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Clean and Cost Effective Industrial Wastewater Treatment Technology for Developing Countries

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Abstract- Industrial processes create a variety of wastewater pollutants which are difficult and costly to treat. Wastewater characteristics and levels of pollutants vary significantly from industry to industry. The growth of industrialization leads to the rise of wastewater from various industries and so the pollution load on the environment is increasing. The high cost for the treatment and disposal of industrial wastewater is now become a challenging problem for developing countries. The sample used in this research was combine wastewater from distilleries, sugar factories, candy factories and textile dyeing factories. Among them, distilleries and textile dyeing factories are the most wastewater producing industries and the wastewater from these are not easily biodegradable. Total chemical oxygen demand COD of wastewater sample was too high about 30000 mg/l and biochemical oxygen demand (BOD5) also high over 7000 mg/l. Conventional wastewater treatment is not sufficient to treat this amount of pollution and chemical processes are now widely adapted. The main weak points of chemical treatment are highly cost and harmful effects of chemical residues. Ionizing radiation has more advantages over the weak points of chemical process. The ability of ionization radiation for converting non-biodegradable substances to more readily degradable ones and its capacity to eliminate microorganisms can help the treatment of industrial wastewater. 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, chemical oxygen demand (COD) and biochemical oxygen demand (BOD). The optimum dose for the disinfection of bacteria and degradation of organic and inorganic pollutants were obtained. The irradiation dose of 7 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.

Index Terms- Industrial Wastewater, Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Microorganisms, Gamma Radiation, Organic Pollutants

I. Introduction

Pollution in its broadest sense includes all changes that curtail natural utility and exert deleterious effect on life. Water pollution is any chemical, biological, or physical change in water qualities that has a harmful effect on living organism or makes water unsuitable for desire use. It has been suggested that it is the leading worldwide cause of death and diseases, and that it account for the death of more than 14000 people daily. The crisis triggered by the rapidly growing population and industrialization with the resultant degradation of the environment causes a grave threat to the quality of life. Degradation of water quality is the unfavorable alteration of the physical, chemical and biological properties of water that prevents domestic, commercial, industrial, agricultural, recreational and other beneficial uses of water [1]. 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.

Water is the main component which is used in all type of industries. Water is used for different processes in industries. It may be used for washing, dilution, formation and other several purposes. Generally, almost all the industries generate wastewater that needs urgent attention. Water used in industry is a doubled-edged sword. On one hand, it puts immense pressure on local water resources and on the other side, wastewater discharged from the industry pollutes the local environment. The main concerning contaminants of industrial wastewater are bacteria, parasites and viruses, inorganic and organic pollutants. 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, its high load of pollutants become the hindrance from beneficial use or safely dispose to the water environment.

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 conventional process. Most of the pollutants in industrial wastewater are chemically and biologically resistant; thus, the application of conventional treatment is often not sufficient. Besides the reduction of microorganisms in wastewater treatment plants with chlorination was found insufficient, and it may generate the formation of carcinogenic chlorinated hydrocarbons. For this reasons, another consideration must be needed to replace conventional processes and the replaced techniques were co-precipitation, adsorption on charcoal and resins, flotation, biodegradation, incineration and recycling.

One of the most widely used methods to treat the organic compounds is adsorption on activated carbon. However, the process only transfers the contaminant from liquid to solid phase. In this treatment the organic compounds are not degraded, and the used (spent) activated carbon has to be decontaminated or properly stored. Another introduced method to the industrial wastewater treatment technology was advanced oxidation process (AOPs), which has attracted many researches because of the capacity to mineralize organic compounds. The most efficient oxidation is the use of OH radicals. There are various methods of generating OH radicals such as the use of ozone, hydrogen peroxide, Fenton reaction, ultraviolet and the interaction of ionizing radiation with water [2].

