RADON REMOVAL FROM THE WATER RESOURCE

Jozef Kriš[1], Karol Munka[2], Monika Karácsonyová[2], Margita Slovinská[2], Stanislav Varga[2], Dušan Rusnák[1]

[1] Department of Sanitary and Environmental Engineering, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Radlinského 11, 813 68 Bratislava, Slovak Republic

[2] Water Research Institute, Nábr. arm. gen. L. Svobodu 5, 812 49 Bratislava,Slovak Republic

Abstract

Concerning the presence of radioactive substances in groundwater used for public supply, particular attention is paid to radon removal in water treatment process. The processes based on water aeration are the most common methods for the reduction of radon concentrations in water. Simple spraying, bubble aeration in the deeper layers of water and various modifications of water aeration in a horizontal arrangement - Inka system and aeration towers - are used for radon removal from water. Vacuum de-aeration is another possibility of reducing the concentration of radon in water. However, this procedure is not widely used in practice as compared to the above methods. The article presents the results obtained from the pilot tests for radon removal by using the aeration tower and Inka aeration system in the water resource supplying the city of Istebné with drinking water.

Key words: *radon, radon removal, aeration tower, Inka aerator, water quality*

1. INTRODUCTION

Radon is a member of the ^{238}U decay series and its concentration in groundwater depends on the content of the nuclide ^{226}Ra in geological formations. It is typical that the nuclide ^{226}Ra occurs in all rocks, and its concentration in volcanic rocks is higher than in sandstones and limestones. Radon is an inert, water-soluble gas that gets balanced with the other members of the uranium series (daughter products) within several hours. These are usually categorized by the half-life into short-term (^{214}Pb with a half-life less than half an hour) and long-term, where ^{210}Pb is the most important with a half-life of 22 years. It can be stated that almost all occurring radionuclides in drinking water resources are of primordial origin. These include radionuclides with a sufficiently long half-life period (^{232}Th, ^{235}U, ^{238}U) and individual members of their decay series. The most important are ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{228}Ra (Cothern, 1991), (Mansfeld 1990). The paper presents selected results of the study "Occurrence and removal of specific inorganic contamination of groundwater resources for town of Istebné".

2. TECHNOLOGICAL METHODS OF RADON REMOVAL IN WATER TREATMENT

The processes based on water aeration are the most common methods for the reduction of radon concentrations in water. Simple spraying, bubble aeration in the deeper layers of water and various modifications of water aeration in a horizontal arrangement - Inka system are used for this purpose. However, the aeration towers have greater efficiency (90-95 %). Vacuum de-aeration is another way to reduce the concentration of radon in water, but this procedure is not widely used in practice as compared to the above methods.

Sorption process using activated carbon has also been designed to remove radon from water. It has not found widespread use in practice because of higher financial cost as well as several technical problems (media fouling with suspended solids, sorption of other radionuclides that may be present) (Rudovský 1996), (Vlček 1996).

3. ISTEBNÉ WATER RESOURCE – PILOT TESTS OF RADON REMOVAL

The pilot tests of radon removal were carried out in the water resource supplying the city of Istebné with drinking water. Two springs (upper and lower), from which water accumulates in the water reservoir, were monitored. The discharge of the upper and lower springs was 8 -10 l/s and 3-5 l/s respectively. Radon concentration in the upper spring ranged from 88 to 130 Bq/l and in the lower spring from 130 to 165 Bq/l during the pilot tests. The aeration tower and Inka aerator were used for the removal of radon.

4. DESCRIPTION OF PILOT TEST INSTALLATIONS

The Inka Aerator was made of stainless steel, and the size of its perforated grid was 210 x 210 mm. The openings in the grid had a diameter of 2 mm, and the distance between the openings was 13 mm. During the pilot tests, the discharge varied from 0.17 to 0.77 l / s, which meant that the aerator worked with hydraulic load from 3.9 to 17.5 l / m2.s and the air-water discharge ratios (Q_{air}/Q_{water}) ranged from 14.3 to 61.2. The blower Rietschle CE D 79650 with a capacity of up to 60 m3 / h was used for the aeration. Two modifications of the aerator were also used to verify the radon removal efficiency:

- placement of mesh screen above the aeration grid
- placement of baffles above the aeration grid.

