original article

Disinfection of water and wastewater of Isfahan water and wastewater treatment plants by gamma irradiation

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ABSTRACT

Aims: The aim of this study was to evaluate the effects of gamma irradiation on the disinfection of the water and wastewater from Isfahan wastewater treatment plants.
Materials and Methods: Using a ^{60}CO gamma radiation machine with emission rate of 405.38 CGy/min, water and wastewater samples were irradiated at doses of 20-160 Gy and 80-240 Gy, respectively. Microbial cultures were performed on the samples to assess the pre- and post-irradiation coliforms content.
Results: The results of microbial tests showed that approximately 100% of the total and fecal coliforms in water samples were inactive at 160 Gy dose of gamma radiation. At a dose of 240 Gy, gamma-ray efficiency for inactivation of the total coliforms in the effluent was different, considering the sample quality. The efficiency for secondary effluent, polished, and filtered samples was 56, 83, and 64%, respectively. In this case, reduction of fecal coliforms was 46, 58, and 81%, respectively. The effective reduction of the coliforms in the effluent samples (80-50%) was also observed at doses of 120-240 Gy. According to the dose-response curves, as the radiation dose increases, the inactivation of the coliforms increases linearly.
Conclusion: At gamma doses used in this study, the coliforms were removed completely. But for wastewater samples, although the removal efficiencies were above 80%, the environmental standards related to microbial parameters were not satisfied. Therefore, it is necessary to use higher doses of gamma radiation.

Key words: Disinfection, gamma-ray, water and wastewater

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INTRODUCTION

Water and wastewater disinfection is performed using chemical or physical agents. Radiation beams used in this method are divided in two main categories, i.e., ionizing beams (including x-ray, gamma, electron beam, α and β) and non-ionizing (ultraviolet ray) beam.[1]

Radiation is an innovative method used for disinfection. The use of radiation has been considered from ancient times as the solar disinfection property was discovered. Recently, the use of ionizing radiation has received much attention due to more efficiency in microbial inactivation without byproducts.[2] In addition, the toxicity of disinfected wastewater using gamma radiation is lower.[3]

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The use of ionizing radiation results in radiolysis of water and produces hydrated electrons, hydrogen, and hydroxyl free radicals. Strong chemical reactivity of these components results in inactivation of microorganisms and decomposition of pollutants.[4,5]

Disinfection using gamma irradiation is an interesting option for direct treatment of water, sewage, and sludge, and in combination with other processes. Gamma rays are electromagnetic waves with short wavelengths and high penetration. This disinfection method is based on exposure of water and wastewater with gamma radiation from radiant isotopes (Co-60 or Cs -137). The strength of gamma-ray source determines the exposure time.[6] The ionizing radiations exchange energy with environment by ionizing and stimulating (excitation) mechanisms. Ionizing, in living tissues, results in production of free radicals. It also changes the Intracellular molecular structures and thereby microcellular components and ultimately causes the cell death.[7]

Radioactive wastes of nuclear power plants can be used as a gamma-ray source. The recovery of these wastes is an effective way for recovery of the reactors' radioactive wastes.[8] Nucleic acids are the main target of ionizing radiation which causes destruction of the genetic material of microbes. The energy level of irradiation is relatively low, and therefore does not produce radioactive waste.

Ionizing radiation makes the microorganisms inactive by production of free radical, directly or indirectly. Gamma radiation can destroy microbes and organic structure. Disinfection with gamma radiation involves various physical factors (temperature and source power), chemical (sensitizing and protective agents), and biological or physiological factors (growth phase and DNA content).[9]

The sensitivity of microorganisms to radiation is various, considering the type of pathogens. The radiation technology is use in water, wastewater, and sludge disinfection and has been studied in different parts of the world. Although nearly 50 years ago, the use of gamma rays was started, only in recent years, there are several reports about the potential role of radiation in sewage treatment plant. Recent studies in different countries have proved the effects of ionizing radiation wastewater treatment.[10]

The India's nuclear energy agency is active in the field of radiation technology to enhance public health and environmental protection. In 1992, this organization studied the wastewater disinfection of sewage treatment plant using gamma radiation to eliminate pathogens. Irradiation equipments for water and wastewater treatment have been installed in many countries. In 1973, the first gamma radiation system for sludge disinfection was installed in Germany.[11] It was also used to reduce the biological fouling of water in the wells.