Radiation processes are like thermal or chemical processes in the point of view that provoke changes on materials by energy transfer. The binding energies of molecular bonds are generally below 12 eV. If any material is submitted to a thermal or chemical process, the incremental of energy transfer is tiny fraction of 1 eV up to approximately 10 eV; ionization transfers a higher energy that changes characteristics and degrades materials and also causes inactivation of microbes. The amounts of energy transferred is not high enough to cause changes of the nucleus of atoms and to make the material radioactive. This technology never left residues and that is why called a clean technology [3].

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 the main wastewater pipe line, no.6 overflow channel and Pa Yan Taw Creek. The first one ends up to Dokhtawaddy River and the latters flow to Taung Tha Man Lake and then finally ends up in Irrawaddy River. Taung Tha Man Lake is one of the most beautiful tourist attractive historical places in our country. A serious pollution problem was occurred in this lake on April 2015 which was the massive death of fishes by the discharging of industrial wastewater without sufficient treatment. So the industrial wastewater treatment and disposal becomes an urgent problem in our country. 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 Experimental Work

A. Materials

Materials used in this research work were industrial wastewater samples, some chemical reagents and gamma irradiation facility

Wastewater sample for this research was collected from the main wastewater pipe line of Mandalay Industrial Zone. There are totally 9 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 constituent elements in this wastewater sample is shown in Table 1.

The chemicals used in this research were sulphuric acid, hydrogen peroxide, ferrous sulphate, calcium hydroxide and activated carbon.

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 liters.

