} \left(\frac{g\, d_c^2 \rho_w}{\sigma_w}\right)^{\frac{3}{5}} \left(\frac{u_a^2}{d_c g}\right)^{\frac{7}{60}}$	[6]
Ostwald coefficient	k	$k = 0.105 + 0.405 e^{-0.0502T}$	[6]

SOLUTION OF MODEL'S EQUATIONS

In other to determination of radon concentration in air, equations (9) and (14) with their conditions must solved simultaneously. 100 volume elements were supposed in axial direction of column. Then finite volume method was used and discrete form of equations (9) and (14) for all of element was obtained[7]. Ultimately, system of linear equations was solved.

RESULTS AND DISCUSSIONS

Experimental results

After preparing setup, 10 tests were carried. There are conditions of each experiment and their time constants in TABLE 2. In order to verifying of model, time constants by models were obtained, too (TABLE 2). According to this table, model can predict this lab setup, satisfactory. Therefore, this model was used for determination of optimize working point of this setup. In other words, at optimum working point:

1 Time constant as much as possible must be minimum.
2 Sensitivity of time constant versus test conditions must be low.

Change concentration of radon in air must be influenced by change concentration in water to applied it for predict earthquake. As shown in figure 3, final concentration of radon in air also influenced by temperature.

TABLE 2 : Results of experiments

Error of model (%)	$_M\tau$ (min)	$_E\tau$ (min)	C_{w0} (Bq/m^3)	T (c°)	Q_a (lit/min)	Q_w (lit/min)
9.7	12.49	13.84	1060	23	5	0.3
10	12.43	13.81	1400	23	5	1
7.6	12.38	13.4	2720	23	5	1.85
6.1	12.36	13.17	2880	23	5	2.5
3.2	48.8	50.42	5300	23	0.8	2.5
6.7	23.49	25.17	2140	23	2	2.5
7.6	15.7	16.99	3530	23	3.5	2.5
9.8	12.66	14.04	2710	30	5	1
11.4	12.71	14.34	2830	35	5	1
9.5	12.62	13.94	5750	38	5	1

Mathematical modeling results

Water flow rate effect

Effect of water flow rate on time constant was shown in figure 4. Increasing water flow rate causes a little decreasing of time constant. This effect is same in other temperatures. Experimental data in TABLE 2 confirm this result.

When water flow rate was increased, mass trans-

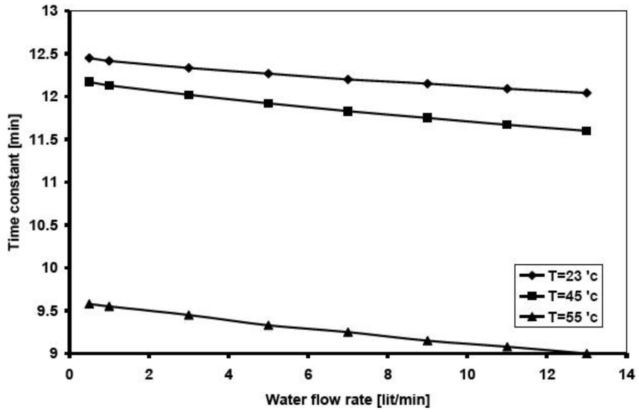

Figure 4 : Effect of water flow rate on time constant (C_{w0} = 3000Bq/m^3, Q_a = 5 lit/min)

fer of radon between water and air also increase a little. Therefore, Time constant was decreased a little. As a result, if water flow rate be more then time constant is a little smaller. Therefore, with attention to restriction of rate of spring, water flow rate *2- 4* liter per minute is suitable for this setup.

Air flow rate effect

Effect of air flow rate on time constant was shown in figure 5. Increasing of air flow rate from *0.5lit/min* to *5lit/min* decrease time constant appreciably. More increasing of water flow rate doesn't appreciable effect on time constant. Then, with attention to figure 5 and restriction of air pump power (electricity optimization), *6 lit/min* is suitable rate for air cycle. Time constant at this flow rate is satisfactory. In addition, it has low sensitivity regard to changing of 1-2lit/min of air flow rate.

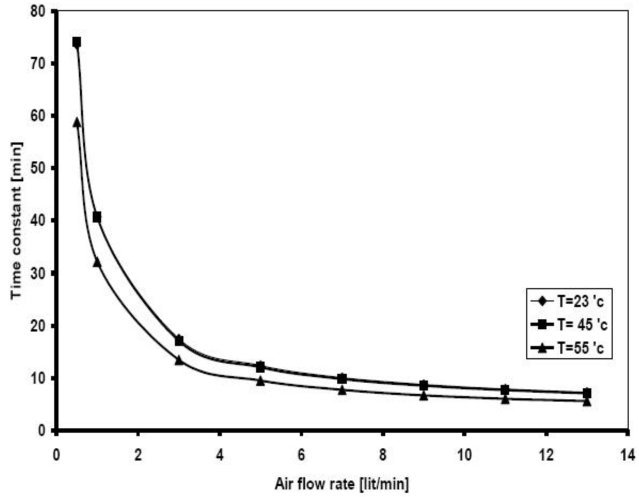

Figure 5 : Effect of water flow rate on time constant (C_{w0}= 3000Bq/m^3, Q_w = 2.5 lit/min)

Water temperature effect

Effect of water temperature on time constant was shown in figure 6. It is observed that changes of time constant with temperature has two reigns, increasing and decreasing. Therefore it has a maximum at temperature about 35 C. Experimental data in TABLE 2 confirm this result.

