UTILIZATION OF GAMMA RADIATION IN INDUSTRIAL WASTEWATER TREATMENT

[1]TUN TUN NAING, [2]KHIN KHIN LAY

[1,2]Energy Research Department, Mandalay Technological University, Ministry of Science and Technology, Myanmar
E-mail: [1]naing.ttn@gmail.com

Abstract- Environmental pollution has become a world-wide problem. The growth of industrialization leads to the rise of wastewater produced from various industries and the pollution load on the environment is increasing. The treatment and disposal of industrial wastewater is becoming a challenging problem for developing countries. Industrial wastewater is very complex and the main concerning contaminants are bacteria, parasites and viruses, inorganic and organic pollutants. The main purpose of this research is to develop the industrial wastewater treatment technology in Myanmar. Ionizing radiation has more advantages over the chemical or biological treatment process of industrial wastewater. Very few amount of chemical reagents as initiators and Co-60 gamma radiation source were used to reduce massive load microbial count (~10^{10}CFU/ml), biochemical oxygen demand (BOD ~7000 mg/l) and chemical oxygen demand (COD~30000 mg/l) to safety disposed level in this research. The sample used in this research was combined wastewater from distilleries, sugar factories, candy factories and textile factories. The collected sample was pre-treated with some chemical process and then was to be irradiated into the gamma chamber at a dose of 1 kGy to 18 kGy. Effects of gamma radiation on industrial wastewater and sludge were determined by the reduction rate of total microbial counts, COD and BOD. The optimum dose for the disinfection of bacteria and degradation of organic and inorganic pollutants were obtained. The irradiation dose of 6 kGy was adequate for the disinfection of wastewater and the reduction of COD and BOD to the permissible level was achieved at 18 kGy irradiation dose.

Keywords- Industrial Wastewater, Ionization Radiation, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Microbial Counts, Gamma Radiation, Organic Pollutants

I. INTRODUCTION

Industrialization is the main vein of a country. A developed country cannot be built without industrialization. The growth of industrialization leads to the rise of wastewater produced from various industries and the pollution load on the environment is increasing. The main concerning contaminants of industrial wastewater are bacteria, parasites and viruses, inorganic and organic pollutants. The cost for the industrial wastewater treatment is very expensive and it becomes a serious problem for developing countries. Discarding of industrial wastewater to the river or lake without proper treatment can cause the damage of eco-system and human's welfare. Beside the unwanted pollutants, industrial wastewater contains valuable constituents, such as macro or micro-nutrients and organic matters which all are essential for the plant growth promotion. Sludge is produced as by-product of industrial wastewater treatment process and it is also become a good source of organic fertilizer. The use of industrial wastewater sludge as fertilizer or soil conditioner is the best recycling option for agriculture and environmental preservation point of view. However, high load of pollutant become hindrance from beneficial use or safely dispose to the water environment [12].

Conventional wastewater treatment includes primary treatment (physical sedimentation), secondary treatment (chemical sedimentation) and tertiary treatment (disinfection). Chlorine is used for the purpose of disinfection in the conventional process. The residue of chlorine is also a severe problem to the environment. Industrial wastewater is very complex because of its high load of biochemical oxygen demand (BOD), chemical oxygen demand (COD), trace of heavy metal, toxic organic compounds, inorganic compounds and pollutional microorganisms (bacteria, pathogen, coliform and virus) [8]. For this reason, conventional wastewater treatment is not sufficient for industrial wastewater and special consideration must be needed for industrial wastewater treatment.

Radiation techniques are well established for sterilization of medical devices and polymer modification. Radiation processing of waste may be considered a promising technology due to radiation ability to penetrate the material and induce fundamental changes. When industrial wastewater or sludge is submitted to ionization radiation field, the following events can be observed: oxidation of organic molecules, disturbance of the structure of organic and inorganic molecules, changes in colloidal systems followed by the killing of microorganisms [13]. The objective of this research is to use the existing gamma radiation to study the removal and degradation efficiency of toxic materials, refractory pollutants and the disinfection of pathogenic micro-organisms in wastewater, industrial effluents and sludge without using massive amount of chemical reagents. Mandalay, the second largest city of our country Myanmar has no special treatment plant for industrial wastewater treatment. Wastewater from Mandalay industrial zone is disposed into three waste stream lines namely as Main Sewage Pipe-line, no.6 overflow channel and Pa Yan Taw Creek. The first one end up to Dokhtawaddy River and the latters flow to Taung Tha Man Lake and then finally end up in Irrawaddy River. The main purpose of this research is to develop the industrial wastewater treatment system of our country, Myanmar with the peaceful use of atomic energy.