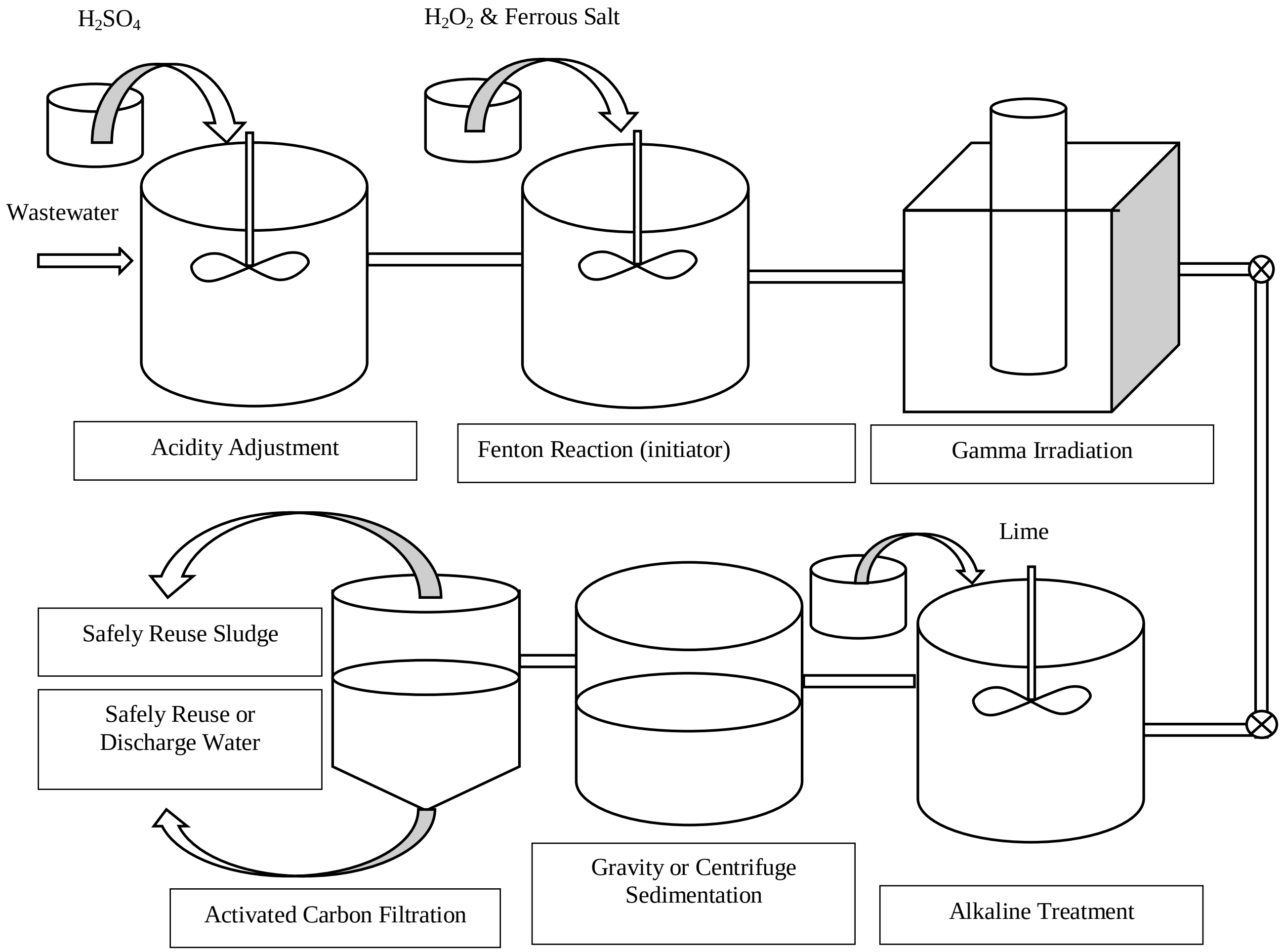

Figure 1: Diagram of Experimental Work

B. Experimental Works

In experimental procedure, there were five steps to be performed. The first step was acidity adjustment in which the pH value of the wastewater was adjusted between one and three with the use of sulphuric acid. The next step was oxidation process in which hydrogen peroxide and ferrous sulphate were used to form Fenton reaction. Only trace amount was added as initiator. After that, the sample was going to be irradiated and gamma irradiation was conducted at room temperature in the gamma chamber. The sample was filled into one litre glass bottles and marked accordingly. Then they were irradiated using following doses: 0 kGy, 1 kGy, 2 kGy, 3 kGy,…to 18 kGy respectively.

After irradiation process, samples were carried on the alkaline sedimentation process. In this process, the pH value of the sample was adjusted to a value not less the 10 with calcium hydroxide and then performed sedimentation with gravity or centrifuge method. The final step of this experiment was activated carbon filtration was for the purpose of colour removal. Diagram of the experimental work was mentioned in Figure 1.

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 was shown in Table 2.

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 COD and BOD changes under gamma radiation were shown in Table 3.

Table I: Constituent Elements of Industrial Wastewater Sludge

No.	Formula	Z	Net Int (kcps)	Cal. 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

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	-

Table III: COD and BOD Analysis of Irradiated Samples

Radiation Dose (kGy)	**COD1 (mg/l) [pH-3, H_2O_2 - 0 ml/l, Ferrous Salt – 0 mg/l]**	**COD2 (mg/l) [pH – 3, H_2O_2 – 0.5 ml/l, Ferrous Salt – 0.5 mg/l]**	**COD3 (mg/l) [pH – 2.0, H_2O_2 – 0.2 ml/l, Ferrous Salt – 0.2 mg/l]**	**BOD (mg/l)** [pH-3, H_2O_2 - 0 ml/l, Ferrous Salt – 0 mg/l]	**BOD1** (mg/l) [pH – 3, H_2O_2 – 0.5 ml/l, Ferrous Salt – 0.5 mg/l]
0	32664	32664	32664	7093	7093
1	32200	32180	31720	7000	7043
2	31844	31900	31200	7020	7001
3	31200	31210	30810	6944	6820
4	30156	30704	30405	6900	6733
5	29778	29344	28944	6888	6105
6	28426	28768	26880	6600	5450
7	28122	27542	25350	6420	5307
8	27480	25940	20776	6200	5100
9	27008	22188	15177	6288	4312
10	26880	20422	10816	5800	4180
11	25948	17360	7929	5475	2970
12	25012	15088	6447	5006	2852
13	24270	12474	5480	4204	2373
14	23784	9806	4287	3974	1505
15	23008	6978	2012	3490	984
16	22186	4042	1470	2942	578
17	20444	2118	790	2660	232