The aim of this study is to investigate the effect of gamma irradiation on the disinfection of water and wastewater. Literature review of the recent national research projects showed that no investigation has been conducted about water and wastewater disinfection using gamma radiation in Iran.

MATERIALS AND METHODS

Experiments were done in a laboratory-scale batch reactor. In the current study, the efficacy of gamma radiation in eliminating the coliforms was evaluated. Microbial samples of raw water entering the treatment plant and after filtration (prior to disinfection unit) of the Isfahan water treatment plant were collected. The microbial samples from the final output of the Isfahan north wastewater treatment plant, the final polished effluent of a pilot unit with 1-day retention time, and final filtered effluent of an under-pressure sand-filter pilot plant with sand grains of 4-6 mm diameter were also collected. Using the multiple tube fermentation method, the water and wastewater samples were tested to assess the total coliforms and fecal microbial load.

The samples were transferred to the radiotherapy section of "Seyyedo-al-shohada" Hospital and irradiated by ^{60}Co equipment as gamma-rays source. Cobalt-60 Phoenix equipment is a perfect device for teletherapy. It consists of a ^{60}Co source, rotational gentry, rotational treatment tip, adjustable collimator, therapeutic bed, hand controls, and a control table, as shown in Figure 1.

Irradiation level of the samples was calculated as cGy per minute. Calculation was performed using the output data of ^{60}Co equipment which is determined monthly as Gray (unit of the absorbed dose):

Dose of gamma radiation from ^{60}Co equipment = $378.61 \times 1.087 \times 98.5\% = 405.38$ cGy/min

Figure 1: The ^{60}Co equipment used for irradiation of the samples

Water and wastewater samples were irradiated for 5-40 minutes and 20-60 minutes, respectively. Considering the output beam intensity and irradiation time of the samples, the dose received by each sample was determined using the following equation:

$$D = I \times T$$

Where, I is beam intensity and t is irradiation time.

After irradiation, microbial experiment was performed again to assess the removed coliforms in the irradiated samples and also to determine the irradiation efficiency in disinfection process. Microbial tests were performed on water samples using multiple tube fermentation technique (10-tube at broth concentrations lactose environment). The experiments were done on the effluent samples at 10^{-3}, 10^{-4}, and 10^{-5} dilutions.

RESULTS

Irradiation with doses of 200 to 300 krad reduces the bacterial pathogens, effectively (6-8 log). A dose of 5 kGy of high-energy electrons reduced the microbial load of wastewater by 90%. In this study, after irradiation with a dose of 160 Gy, the total and fecal coliforms content in raw water samples reduced from 23 MPN/100 ml to zero [Figure 2a]. The coliforms content in filtered water samples decreased from 16 MPN/100 ml to zero [Figure 2b].

The coliforms content in the sample of secondary effluent wastewater from wastewater treatment plant of Isfahan decreased from 1.7×10^5 MPN/100 ml to 7.5×10^4 MPN/100 ml after irradiation with a dose of 240 Gy. The fecal coliforms decreased from 5×10^4 MPN/100 ml to 2.1×10^4 MPN/100 ml [Figure 3a]. The total coliforms content in the polished effluent sample of the pilot unit (with a retention time of 1 day) reduced from 7.5×10^4 MPN/100 ml to 2.7×10^4 MPN/100 ml at this radiation dose. In this case, the fecal coliforms decreased from 3.3×10^4 MPN/100 ml to 1.2×10^4 MPN/100 ml [Figure 3b]. The results of a research with the irradiation power of 80 kGy showed that a dose of 2 kGy of gamma-ray results in reduction of coliforms load in raw sewage to lower than 100 CFU/ml. The physicochemical parameters of the disinfected effluent using gamma radiation were also measured. The results showed that the disinfected effluent is suitable for use in agriculture.