A mesh screen was made of stainless steel with the size of openings of 0.5 mm. It was fixed to the steel frame, and it possible to fix its position at the height of 5, 10 and 15 cm above the grid (aerated water level = 25 cm). The baffles were mounted on a common support frame inserted into the space above the grid. Three baffles were mounted on the support frame, perpendicular to the flow direction. Two outer baffles were placed just above the grid. The height of these baffles was 10 cm, so that both were completely immersed in aerated water. The bottom of the central baffle was placed 5 cm above the grid, and its upper part was above the level of aerated water.

Aeration tower was made of stainless steel and consisted of inflow segment, three aeration segments and outflow segment (Figure 1). Aeration segments containing the media were 1000 mm in height with a surface of 0.04 m^2 mm (200 x 200 mm). At the end of each aeration segment a sampling valve was placed. The effective height of the aeration tower was 3 m in the pilot tests, while the total height reached 3.8 m. Fiberglass roofing material was used as a medium in aeration tower.

- length of media (wave profile): 90 cm
- wave height: 4 cm
- centre distance of two adjacent waves: 10 cm
- actual length of media: 112.7 cm (in one aeration segment)
- width of media: 19,5 cm.

During the pilot test a specific surface area of the media varied. This was achieved by changing the number of pieces of media in each aeration segment. At the changed specific surface of the media during the pilot test, each aeration segment contained the same number of pieces of the media. At the discharge in aeration tower of 0.3 - 0.7 l/s and the hydraulic surface loading H = 7.7 - 17.5 $l/m^2.s$, the specific surface of media was M_P = 44; 88 and 132 m^2/m^3. The off-gas was vented using the blower Rietschle CE, D 79650 with the performance of 60 m^3/h. The airflow was measured by using a rotameter.

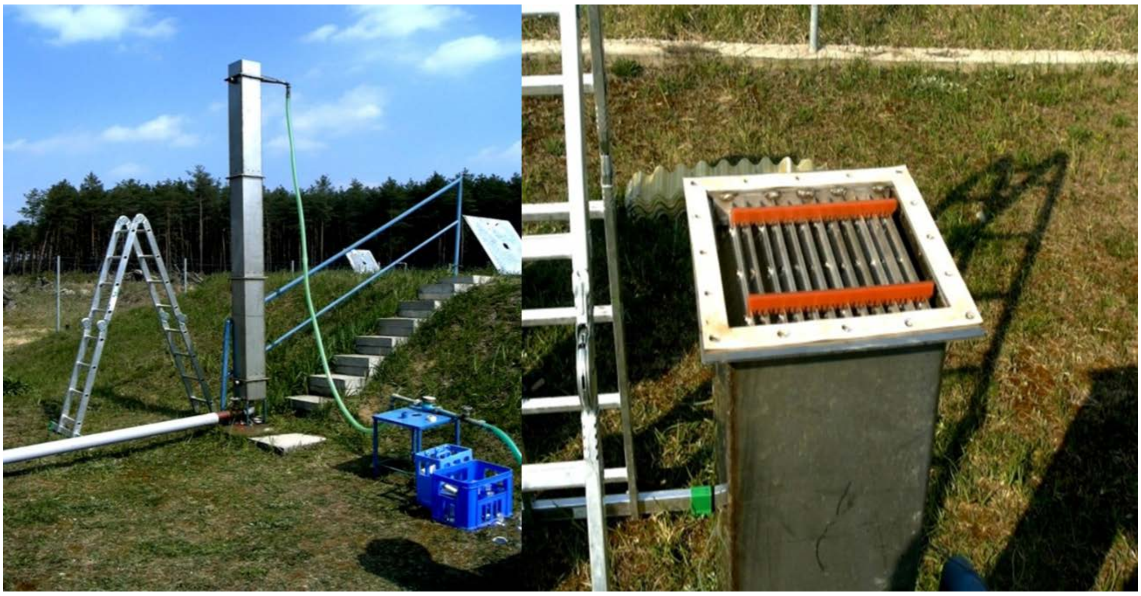

Fig 1. Pilot-scale aeration tower for radon removal (Photo - Munka)