18	18268	988	180	2084	65

III. Results And Discussions

A. Basic Concept of Water Radiolysis

In wastewater, industrial wastewater as well as sewage, the principal component is water. So, it would be expected that the effect of ionizing radiation may be dominated by the interaction of radiation and water. As far as pure water is concerned, when exposed to ionizing radiation, the radiolysis of water can be presented as following equation:

$$H_2O \rightarrow OH^* + e_{aq}^- + H^* + H_3O^+ + H_2O_2 + H_2$$

In aqueous media, the oxidizing hydroxyl radical OH^*, the reducing hydrated electron e_{aq}^- and the hydrogen radical H^* are the predominant products, all of which are highly reactive transient species and are responsible for the various effect including the reduction of pathogens, the oxidation of hazardous organic pollutants, the destruction of molecular structures of targeted pollutants, the elimination of odour nuisance as well as various characteristics changing when the ionizing radiation is employed in the industrial wastewater treatment [4].

B. Effect of Gamma Radiation on Microorganisms

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.

On the other sample, sludge, which contain high load of BOD, COD, and more polluted than treated water. In Table 2, there can be seen about 10^{10} bacteria counts at 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 an effective disinfection dose for the industrial wastewater sludge. Figure 2 shows the survival of total bacteria under irradiation doses.

Gamma radiation was widely used as disinfection tool in several countries. Most of them applied to disinfect municipal (domestic) wastewater and sludge. Municipal wastewater and sludge contains lower concentration of microorganisms than industrial wastewater. Only about 0.8 to 1 kGy gamma irradiation dose was needed to reduce initial amount 105 to few tens of microorganisms [5].

The action of radiation on a living organism can be divided into direct and indirect effect. If the radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is a direct effect, which will eventually affect the ability of the cell to reproduce and survive. The formation of major radiolysis products from water and their subsequent interactions with organic molecules are described as indirect effect, which is generally caused by energy deposition in the medium resulting in the formation of secondary reactants generated through free radical production, sensitizer reaction and secondary ionizations. Indirect ionization effects are rapid and typically occur within about 10-7 s of exposure. The radiolysis products OH*, eaq‾ and H* are responsible for indirect effects caused by ionizing radiation. And indirect effect is generally considered more significant than direct effect in the application of ionizing radiation to industrial wastewater treatment. Both direct and indirect effect on microorganisms caused by radiation may result in damage of genetic material, i.e. DNA and RNA, thus the cell will be killed and the aim of disinfection is achieved [4].