As mentioned already, solubility of radon in water is exponential function of temperature (figure 3). Increasing of temperature cause decrease solubility of radon in water, then amount of final concentration of radon in air,that contact with water, rises. Therefore time constant of system increases. Rise of temperature also, transcends coefficient of mass transfer and slakes time constant. With attention to this discussion, at initial time solubility factor dominates and cause initial time constant increase. With higher temperature, coefficient mass transfer factor in proportion to solubility is dominate, then time constant decrease.

With change in water temperature, solubility in water and final concentration of radon in air revolve. Therefore for optimum performance of system, a temperature must be chosen that: sensitivity of equilibrium radon concentration on change of temperature be negligible, time constant be enough small at this temperature and energy consumption for heat of system be low.

With respect to given discussions and figures. 3 and 6, temperature about 50 C is an appropriate temperature for optimum performance of this system.

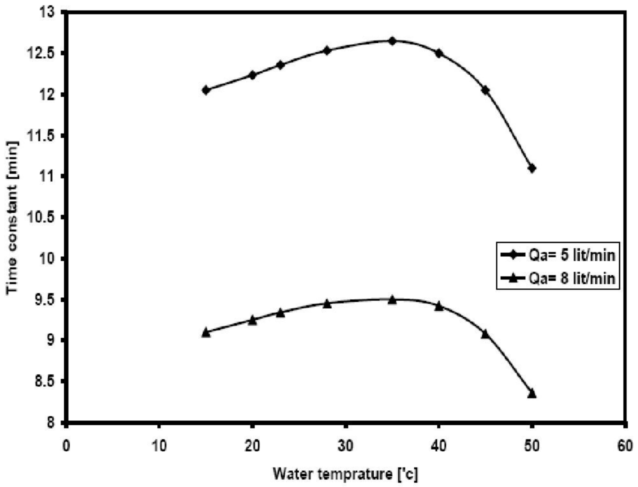

Figure 6 : Effect of water temperature on time constant (Q_w= 2.5 lit/min, C_{w0} = 3000Bq/m3)

NOMENCLATURE

A : bubble column cross area (*m^2*)
C_a : radon concentration in air (*Bq/m^3*)
Cw : radon concentration in water (*Bq/m^3*)
C_w^* : Radon concentration at interface (*Bq/m3*)
$D_{R,w}$: diffusivity of radon in water (*m^2/s*)
d_c : column diameter (*m^2*)
E_a : dispersion coefficient of air (*m^2/s*)
E_w : dispersion coefficient of water (*m^2/s*)
k: radon water solubility (—-)
K_La : volumetric mass transfer coefficient based on liquid phase (*s^{-1}*)
L : bubble column height (*m*)
$\dot{N}_a^{conv}$: radon mass transfer rate in air due to convection (*Bq/s*)
$\dot{N}_a^{disp}$: radon mass transfer rate in air due to dispersion (*Bq/s*)
$\dot{N}_w^{conv}$: radon mass transfer rate in water due to convection (*Bq/s*)
$\dot{N}_w^{disp}$: radon mass transfer rate in water due to dispersion (*Bq/s*)
$\dot{N}_R$: radon mass transfer rate from water to air (*Bq/s*)
Q_a : air volume flow rate (*m^3/s*)
Q_w : water volume flowrate (*m^3/s*)
T : water temperature (*ëc*)
t : time (*s*)
u_a : superficial velocity of air (*m/s*)
u_w : super facial velocity of water (*m/s*)
Vm : volume of air store including pump and RAD7 system (m^3)
ρ_w : water density (*kg/m^3*)
μ_w : kinematic viscosity of water (*kg/(m.s)*)
v_w : dynamic viscosity of water (*m^2/s*)
σ_w : surface tension of water (*s*)
ε_a : air hold-up (—-)
ε_w : water hold-up (—-)

CONCLUSIONS

1. Increasing water flow rate doesn’t have any appreciable effect on time constant.
2. Increase air flow rate to 4 lit/min cause time constant considerably decrease, and with higher flow rate, this decreasing trend is negligible.
3. at initial time, when temperature of water increase, time constant also increase but with higher temperature, trend of time constant is not increasing and from about 35 C, it decrease.
4. With aspect to time constant of system, it is resulted that this system is appropriate for measure of radon concentration. Only defect of this system is high consumption of desiccant.
5. With attention to good agreement between mathematical model and experimental data, can say that axial dispersion model is an appropriate model for analysis of bubble column.

REFERENCES

[1] F.S.Erees et al; Radon concentrations in thermalwaters related to seismic events along faults in the DenizliBasin,Western Turkey, J. Radiation Measurements, **42**, 80–86 **(2007)**.

[2] H. Surbeck, A radon- in- water monitor based on fast gas transfer membranes, Int. Conf. On TENR, October 16- 19, **(1996)**.

[3] W.D.Deckwer; Modeling for bubble column reactors, 1st edition, John Wiley & sons, **(1992)**.

[4] J.Behin, G.Soltanian, M.Jafari Nasr, M.FalahiYekta; Modeling and simulation of multi stages bubble column in produce of hydrogen peroxide prosess, paper presented at the 10th conference of chemical engineering, Zahedan,Iran, **(2004)**.

[5] D.NikeziL, V.Urosevic; A theoretical study of radon measurement with activated charcoal, J. Nucl. Instr.And Meth.In Phys.Res.A, **406**, 486-498 **(1998)**.

[6] K.Shimizu, S.Takada, K.Minekawa, Y.Kawase; Phenomenological model for bubble column reactors: prediction of gas hold-ups and volumetric mass transfer coefficients, Chem.Eng.J, **78**, 21 **(2000)**.

[7] S.V.Patankar; Numerical Heat Transfer and Fluid Flow, Hemisphere Publishing Corporation, New York, **(1980)**.