5. THE RESULTS OF PILOT TESTS FOR RADON REMOVAL USING THE AERATION TOWER

The pilot tests showed that the best radon removal efficiency at the hydraulic surface loading (SL) of 8-15 $l/m^2.s$ were obtained at the media specific surface (SS) of 44 m^2/m^3. Radon concentration at the outlet of aeration tower reached 13-20 Bq/l; at the 2-times larger specific surface (88 m^2/m^3), and the same hydraulic surface loading the radon concentration was 20-28 Bq/l; at the 3-times larger specific surface (132 m^2/m^3) it was 29-31 Bq/l. At the media specific surface of 44 m^2/m^3, the hydraulic surface loading of 8.0 and 15.0 $l/m^2.s$ and the activity concentration of radon in raw water of 89 - 102 Bq /l, the activity concentration of radon was lower than 50 Bq /l already after the first aeration segment (height of 1m). For larger specific surface area (88 and 132 m^2/m^3) the activity concentration of radon less than 50 Bq/l was reached only at the outlet of 2nd aeration segment (media height of 2 m) (Figure 2).

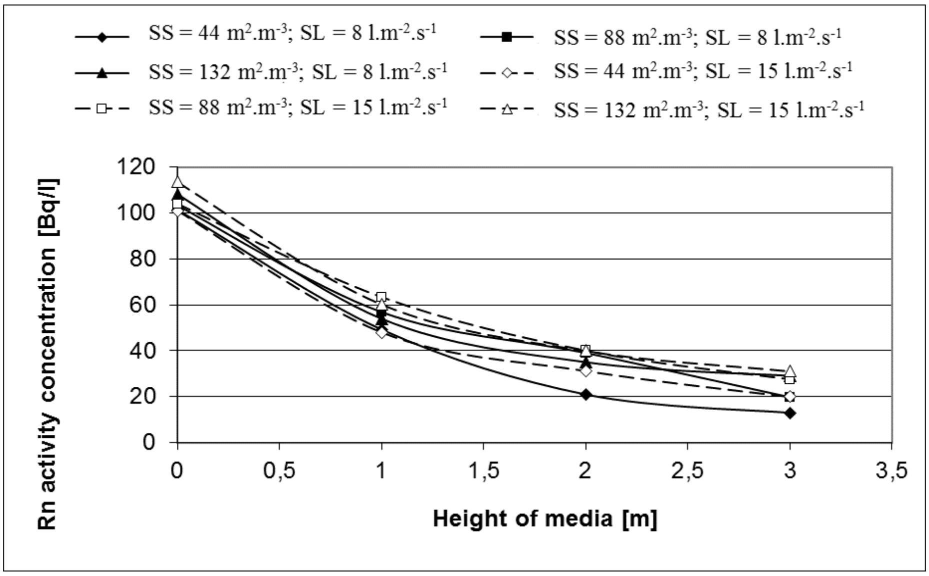

Fig 2. Changing activity concentration of radon at the different heights in the aeration tower for different specific surfaces of the media, water resource of Istebné - upper spring (natural off-gas venting)

Figure 3 shows the results of pilot tests aimed to compare the efficiency of radon removal for the media specific surface area of 44 m^2/m^3 and the hydraulic surface loading of 15 $l/m^2.s$ depending on the air-water discharge ratio. The ventilation of aeration tower was carried out in three different ways:

- natural venting of the off-gas
- co-current flow of air from the blower through the aeration tower
- counter-current flow of air from the blower through the aeration tower

By comparing natural and forced off-gas venting it can be concluded that the forced one was more effective, where the activity concentration of radon in the treated water reached 20-25 Bq/l (raw water ranged from 88 to 104 Bq/l). The removal efficiency was greater than 75%. Using the natural venting of the off-gas, the activity concentration of radon in the treated water reached 37 Bq/l (raw water 115 Bq/l, 67.5% removal efficiency). The comparison of the efficiency of radon removal in co-current and countercurrent air flow shows that countercurrent air flow was more efficient, especially at lower air-water discharge ratio (10.3 - 10.4). This difference decreased by increasing the air-water discharge ratio.

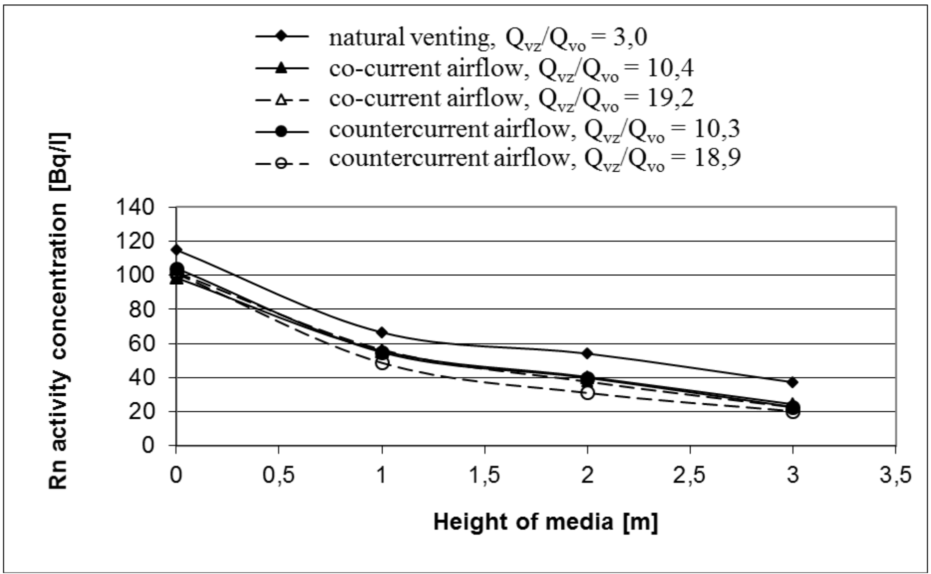

Fig 3. Changing activity concentration of radon at the different heights in the aeration tower for different methods of the off-gas venting (specific surface if the media: 44 $m^2/m^{3,}$ hydraulic surface loading: 15 $l/m^2.s$), water resource of Istebné – upper spring

No significant difference in the efficiency of radon removal between co-current and countercurrent flow of air into the aeration tower was observed at the radon activity concentration of 130Bq/l in raw water and air-water discharge ratio of 10 and 18.3. Following the above parameters, the activity concentration of radon met the limit of 50 Bq/l at the outlet of the 2nd aeration segment. Pilot tests on the lower spring were carried out for the media specific surface of 44 m^2/m^3 and hydraulic surface loading of 17.5 $l/m^2.s$ depending on the air-water discharge ratio (for co-current and countercurrent air flow of 9.1 and 16.2 respectively). The ventilation of the aeration tower was done in three different ways:

- natural venting of the off-gas
- counter-current flow of air from the blower through the aeration tower
- co-current flow of air from the blower through the aeration tower

The results obtained from the pilot tests show that the difference in radon removal efficiency between natural and forced off-gas venting decreases by increasing the hydraulic surface loading at the optimum specific surface of the media,. At the above technological parameters and the radon activity concentration of 160 Bq/l in raw water, the activity concentration less than 50 Bq/l was measured at the outlet of the 3rd aeration segment (32-33 Bq/l using co-current and countercurrent flow; 39 Bq/l using natural off-gas ventilation). Radon concentrations at the outlet from the 2nd aeration segment reached nearly the limit value of 50 Bq/l (51-56 Bq/l) (Munka 2009).