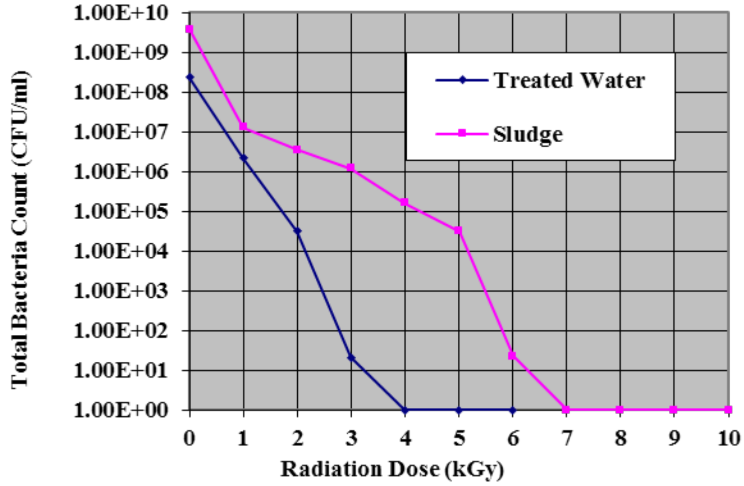

Figure 2: Survival of Microorganisms under Radiation

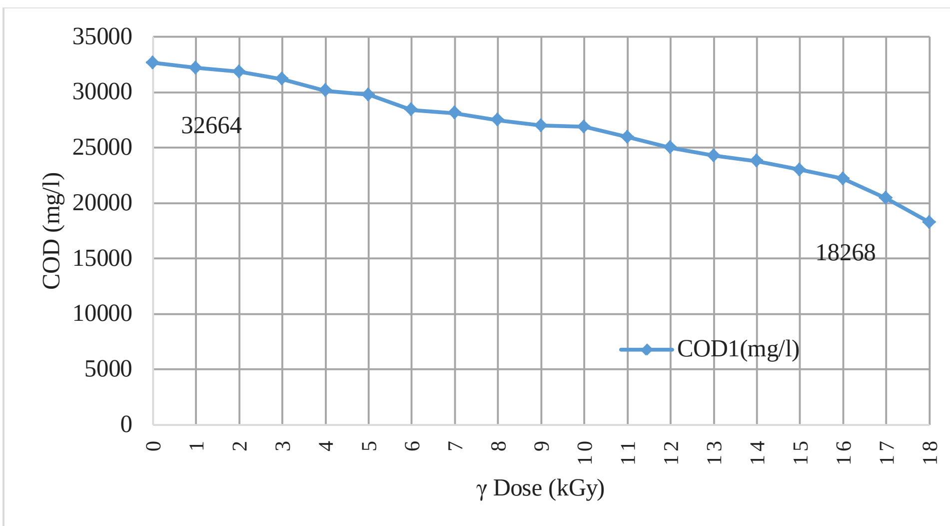

Figure 3(a): Effect of Gamma Radiation on COD Reduction at pH-3, H_2O_2 - 0 ml/l, ferrous salt – 0 g/l

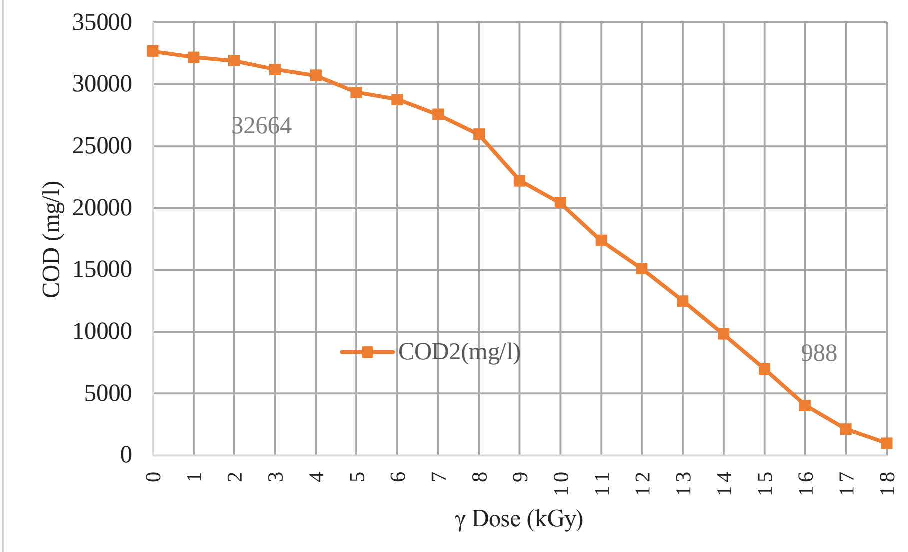

Figure 3(b): Effect of Gamma Radiation on COD Reduction at pH-3, H_2O_2 –0.5 ml/l, ferrous salt –0.5 g/l