II. MATERIALS AND METHODS

A. Samples

Wastewater sample for this research was collected from the main sewage pipe line of Mandalay Industrial Zone. There are totally nine factories discarding wastewater into this pipe line. These factories are, five distilleries, one sugar factory, one candy factory and two textile factories. Total discharge rate of this pipe line is 327169 gallons per day (3.786 gallons per second). The most wastewater produced factories are distilleries and textile factories and they occupy about 96 percent of total discharge. Some characteristics of wastewater sample are as follows;

- pH – 2 to 3
- colour – reddish brown
- smell – rotten egg (bad smell)
- total solid - ~10%
- BOD – 7093 mg/l
- COD – 32664 mg/l.

X-ray fluorescence analysis of constituents elements in this wastewater sample are shown in Table I.

TABLE I
CONSTITUENT ELEMENTS OF INDUSTRIAL WASTEWATER SLUDGE

No.	Formula	Z	Net int. (kcps)	Calc. conc(%)
1	Na	11	0.7806	1.22
2	Mg	12	2.949	0.842
3	Al	13	0.1499	0.038
4	Si	14	2.773	0.494
5	P	15	16.12	1.97
6	S	16	52.79	4.094
7	Cl	17	12.91	1.69
8	K	19	190.4	19.08
9	Ca	20	16.37	2.28
10	Mn	25	1.46	0.0585
11	Fe	26	30.86	0.853
12	Cu	29	3.787	0.0389
13	Zn	30	1.895	0.01
14	Rb	37	8.296	0.08
15	Sr	38	2.114	0.022

B. Pre-treatment or Chemical Treatment

Industrial wastewater contain massive amount of BOD and COD. This means the high load of organic pollutants and huge amount of chemical will be need in conventional treatment process. Very few amounts of chemical agents were used in this research to degrade the organic pollutants. Chemical treatment was done by the use of oxidation agent and coagulation and flocculation agent. Hydrogen peroxide was used for oxidation and ferrous salt is used for coagulation and flocculation. The usage of chemical agents were very low compare to conventional process and 0.5 g/l of analar grade ferrous salt and 0.5 ml/l of hydrogen peroxide were used in this research.

C. Gamma Irradiation

Gamma Chamber 5000 was used as the irradiation facility for this research. Gamma source is Co-60 and activity was 1.24 kCi (1.61 kGy per hour) and the capacity of the chamber is 5 litres. Chemically treated water sample were bottled into one litre bottle and then irradiated in the gamma chamber at different doses from 1 kGy to 18 kGy.

After irradiation process, samples were carried out to analyse the microbiology and physicochemical changes.

Figure. 1 Main Sewage Pipe Line

III. ANALYTICAL METHODS

A. Microbiological Analysis of Irradiated Wastewater Samples

Nutrient ager plate count was used for the determination of microbial concentration in irradiated wastewater samples. Samples to be analysed were diluted with serial dilution technique and then counted on ager plate. Total bacteria count was calculated as colony forming unit per millilitre (CFU/ml). Microbiological analysis is shown in Table II.

B. Physicochemical Analysis of Irradiated Samples

Biochemical oxygen demand and chemical oxygen demand were employed for the examination of physicochemical effects of gamma radiation on industrial wastewater. Azide modification with modified Winkler method was used to determine biochemical oxygen demand (BOD) and potassium dichromate digestion method was applied for the examination of chemical oxygen demand (COD). The BOD and COD changes under gamma radiation were shown in Table III.

TABLE II
MICROBIOLOGICAL ANALYSIS OF IRRADIATED SAMPLE

Radiation Doses (kGy)	Total Bacteria Counts (CFU)	
	Sludge	Treated Water
0 (Control)	38×10^8	24×10^7
1	13×10^6	22×10^5
2	36×10^5	32×10^3
3	12×10^5	21
4	16×10^4	Nil
5	32×10^3	Nil
6	23	Nil
7	Nil	-
8	Nil	-
9	Nil	-
10	Nil	-

