

Submerging Aquaculture Tank Spray Bars Reduces Airborne Radon Levels

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Abstract

Radon gas can be liberated every time that radon-containing ground water is aerated for use in aquaculture, creating an occupational health concern. Typical hatchery tank designs have water entering a rearing unit via a spray bar, resulting in radon liberation even in previously aerated ground water. This study evaluated a novel technique to reduce airborne radon levels resulting from secondary aeration by placing rearing tank spray bars either above or below the water surface. Radon levels were significantly decreased when the spray bar was submerged under the surface of the water. The mean (SE) radon level from tanks with a submerged spray bar was 11.80 (0.73) pCi/L, while the radon level from tanks with an elevated spray bar was 43.95 (3.04) pCi/L. In situations where aeration from elevated spray bars is unnecessary, submerging spray bars would be an inexpensive and energy-saving technique to reduce airborne radon levels compared to exhaust fans, intensive aeration, and filtration.

Keywords

Radon, Spray Bars, Aquaculture, Occupational Health

1. Introduction

Radon gas is an odorless, colorless radioactive by-product of uranium decay naturally occurring in soil and bedrock [1]-[3], with high levels in groundwater typically associated with high uranium concentrations [4] [5]. Because radon has low solubility in water, it is easily liberated [4] [6] [7]. Aeration of water facilitates radon gas liberation. Aquacultural operations frequently use aeration to increase oxygen and remove gaseous nitrogen, indirectly liberating radon gas [2] [4] [6]-[8]. Once airborne in enclosed spaces, radon gas can accumulate [6] [9] [10], with long-term exposure to high concentrations hazardous to human health [1] [4] [6].

The negative effects of radon on human health are well documented [1] [4] [6] [11]. The United States Environmental Protection Agency [12] estimates that radon is the number one cause for lung cancer in people who do not smoke and is second to smoking as the leading cause of lung cancer in people who do smoke. Approximately 14% of all radon-induced lung cancer deaths occur in people who have never smoked [12], putting people who smoke at higher risk for developing radon-induced lung cancer [13] [14].

If radon levels are at or above four picocuries/liter (pCi/L) within indoor areas, including workplaces, mitigation is strongly recommended [12] [15]. According to Council Directive 2013/59/Euratom, EU Member States have a maximum reference level of 8.1 pCi/L or 300 Bq/m³ (37 Bq/m³ = 1 pCi/L) [16]. Additionally, the United States Occupational Safety and Health Administration (OSHA) set an exposure limit of 100 pCi/L for 40 hours in a seven-day [9]. Although airborne radon exposure recommendations limit health impacts, measurable human health risks may still exist at or below recommended levels [10] [17].

Although radon exposure is a widespread issue, radon levels have only been reported within a small number of fish hatcheries [1] [2] [8] [18] [19]. Typically, aeration of large amounts of groundwater within fish hatcheries causes the accumulation of gaseous radon [1] [2] [8] [18] [19], resulting in employee health risks without radon mitigation [6] [14] [17]. For example, Lewis [8] conducted a survey of radon levels within 12 fish hatcheries in Pennsylvania and reported three of the hatcheries indoor radon levels ranged between 17.2 and 40 pCi/L. Similarly, a fish hatchery in Montana reported radon levels within a rearing building as high as 250 pCi/L [1] and Kitto *et al.* [2] reported radon levels of 81 pCi/L in a commercial hatchery. A state fish hatchery in South Dakota reported radon levels up to 62.64 pCi/L in fish rearing buildings with little to no ventilation [18].

Although airborne radon is a significant concern inside fish hatchery buildings, mitigation strategies such as diffused-bubble aeration, exhaust fans, and granular activated carbon can be relatively-expensive and energy-intensive [7] [19]-[21]. While passive aeration outside using aeration/degassing towers removes some radon [1] [18] [19] [22], further radon liberation occurs with additional aeration [19]. This typically occurs when previously-aerated water enters hatchery rearing units via spray bars located above the water surface.