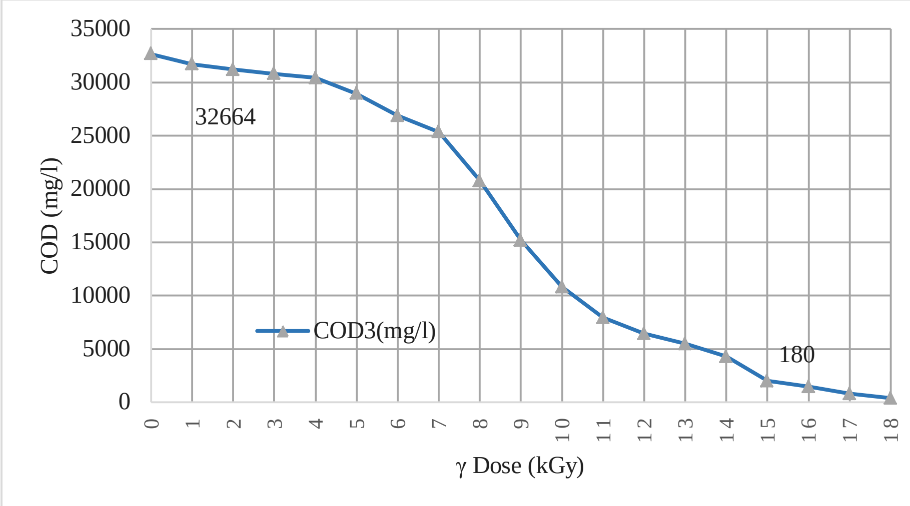

Figure 3(c): Effect of Gamma Radiation on COD reduction at pH –2, H_2O_2 –0.2 ml/l, ferrous salt –0.2 g/l

C. Effect of Gamma Radiation on Organic or Inorganic Pollutants

When the wastewater was exposed to ionizing radiation, the water molecule undergoes radiolysis process to produce ionized and excited water molecules and free electrons (reactive species). Reactions between pollutants and primary products of water radiolysis (OH*, e_{aq}^{-} , H*) and secondary short-lived species formed from the pollutants causes the removal of pollutants from the wastewater [6].

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. COD determines the amount of organic pollutant in water. The basis for the COD test is that nearly all organic compounds can be fully oxide to carbon dioxide with strong oxidizing agent under acidic condition. Thus, reduction of COD suggests the decomposition of organic pollutant. There is reduction of COD observed after irradiation.

In Figure 3(a), the line COD1 represents the reduction of COD at a condition of pH-3, without adding any chemical initiator. Not significance amount of COD was removed till 5 kGy irradiation dose and only about half of initial COD was reduced at 18 kGy gamma irradiation dose. The trend of reduction with adding hydrogen peroxide 0.5 ml/l and 0.5 mg/l of ferrous salt at pH-3 was shown in Figure 3(b). In this condition, about half of initial COD (15088 mg/l) was reduced at 12 kGy irradiation dose and the value reduced to 988 mg/l at 18 kGy. When the pH value of the sample was adjusted to 2 and then the volume of initiator reagents was deducted to 0.2 ml/l hydrogen peroxide and ferrous salt to 0.2 g/l, the COD removal efficiency was slightly improved and the trend was shown in Figure 3(c). Half value reduction of initial COD was successfully achieved at 9 kGy irradiation dose and the COD steeply fall down with the increase of irradiation dose. The successive COD reduction of initial value 32664 mg/l to 180 mg/l was obtained at 18 kGy gamma irradiation dose. Fenton chemical reaction was widely applied in conventional industrial wastewater treatment process. The yield of the hydroxyl radical production depends on the concentration of hydrogen peroxide and ferrous sulphate. Fenton reaction leads to increase the hydroxyl radical production which is essential for organic pollutant degradation. In Fenton reaction, the huge amounts of chemical reagents (2 g/l ferrous salt and 2 ml/l hydrogen peroxide) were used to reduce COD to safety dispose level. Only one tenth of Fenton chemical reagents were used in this research. About 20% of COD reduced at 7 kGy and only 20% left at the irradiation dose of 12 kGy. Acceptable COD removal (99%) remaining 180 mg/l was achieved at 18 kGy.