IV. RESULTS AND DISCUSSIONS

A. Microbiological Effect of Gamma Radiation on Bacteria in Wastewater and Sludge

Total bacterial count of non-irradiated treated water was about 10^8 CFU/ml and it dropped into two log scales at 1 kGy dose to 10^6 CFU/ml. It remained dropping down by two log scales at 2 kGy which was about 10^4 CFU/ml. At 3 kGy, there can only be seen about 20 CFU/ml. No bacteria can be found at 4 kGy irradiation dose. This shows that the chemically treated water can be completely disinfected by the gamma radiation dose of 4 kGy. Lethal dose for treated water is 4 kGy. Early investigations were done for the disinfection of municipal wastewater and sludge with gamma radiation utilization. Municipal wastewater contains about 10^6 cfu/ml of bacteria and 99.9% disinfection was done with no more 3kGy gamma radiation dose [12]. On the other sample, sludge, which contain high load of BOD, COD, and more polluted than treated water. In Table III, there can be seen about 10^{10} total bacteria counts in non-irradiated sewage sludge. It steeps down to three log cycles at a radiation dose of 1 kGy. Total bacteria count is slightly decreased five log cycles while increasing the radiation dose to 4 kGy. At 5 kGy, a few thousands of bacteria can survive and only tens of bacteria can be found at 6 kGy.

There is no colony can be found at a dose of 7 kGy and no bacteria can survive at this dose. So it can be defined 7 kGy as a successfully disinfection dose for the industrial wastewater sludge. Figure 2 shows the survival of total bacteria under irradiation doses.

B. Physicochemical Effects of Gamma radiation on organic and inorganic pollutants in wastewater and sludge

Industrial wastewater contains high load of organic pollutants and most of them are highly persisted to conventional treatment processes. The persistent compounds are hydrophobic and they bind to soil organic matter. Examples of toxic organic compounds are polychlorinated biphenyl “PCBs”, polycyclic aromatic hydrocarbon “PAH”, phenolic compounds, dioxins, phthalates, and surfactants. These compounds are very toxic, carcinogenic and highly reactive, but when it is subjected to ionizing radiation, gamma radiation, it produce highly reactive species resistant to degradation [13].

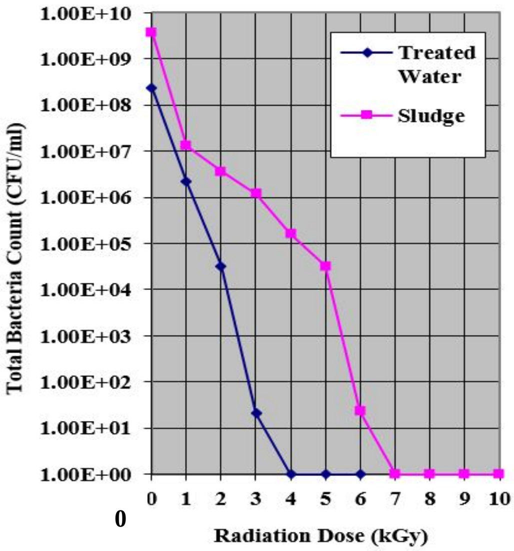

Figure 2. Survival of Bacteria under Gamma Irradiation

TABLE III
MICROBIOLOGICAL ANALYSIS OF IRRADIATED SAMPLE

Radiation Dose (kGy)	BOD (mg/l)	COD (mg/l)
0	7093	32664
1	7043	31720
2	7001	31200
3	6820	30810
4	6733	30405
5	6105	28944
6	5450	26880
7	5307	25350
8	5100	20776
9	4312	15177

10	4180	10816
11	2970	7927
12	2852	6447
13	2373	5480
14	1505	4287
15	984	2012
16	578	1470
17	232	490
18	65	380

Wastewater itself is not normally reactive, but when it is subjected to ionizing radiation, gamma radiation, it produces highly reactive species. Gamma radiation can decompose the water itself in a process called radiolysis. Radiolysis of water results in the formation of hydroxyl radicals and solvated electrons and hydrogen ion. This process is often known as advanced oxidation process, and radical products are highly reactive and are responsible for most chemical reactions which leads to disturb the molecular structure of the toxic organic pollutant from non-degradable to degradable formation. The degradability of pollutants in wastewater can be determined by the ratio of BOD and COD. Besides microbiological deactivation and degradation of organic pollutants, gamma radiation has also efficacy on the reduction of heavy metal stability and solubility [5]. The initial amount of biochemical oxygen demand was too high about 7093 mg/l and only about 10 percent can be reduced till 5 kGy gamma radiation dose. The BOD removal percentage significantly raised to 25% at 7 kGy and 40% removal (4312 mg/l) was achieved at 9 kGy. At 14 kGy gamma radiation dose, the BOD was reduced to 70 %, but it was about 1505 mg/l and which was too high for safely disposed to the water environment. The permissible BOD removal was obtained at 18 kGy dose and 99% of initial BOD was reduced at this dose. The percent removal of BOD versus gamma radiation can be seen at Figure 3. The reduction of BOD and COD under the different gamma radiation dose was illustrated in Figure 4.