In the filtered wastewater sample of the sand-filter pilot plant, the coliforms content reduced from 2.3×10^4 MPN/100 ml to 4 000 MPN/100 ml. The fecal coliforms content decreased from 2.1×10^4 MPN/100 ml to 4 000 MPN/100 ml [Figure 3c]. It is to be noted that the coliforms load of the samples decreased effectively (50-80%) at doses of 120-240 Gy.

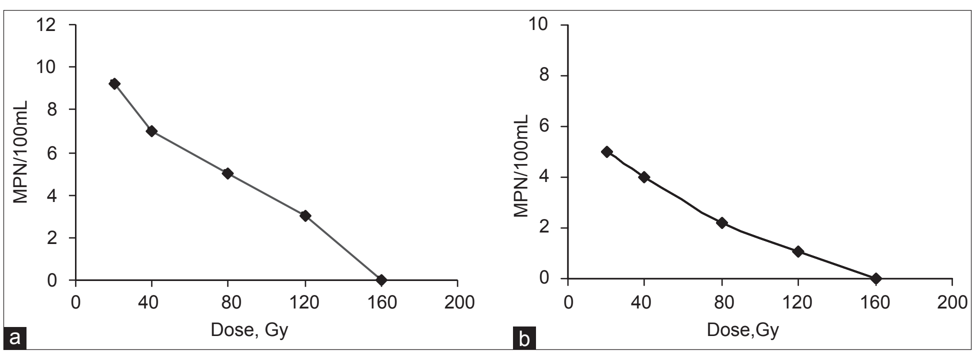

Figure 2: Total and fecal coliforms content after disinfection using gamma irradiation at a dose of 160 Gy in (a) raw water and (b) filtered water from Isfahan water treatment plant

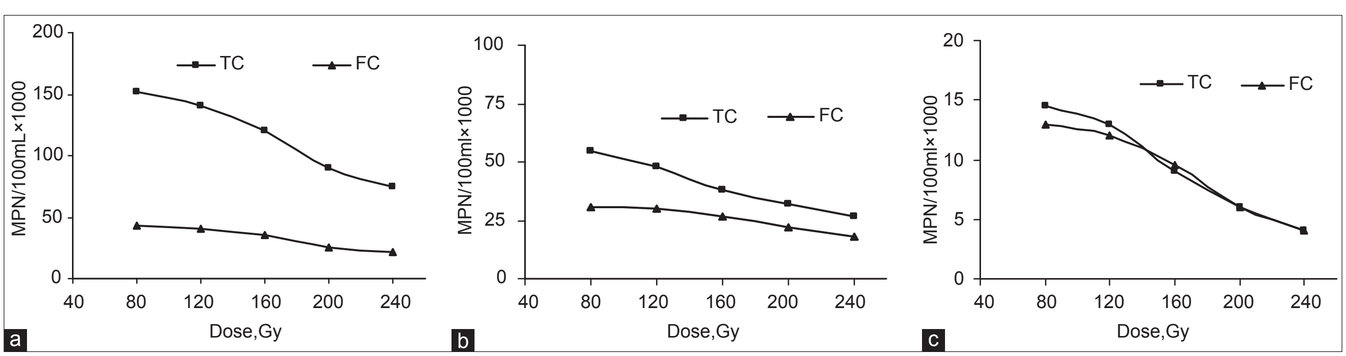

Figure 3: Total and fecal coliforms content after disinfection using gamma radiation at a dose of 240 Gy (a) in the secondary effluent of wastewater treatment plant of north Isfahan, (b) in the secondary polished effluent of the pilot plant unit with 1-day retention time, and (c) in the secondary filtered effluent of the pilot plant unit