If there is no need for additional aeration, spray bars could be submerged to allow water to enter rearing tanks below the water surface. If spray bars were submerged, aeration turbulence would be dramatically reduced, and the resulting radon liberation should be reduced. The objective of this study was to evaluate if airborne radon levels resulting from secondary aeration could be reduced by placing rearing tank spray bars below the water surface.

2. Methods

This study was performed in the tank room at McNenny State Fish Hatchery, Spearfish, South Dakota, USA. Radon levels were measured using self-calibrating radon meters (Corentium Home, Airthings, Norway) with an accuracy/precision

of 5.4 pCi/L/200 Bq/m³.

Six 1.8-m diameter and 78.5-cm deep (60.8 operating depth) circular fiberglass tanks were used in this study. Ground water, previously aerated to oxygen saturation at an outside aeration/degassing tower, entered each tank through a 5.08 cm diameter PVC pipe spray bar. The spray bars were 46 cm long with 12 evenly spaced holes for water to enter the tank. Spray bars were set at a slight angle, similar to those used during actual hatchery production to facilitate hydraulic self-cleaning [23]-[25].

Spray bars in three tanks were elevated 12.7 cm above the tank water level, as per the original engineered design (Figure 1). Spray bars in three other tanks were submerged so that water entered 5.2 cm below the surface of the water (Figure 2). Tanks were the experimental unit (N = 3). Previously-aerated well water entered each tank at a flow rate of 47.8 L/min. Each tank was covered with black corrugated plastic [26], with only a small opening for an automated feeder attached to the side of the tank. Radon levels were measured at a 50.8-mm hole drilled through the cover near the location of the spray bar for the radon meter to be placed (Figure 3).



Figure 1. Image of an elevated spray bar in a 1.8-m diameter circular rearing tank.



Figure 2. Image of a submerged spray bar in a 1.8-m diameter circular rearing tank.

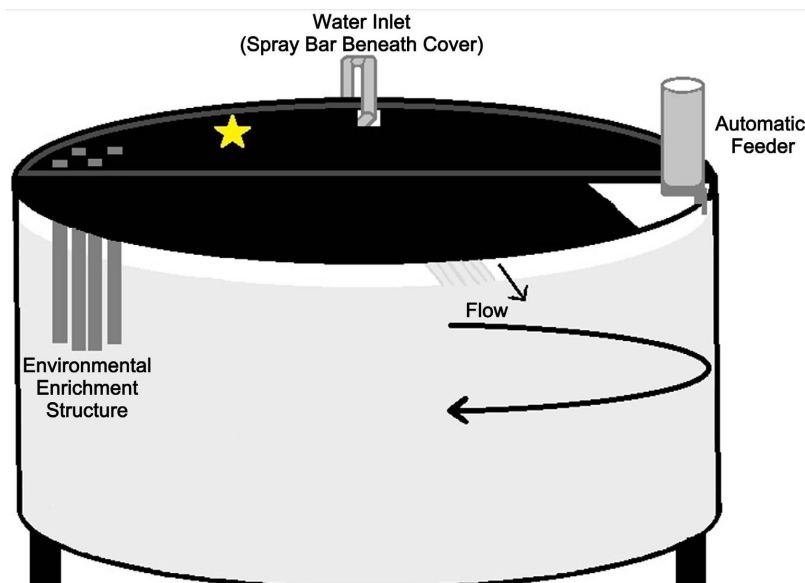


Figure 3. Diagram of a circular tank used for radon measurements. The star indicates where radon levels were measured via a hole in the tank cover. The black portions on the top of the tank denote the corrugated plastic covers.

Radon levels were measured once a day during weekdays from 7 November 2023 to 7 December 2023 (30 days) at approximately the same time each day in the morning. Radon was not measured from the incoming ground water.

Data was analyzed with repeated measures analysis of variance, with tank as a random effect and day as a repeated factor [27]. All data analysis was done using SPSS (24.0) statistical analysis program (IBM, Armonk, New York, USA), with significance predetermined at $P < 0.05$.