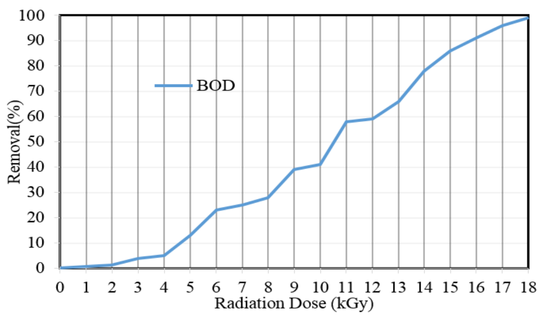

Figure 3. Percent Removal of BOD under Gamma Irradiation [pH-3, initial BOD - 7093mg/l, H_2O_2 – 0.5 ml/l, Ferrous Salt – 0.5 g/l]

For chemical oxygen demand COD, un-irradiated wastewater contained massive amount of COD about 32664 mg/l. This showed the high load of chemical pollutants in industrial wastewater. Fenton chemical reaction was widely applied in industrial wastewater treatment process. Another advanced technology for industrial wastewater treatment was the combination of Fenton chemical reaction and ultraviolet radiation which often known as photo-Fenton reaction [2]. The initial COD of the wastewater in this research was over 30000 mg/l and just half of photo-Fenton chemical reagents were used in this research to remove five times higher load COD. About 20% of COD reduced at 7 kGy and only 20% left at the irradiation dose of 12 kGy. Successfully COD removal (98%) remaining 380 mg/l was achieved at 18 kGy. In photo-Fenton reaction, chemical reagents (1g/L ferrous salt and 1 ml/l hydrogen peroxide) and UV lamp were used to obtain 95% removal of COD (initial amount ~ 7000 mg/l). Figure 5 illustrated the removal percent of COD under the gamma irradiation effects.

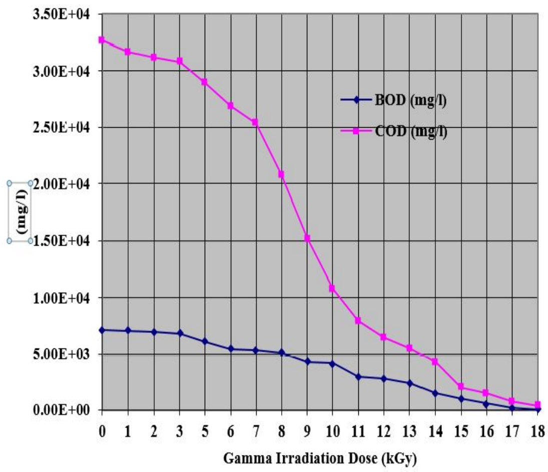

Figure 4. BOD/COD versus Gamma Radiation

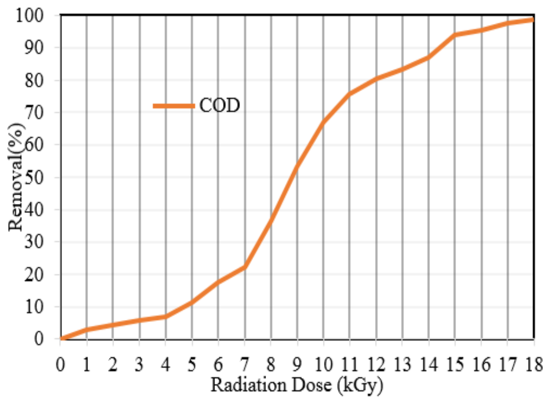

Figure 5. Percent Removal of COD under Gamma Irradiation [pH-3, initial BOD-7093mg/l, H_2O_2 – 0.5 ml/l, Ferrous Salt – 0.5 g/l]

CONCLUSIONS

In our country, industrialization is now developing and wastewater and sludge from the industries are now becoming the main source of water environment and environmental pollution. Proper treatments should be applied in order to eliminate the different pollutants in the wastewater or sludge before discharging to the water body or reuse in the agricultural application. Ionization radiation is the most reliable tool for the pollution control of industrial wastewater and sludge. It is concluded that the utilization of radiation technology is the best recommended means for environmental pollution control. The microbiological and physicochemical effects of gamma radiation on industrial wastewater can be observed in this research and optimum doses for disinfection, BOD and COD reduction to an acceptable level is obtained from this research. Reliable sludge disinfection dose is about 6 and 7 kGy and treated water is completely disinfected at a dose of 4 kGy. The optimum dosage for BOD and COD reduction is 18 kGy.