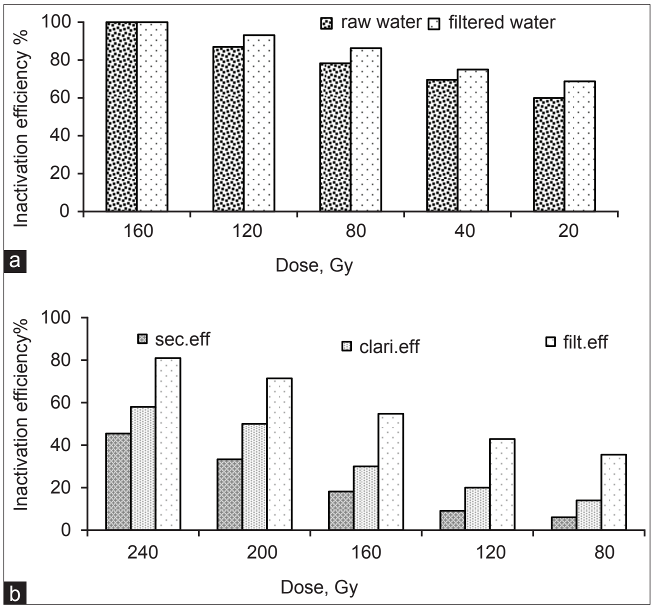

Figure 4: Efficiency of gamma irradiation for inactivation of the fecal coliforms (a) in the water samples at a dose of 160 Gy and (b) in the wastewater samples at a dose of 240 Gy

Figure 4a shows that irradiation with a dose of 160 Gy results in complete inactivation of the coliforms in the raw and filtered water samples. Irradiation with a dose of 240 Gy results in inactivation of 56, 64, and 83% of the total coliforms in secondary effluent sample, polished, and filtered samples, respectively [Figure 4b].

DISCUSSION

A dose of 1 mrad is adequate for elimination of bacterial pathogens, fungi, viruses, and parasites. In 2006, the efficacy of ionizing radiation on the disinfection of municipal wastewater was studied in Baghdad. The results showed that dose of 1-100 rad is effective in reducing microorganisms to the standard range.[2]

The gamma irradiation was used for full-scale sewage disinfection in Germany. The gamma-ray dose for 4-Log inactivation of coliphages and coliforms was determined to be 5 000 Gy. In another study, for 1-Log reduction of the coliforms, a dose of 200 Gy was required. A dose of 1 000-2 000 Gy was required to inactivate 3-4 Log of coliforms in raw sewage. A dose of 5 000 Gy has been reported for bacteria and spores. For inactivation of 1-Log and 4-Log of the *Escherichia coli*, a dose of 80 Gy and 250 Gy has been suggested, respectively. The efficacy of gamma radiation for inactivation of fecal coliform in the secondary effluent, polished, and filtered samples was 46, 58, and 81%, respectively.

From the obtained results of the present study, it can be concluded that there is a significant difference between coliforms content before and after radiation in raw and filtered water samples. Gamma irradiation at a dose of 160 Gy is sufficient for inactivation of the total and fecal coliform bacteria of the Isfahan water treatment plant. Drinking water standards can be achieved using gamma irradiation (P value <0.001). Furthermore, the difference between coliforms content of the effluent samples (secondary, polished, and filtered) before and after irradiation was significant (P value <0.05). In the case of the filtered effluents, gamma radiation at a dose of 240 Gy gives 80% efficiency for removal of coliforms by sand filtration pilot unit. However, it is not still able to decrease the total coliform to 1 000 unit/100 ml and 400 fecal coliforms/100 ml of effluent (standards of Iran Environmental Organization). The results of an independent statistical *t-test* showed that the effect of gamma irradiation on the disinfection of filtered water samples was greater than its effect on raw water samples. In addition, ANOVA results revealed that the effect of gamma irradiation on the disinfection of filtered effluent samples was greater in comparison with secondary and polished effluent samples.

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