Waste Water Sterilization by Cobalt Co-60 for the Agricultural Irrigation: A Case Study

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Abstract: The aim of this paper is to study of establishment a fourth stage of the secondary and tertiary treatments plant for sterilization wastewater. This will reduce the biological loading including vital viruses and parasite eggs by usage of gamma radiation of the Cobalt-60 ($^{60}$Co-$\gamma$) (1.16 Me.V and 1.33 Me.V). The cobalt can't make artificial radiation; therefore it is safe and cheap to solve the chemical treatment problems and to avoid chlorine components in the environment. In this comparative study it was completed between the electron rays (e-beam), UV lamps, ozone unites, chlorine, mechanical regimes treatment and gamma rays for sterilization of both of wastewater and sludge samples from Al Hofuf wastewater treatment plant with determining advantages and disadvantages for each of these sterilization methods and the location where it should to be applied. It was found that a 16.2 kGy dose is generally suitable for the wastewater sterilization and it could be raised to above 25 kGy in case of only secondary treatment stage is applied and 27 kGy for sludge (SAL= $10^{-6}$). This will reduce the chlorine poisons and the waste of livestock chicken and fishes and the industrial dismissal in the environment. Also it was clarified the biological reason behind of not applying these sterilization methods outside the experimental plants by studying the plant stages of the secondary and tertiary treatment in Al Hofuf, Saudi Arabia, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and using the irradiation first at the entrance of the station prevent to take advantage of that. This study demonstrated the potential of ionizing radiation to disinfect sewage and sludge and to increase the water quality in the wastewater by lowering the total heterogeneous bacteria.

Key words: Sterilization · Wastewater treatment · Water reuse · Sludge · Gamma-irradiation · Cobalt-60 · e-beam · UV · Al Hofuf · Saudi Arabia

INTRODUCTION

Water resources are essential and play a significant role in the development processes. The Kingdom of Saudi Arabia (KSA) is known by its arid conditions and limited renewable freshwater resources. Surface water in KSA is very limited and of a little significance in the water budget of KSA. To meet the increasing water demands in domestic, industrial and agricultural sectors, various alternative supplies are surface water, renewable groundwater resources, treated wastewater, desalinated water and non-renewable groundwater.

Al Hassa Oasis is one of the main and old agricultural centers in Saudi Arabia. Al Hassa oasis with an area of 20,000 hectares is located 70 km west of the Arabian Gulf (Fig. 1). An irrigation network of 1,450 Km of concrete canals and drainage network were put into operation in 1971 [1]. This irrigation project delivers 328 million m$^3$ of groundwater for about 22,000 farms. Nowadays, Al Hassa Oasis, face shortage of water resources seriously. The present pumped groundwater amount is not enough to meet the increasing demand on the water and the alternative to solve this problem is to reuse wastewater from Al Hofuf sewage plant after treatment. Therefore, the treatment and re-utilization of industrial and life wastewater are even more important.

With increasing interest in wastewater reuse and in disinfection techniques that reduce the toxicological impact of wastewater to the environment [2], alternatives to chlorine are being studied. One such alternative is radiation processing [3, 4]. It appears that both gamma and electron beam irradiation offer alternatives that insure disinfection and may have the added benefit of increasing the water quality by reducing the chemical constituents...
Fig. 1: Base map of Al Hassa Oasis and Al Hofuf Town.

such as the biochemical oxygen demand (BOD), chemical oxygen demand (COD) and total organic carbon (TOC), all at the same time. There have been numerous studies reported in this area [5-13]. Treatment of sludge using irradiation has also been studied (for example, [14-17]).

Radiation treatment has also been suggested as a way to pre-treat groundwater in extraction wells as it is pumped up [18]. In addition to disinfection, they showed that the irradiation of groundwater using $^{60}$Co (in situ) served two purposes, reduction of biofouling of the wells and removal of cyanide and COD in the water. One of the main reasons for exploring this new technology was to provide an alternative to chlorination for disinfection. There are three reasons that are cited for attempting to find a substitute for chlorine: (1) its toxicological effects to aquatic organisms; (2) the inefficiency of chlorine to remove viruses from wastewater; and (3) the formation of by-products by the combination of chlorine and inorganic ammonia, forming chloramines and/or organic material in the waste, forming organohalogen compounds such as trihalomethanes and haloacetic acids.

There are many kinds of methods of wastewater treatment. Compare with other techniques, the method of applying of ionizing radiation has its special properties and advantages [19]. For example, it can treat some organic systems which are difficult to be degraded biologically and does not cause secondary pollution. There is no trace of polluted materials left in the wastewater after degradation finally. Moreover, the irradiation technique is especially effective for sterilization and killing bacteria.

The combined methods of radiation technique with other methods were also studied [20-23]. Hence, the utilization of radiation technique (including $^{60}$Co-$\gamma$ irradiation, electron beam and UV radiation, etc.) in wastewater treatment is drawing more and more attention around the world.