Combination of conventional treatment and ionizing radiation can reduce tenth fold of the chemical usage for removal of pollutants in industrial wastewater and the reuse of irradiated sludge is economically or environmentally benefit for recycling in agriculture. The capability of ionizing radiation on the environmental pollution control is presented in this research and the combination of radiation technology with conventional treatment is strongly recommended for the future research for the purpose of human welfare and environmental protection point of view.

ACKNOWLEDGMENT

I would like to express heartfelt gratitude to Dr. Khin Khin Lay, my supervisor and main source of inspiration, for her tireless, interest, encouragement and patience on this research work. I also thank to Dr. Aye Aye Toe and other technical staff members in the analytical laboratory at Pyin Oo Lwin (GTI) for the analysis of XRF method. My sincere gratitude to Dr. Tin Tin Myint, other teachers and friends from the Energy Research Department, Mandalay Technological University (MTU) for their helpful facilities and suggestions. I would like to express the special thanks to Daw Mi Cho Cho, principal scientist, and other technical staff members in the Department of Atomic Energy (DAE) (Yangon) for the permission and help of the gamma chamber application. I would like to thank to bio-technology departments in Mandalay Technological University (MTU) and in Material Science and Material Engineering Research Department (MSMERD) for their help. I would like to give my special thanks to sayar Dr Khin Maung Latt, Director General of Department of Atomic Energy who reviewed my research paper and gave advices and motivation for this research.

REFERENCES

[1] Andrzej G. Chmielewski, “Application of ionizing radiation to environment protection”, NUKLEONIKA 2005;50(Supplement 3):S17-S24

[2] Ebrahiem E. Ebrahiem, “Removal of organic pollutants from industrial wastewater by applying photo-Fenton oxidation technology”, Arabian Journal of Chemistry (2013)

[3] H. El Karamany, “Study for the Industrial Wastewater Treatment using Some Coagulants”, Fourteenth International Water Technology Conference, IWTC 14 2010, Cairo, Egypt

[4] IAEA, “Radiation Treatment of Polluted Water and Wastewater”, IAEA-TECDOC-1598

[5] J. Tolgyessy, “Chemistry and Biology of Water, Air and Soil, Environmental Aspects, Studies in Environmental Science 53

[6] Jusof Khadidi, M.H., “A New Flocculant-Coagulant with Potential Use for Industrial Wastewater Treatment”, 2013 2nd International Conference on Environment, Energy and Biotechnology, IPCBEE vol.51 (3013)

[7] Mohammed Y. Al-Ani, “Use of Ionizing Radiation Technology for Treating Municipal Wastewater”, Int. J. Environ. Res. Public Health 2006, 3(4), 360-368

[8] Nicola Getoff, “Radiation-Induced Degradation of Water Pollutants-State of the Art”, “Radiation Phys. Chem. Vol.47, No. 4, pp, 581-593,1996

[9] Pei Wen Wong, “Efficiency of the Coagulation-Flocculation Method for the Treatment of Dye Mixtures Containing Disperse and Reactive Dye”, Water Qual. Res. J. Canada, 2007. Volume 42, No. 1,

[10] PIKAEV, A.K., “Mechanism of radiation purification of polluted water and wastewater”, Water Sci. Technol. 44(2001)131-138.

[11] R.A. El-Motaium.; El-Ammari M.F. and Sabry A. (2005). Improving sewage water charcteristics using radiation treatment. Isotope and Radiation Research Bulletin, Vol, 37, No. 1, pp.253-262, ISSN 0021-1907

[12] R.A. El-Motaium, “Application of Nuclear Techniques in Environmental Studies and Pollution Control,” Proceedings of the 2nd Environmental Physics Conference, 18-22 Feb.2006 Alexandria, Egypt

[13] S. I. Borrely, A.C. Cruz, N.L. Del Mastro, M.H.O. Sampa, E.S. Somessari, Radiation Processing of Sewage and Sludge. A review. Instituto de Pequisas Energeticase Nucleares, IPEN/CNEN-SP, Sao Paulo, Brazil. 1997.

★★★