3. Results

Radon levels were significantly decreased when the spray bar was submerged under the surface of the water ($F = 36.517$, $P = 0.004$). The mean (SE) radon level from tanks with a submerged spray bar was 11.80 (0.73) pCi/L, while the radon level from tanks with an elevated spray bar was 43.95 (3.04) pCi/L (Table 1).

Table 1. Mean radon (SE) levels for tanks with either submerged or elevated spray bars. Radon was recorded daily for 30 days.

Tank Replicate	Submerged Spray Bar	Elevated Spray Bar
1	35.1 (3.1)	10.7 (1.1)
2	34.4 (2.9)	11.3 (1.5)
3	62.3 (6.7)	13.4 (1.2)

4. Discussion

The significant reduction in airborne radon levels in the tanks with submerged spray bars confirms that additional radon is liberated by spray bar aeration after

prior aeration/degassing outside of the hatchery building. After initial aeration, even to oxygen saturation, aerated ground water can still contain radon [7] [28]-[30]. That previously aerated ground water can release additional radon from spray bar aeration turbulence is also indicated by the correlation between the number of spray bars in operation or water flows and indoor radon levels, particularly observed in production fish hatcheries [8] [18] [19].

The results of this study indicate that submerging spray bars may be an effective technique to reduce airborne radon levels. However, the combined effects of submerging all spray bars in a fish rearing building are unknown. Prior radon research at McNenny State Fish Hatchery indicated mean radon levels of 25.40 pCi/L in the tankroom with elevated spray bars [19]. This is substantially lower than the 43.59 pCi/L observed in an individual tank with a submerged spray bar, likely indicating that the radon escaping from the submerged spray bar tanks would be greatly diluted by the larger air volume of the entire tankroom [31]-[33]. Thus, even though the radon measurements directly above the tank surface in the area mostly confined by the tank cover were still greatly reduced from those levels observed in tanks with submerged spray bars, which were still high enough to advise remediation [12], it is possible that radon concentrations after dilution in the entire tankroom could drop below the level requiring additional remediation. Additional research is needed to determine if this would indeed occur.

Even if submerging spray bars is beneficial for radon remediation, it still must be either benign or beneficial for fish production. While research is limited, in the only study directly comparing the effects of elevated and submerged spray bars on fish rearing performance, Huysman *et al.* [34] observed no difference in the growth of juvenile rainbow trout (*Oncorhynchus mykiss*) reared with either elevated or submerged spray bars. In general, elevated spray bars are typically used, but the use of submerged spray bars in conjunction with circular tanks in recirculating aquaculture systems has also occurred [35], with no documented negative effects on fish rearing. Additional research is needed with other species and sizes of fish.

Several limitations of this study should be acknowledged, including the possible influence of humidity and radon measurement location on the results. While the meter used in this study is relatively accurate at humidity levels up to 70% [36], performance errors of up to 20% can occur at higher humidity levels. Humidity levels were not recorded in this study. However, condensation was observed occasionally accumulating on the exposed portion of the radon meter above the circular tank, indicating likely high humidity. While the surface area of the tank was relatively small, the location of the meter could have possibly influenced the results. By being located opposite the cover opening for the feeder and directly adjacent to the spray bar, the measured radon levels in this study may have been higher than if the meter was located elsewhere. Other potential influences on radon levels, such as temperature and wind speed [37], should have been minimal. Water temperatures were a constant 11°C and air movement inside the building was minimal.

5. Conclusion

In conclusion, submerging spray bars appears to be another technique to reduce radon liberation and occupational exposure in fish hatcheries and aquacultural facilities using groundwater. Submerging spray bars would likely not impact fish production if the water to the tanks is already fully-saturated with oxygen, negating the need for additional aeration by spray bar elevation. Additional research is needed to determine its effectiveness at a production scale, both alone and in conjunction with other radon remediation techniques.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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