6. THE PILOT TEST RESULTS OF RADON REMOVAL BY USING THE INKA AERATOR

The pilot tests using the Inka aerator were conducted to investigate the effectiveness of radon removal in relationship with the air-water discharge ratio for the water level height of 25 cm above the aeration grid. The results show that the radon concentration reached the value of 35 Bq/l in aerated water at the ratio Q_{air}/Q_{water} = 17.5 and a concentration of radon in raw water = 131 Bq/l. Radon concentration gradually decreased by increasing the value of this ratio. A concentration of radon in aerated water was only 15 Bq/l at the ratio Q_{air}/Q_{water} = 60 (Figure 4).

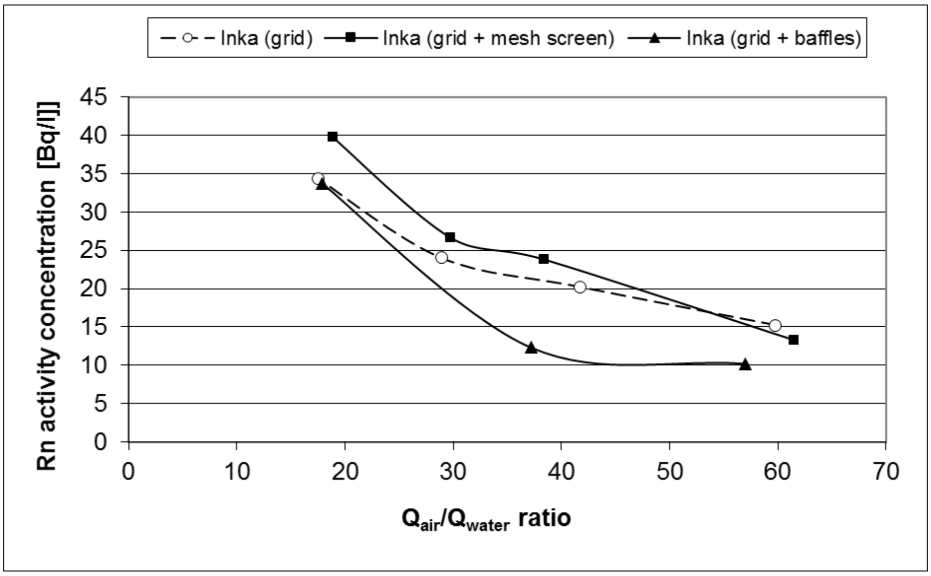

Fig 4. Relationship between the activity concentration of radon at the outlet of Inka aerator and the air-water discharge ratio for different modifications of aerator design (radon activity concentration in raw water: 120-130 Bq/l), water resource Istebné – upper spring

Placement of baffles increased more significantly the efficiency of radon removal at the air-water discharge ratio of 37, where radon concentration reached only 12 Bq/l in aerated water (the lowest value obtained during the pilot tests). The efficiency reached 90%. Further increase in the Q_{air}/Q_{water} ratio did not lead to increased effectiveness of radon removal (Figure 4).

Placement of a mesh screen at a distance of 10 cm above the aeration grid at the Q_{air}/Q_{water} ratio of 17-60 has almost no effect on increased effectiveness of radon removal in comparison with the conditions without mesh screen. As demonstrated by the results, the Q_{air}/Q_{water} ratio increased up to 30 resulted in the decrease in radon concentration to 27 Bq/l. Further increase of the ratio to value of 61.5 led to decreased radon concentration of 13 Bq/l. The difference in efficiency has decreased by increasing the Q_{air}/Q_{water} ratio. Nearly the same efficiency was reached at Q_{air}/Q_{water} ratio of 50 (Figure 4).