In present study, ionizing radiation is used as a method for wastewater treatment by the use of irradiation, so as to provide valuable experimental data for the future application of irradiation in the environmental protection in Al Hassa as a case study. The wastewater treatment plant of Al Hofuf is the biggest wastewater treatment plant in the area. The amount of tertiary treated water from Al Hofuf plant is about 70000 cubic meters per day while the amount of treated water from the secondary stage is about 130000 cubic meters per day.

The objective of this study was to determine the effectiveness of gamma irradiation in the disinfection of wastewater/sludge and the improvement of the water quality by studying the inactivation of microorganism in the wastewater and sludge with irradiation at different doses on samples from Al Hofuf municipal wastewater treatment plant.

**MATERIALS AND METHODS**

**Irradiation:** The studies were conducted using a laboratory scale $^{60}$Co gamma source. The irradiations were conducted at 25 °C using $^{60}$Co Gamma Cell 220 from MDS-Nordion-Canada International available at Institute of Atomic Energy Research, King Abdulaziz City for Science
RESULTS AND DISCUSSION

Inactivation of Microorganism in the Wastewater:
Several samples were obtained from Hofuf Wastewater Treatment Plant to examine the inactivation of microorganism at various radiation doses. Table 2 summarizes the data for the total heterogeneous bacteria for effluent/sludge samples collected from different places/stages of treatment plant at various radiation doses. With the reference to Fig. 2, these samples include: 1) sewage water from aeration chamber, 2) sewage water from sewage ponds, before secondary treatment, 3) sludge after drying and Squeezing, 4) sewage water after secondary treatment (Before Sand Filtration), 5) sewage water samples before chlorination and 6) sewage water samples after chlorination.

Figure (4a) shows the inactivation of coliform (organisms) in the unchlorinated effluent samples at various radiation doses. Figure (4b) shows the plot of the logarithmic of Colony forming units (CFU)/g for effluent samples collected from aeration chamber versus gamma radiation doses for the purpose of calculation of the D_{10} value, the reduction to 10^3 ppm value and D_{90} as shown in Table 3.

The D_{10} value, the dose required to achieve a reduction of 90%, was obtained for the unchlorinated effluent sample and sludge sample (Table 3). The total coliform appeared to be very sensitive to radiation with low D_{10} values (Fig. 4b and 5 b).
Table 2: Inactivation of total heterogeneous bacteria in unchlorinated, chlorinated secondary effluent and sludge with several irradiation doses for samples collected from Al Hofuf wastewater treatment plant

<table>
<thead>
<tr>
<th>Dose (KgY)</th>
<th>Sewage water from samples</th>
<th>Sewage water Samples Before Secondary treatment (ponds of sludge collection)</th>
<th>Sludge after drying and squeezing (with moisture of about 70%)</th>
<th>Sewage Water After Secondary Treatment (Before Sand Filtration)</th>
<th>Sewage Water samples Before chlorination</th>
<th>Sewage Water samples After chlorination</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0001</td>
<td>9800000</td>
<td>1600000</td>
<td>6200000</td>
<td>77000</td>
<td>27000</td>
<td>8500</td>
</tr>
<tr>
<td>15</td>
<td>30000</td>
<td>7500</td>
<td>15000</td>
<td>95</td>
<td>2500</td>
<td>910</td>
</tr>
<tr>
<td>20</td>
<td>640</td>
<td>750</td>
<td>850</td>
<td>50</td>
<td>85</td>
<td>50</td>
</tr>
<tr>
<td>25</td>
<td>600</td>
<td>150</td>
<td>520</td>
<td>35</td>
<td>60</td>
<td>25</td>
</tr>
</tbody>
</table>

Fig. 3: Typical bacteria species found in the investigated samples
Table 3: $D_0$ values for total coliform bacteria in the effluent samples before chlorination and for sludge from Al Hofuf wastewater plant

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>$D_0$ (KgY)</th>
<th>$D$ (KgY) reduction to 10^3 ppm</th>
<th>$D$ (KgY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchlorinated effluent sample</td>
<td>2.7</td>
<td>10.8</td>
<td>16.2</td>
</tr>
<tr>
<td>Sludge Sample</td>
<td>4.5</td>
<td>18</td>
<td>27</td>
</tr>
</tbody>
</table>

Fig. 4a: Inactivation of Colony forming units (CFU)/g for effluent samples collected from aeration chamber with gamma radiation.

Fig. 4b: Log of Colony forming units (CFU)/g for effluent samples collected from aeration chamber versus gamma radiation.