The results showed that the radon concentration reached the value of 54 Bq/l in aerated water at the ratio Q_{air}/Q_{water} = 15 and a concentration of radon in raw water = 131 Bq/l. The limit of 50 Bq/l was met by increasing the ratio value to 17. By increasing the value of the ratio to 40 and 60, the radon concentration in aerated water gradually decreased to 28 and 21 Bq/l, respectively. (Munka 2009)

7. CONCLUSION

The results obtained from the pilot tests using the aeration tower can be summarized as follows:

1. The best radon removal efficiency for the aerator hydraulic surface loading of 8-15 $l/m^2.s$ was obtained with the media specific surface of 44 m^2/m^3. The radon concentration at the outlet of the aeration tower (media height = 3 m) was 15-20 Bq/l. The radon concentration of 20-28 Bq/l and 29-32 Bq/l was measured at the outlet under the same conditions, but with 2-times and 3-times greater specific surface of the media, respectively.
2. The radon concentration was already less than 50 Bq/l after the 1st aeration segment (media height 1 m) at the media specific surface of 44 m^2/m^3, hydraulic surface loading of 8-15 $l/m^2.s$ and the radon concentration of 90-100 Bq/l in raw water.
3. By comparing the efficiency of radon removal under the conditions of the natural and forced off-gas venting it can be concluded that the radon was removed more efficiently by forced off-gas venting, where radon concentration in the treated water ranged from 20 to 25 Bq/l (raw water from 90 to 105 Bq/l). When using natural off-gas venting process, the radon concentrations reached 35-38 Bq/l in treated water. The measure proves to be ineffective due to inadequate increase in efficiency (under the given conditions only by 8%) and increased energy demands for the operation of installation with a forced off-gas venting. In addition, the radon concentration lower than the limit under the Decree 12/2001 (50 Bq/l for water from public water supply) in treated water was met by using both methods.

The results obtained from the pilot tests using the Inka aerator can be summarized as follows:

1. The results show that the radon concentration reached the value of 35 Bq/l in aerated water at the ratio Q_{air}/Q_{water} =17 and at a concentration of radon in raw water =130 Bq/l. (water level 25cm above the aeration grid). Radon concentration gradually decreased by increasing the value of the ratio. A concentration of radon in aerated water was only 15 Bq/l at the ratio of 60.
2. Placement of the stainless steel mesh screen with the openings of 0.5 mm at a distance of 10 cm above the aeration grid at the Q_{air}/Q_{water} = 17 did not have any effect on increasing the efficiency of radon removal as compared to the conditions without the mesh screen.
3. Radon removal efficiency was increased by installing the system of three baffles to the space above the aeration grid. Placement of baffles increased more significantly the efficiency of radon removal at the air-water discharge ratio of 35, where radon concentration reached only 12 Bq/l in aerated water. The efficiency reached 90%.

ACKNOWLEDGEMENT

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0372-12.

REFERENCES

Cothern, R.C., Rebers, P.A.1991 Radon, Radium and Uranium in Drinking Water. Lewis Publishers, INC.

Mansfeld, A. - Hanslík, E. 1990 Radium-226 content reduction in waters used for drinking purposes. Papers and studies No. 177, WRI in State Agricultural Publishing House, Praha

Munka K. et al. 2009 Presence and removal of specific inorganic pollution for groundwater resources. Final Report, VÚVH, Bratislava, (Slovak version)

Rudovský, J., Janda, V. 1996 Modifications of aeration devices for 222-Rn removal from water, assessment of the efficiency of radon removal installations.Radionuclides and ionizing radiation in water management, České Budějovice (Czech version)

Vlček, J., Hanslík, E. 1996 Current approaches to the assessment and the need of investigation of 222-Rn and other radionuclides concentrations in drinking water. Radionuclides and ionizing radiation in water management, České Budějovice (Czech version)