Accordingly, if we want to disinfect wastewater to $10^3$ ppm we find according to the formula $D_0$:

$$10^7 to 10^3 = 4.\log\text{reduction}$$
$$D_{value} = 2.7\text{KgY}x4.\log\text{reduction} = 10.8\text{KgY}$$

And $D_0$ then is:

$$10^7 to 10^1 = 6.\log\text{reduction}$$
$$D_{value} = 2.7\text{KgY}x6.\log\text{reduction} = 16.2\text{KgY}$$

Also, if we want to disinfect sludge to $10^3$ ppm we find according to the formula $D_0$:

$$10^7 to 10^3 = 4.\log\text{reduction}$$
$$D_{value} = 4.5\text{KgY}x4.\log\text{reduction} = 18\text{KgY}$$

And if we calculate $D_1$ the dose needed for full sterilization:

$$10^7 to 10^1 = 6.\log\text{reduction}$$
$$D_{value} = 4.5\text{KgY}x6.\log\text{reduction} = 27\text{KgY}$$

The inactivation of coliform in the chlorinated effluent samples at various radiation doses is shown in Fig. 6. It is worthy to mention, the effect of the chlorination on decreasing of total number of coliform organisms in the wastewater sample is obvious if it compared with total number of coliform organisms in unchlorinated samples (Table 2 and Fig. 6) and however, it still needs for irradiation to reduce the total number of coliform organisms to acceptable limit of reusing the treated wastewater.

The inspection of data listed in Tables 2 and 3 and Figures 4-6, It was found that, although, a considerably higher dose was required to lower number of bacteria for the coliform organisms, it was observed greater than 99% removal.
There have been numerous studies reported in using of sludge sterilization. [6] reported that sludge could be sterilized using a dose up to 4 kGy from electron accelerator. While, [25], found that D$_{av}$ for sludge is 5 kGy. [26] reported that the best treatment effect reached when the absorbed dose is about 17.5 kGy. These variations in the suggested doses by these studies are attributed to that, the bacteria and viruses are variant groups. Moreover, some species could survive even higher doses are implemented.

It is well known, that of the sterilization of medical instruments is executed at dose of 50 kGy and for spices it needs 10 kGy for sterilization. So, a dose of 2-4 kGy is not enough to sterilize the sludge (solid waste), as it is reported in some studies. In our review to these studies we noticed that some of these studies were conducted their experiments after air processing and some of them were effective after exposing the samples to the sun for seven days.

Also it is not enough to accept the D$_{av}$ limit, the residual 10% of the viruses, germs and bacteria it might be very dangerous for the human and animal health. However, the using of the gamma irradiation has the advantages over the other methods for bacteria sterilization.

Thus, according to the current study and to the D$_{av}$ values, it is found that dose 4 kGy is not enough to sterilize the sludge and to kill viruses. Complete inactivation of total coliform with no regrowth was achieved at a dose of 25 kGy in the sludge samples.

A dose of 25 kGy is necessary for the sterilization of the AIDS virus, which is still able to drop with the sludge and wastewater even after treatment by chlorine, despite the ability of chlorine sterilization at only very high concentrations and localized and these concentrations cannot be used in wastewater. Some experiments note that the minimum dose for the termination of HIV is 30 kGy [27].

Also, it was found the biological reason behind of not applying these sterilization methods at the entrance of experimental plants by studying the station stages of the secondary and tertiary treatment plant in Al Hofuf, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and if the irradiation is used at the entrance of the station will prevent to take advantage of that.

Due to some organism can live up to use of dose off 50 Kgy, we recommend to utilize Gamma rays or ultra violet rays (UV) after the tertiary treatment stage at Al Hofuf wastewater plant. This would improve the economics of the process and reduce any public acceptance issues associated with the use of radioisotopes. This will call a fourth treatment stage of the secondary and tertiary treatments plants for sterilization wastewater. For the case of Al Hofuf wastewater treatment plant we suggest to fix the UV lamps at the entrance of irrigation canals in which the treated wastewater is discharged or anywhere along these irrigation canals.

**CONCLUSIONS**

It was found that a 16.2 kGy dose is generally suitable for the wastewater sterilization and it could be raised to above 25 kGy in case of only secondary treatment stage is applied and 27 kGy for sludge. This will reduce the chlorine poisons and the waste of livestock chicken and fishes and the industrial waste in the environment. Also it was clarified the biological reason behind of not applying these sterilization methods outside the experimental plants by studying the station stages of the secondary and tertiary treatment in Al Hofuf, Saudi Arabia, which it was to let the aerobic bacteria to feed on organic material in wastewater and then the subsequent processing stages in the sedimentation downstream and using the irradiation first at the entrance of the station prevent to take advantage of that. Also the only way for sludge sterilization is Gamma rays and there is nothing can compare with it.

We recommend utilizing ultra violet rays (UV) after the tertiary treatment stage at Al Hofuf wastewater plant. This would improve the economics of the process and reduce any public acceptance issues associated with the use of radioisotopes.
Overall, irradiation appears to be an alternative to tradition chlorination of wastewater, especially if reuse is to be considered. The improvement in quality of the irradiated samples was demonstrated by the reduction in bacteria. Radiation of the wastewater provided adequate disinfection while at the same time increasing the water quality. This treatment could lead to additional opportunities for the reuse of this valuable resource.

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