BOD5 measures the oxygen utilized mainly for biochemical degradation of organic material. High BOD value can be interpreted as high concentration of oxidizable materials found in water sample. Therefore the reduction of BOD implies that oxidizable materials found in the sample have been reduced. This reduction can be expected and is in agreement with the result obtained for COD as mentioned above. The reduction of oxidizable materials was due to complete decomposition of organic pollutants found by ionizing radiation.

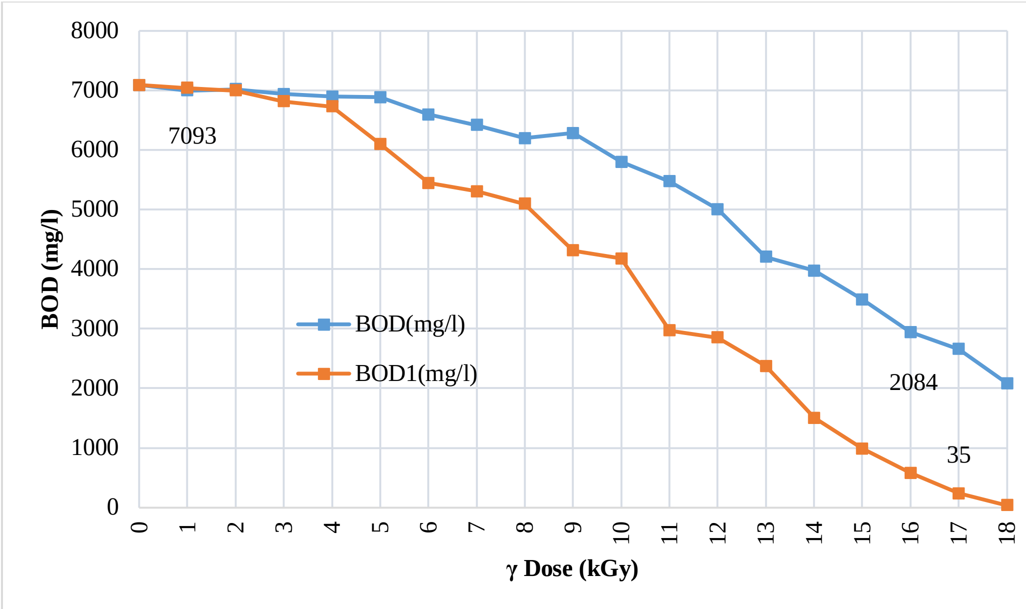

Figure 4: Effect of Gamma Radiation on BOD Reduction

The BOD5 results of gamma irradiation are shown in Figure 4. The line BOD represents the reduction of BOD under irradiation without using chemical additive at pH-3 and initial BOD was 7093 and only about 1000 mg/l was reduced until 10 kGy gamma irradiation doses. At 14 kGy, nearly half of initial BOD was removed and there was 2084 mg/l BOD remain after 18 kGy irradiation dose. The line BOD1 represents the trend of BOD reduction with adding hydrogen peroxide 0.2 ml/l and 0.2 mg/l of ferrous salt at pH-2 The initial amount of biochemical oxygen demand was too high about 7093 mg/l and only about 10 percent was removed after 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 1505 mg/l and which was too high for safely dispose to the water environment. The permissible BOD removal was obtained at 18 kGy dose and 99% of initial BOD was reduced at this dose.

IV. CONCLUSION

In this research, over 95 percent of the collected wastewater sample was produced from distilleries and textile factories. This type of wastewater contain high pollution load too hard to treat and the huge amount of chemical reagents were needed for chemical treatment process. Although radiation technology can adapt to eliminate the use of chemical reagent, a high dose of gamma radiation about 50~100 kGy was needed to remove the pollutants from this type of wastewater [6]. However, time consumption to obtain these high doses was becoming a problem in this research. Moreover, it was found that some chemical used as pH adjustment and as initiator can reduce the dose requirement for the treatment. This fact shows that not only radiation facility but also chemicals are required to obtain the successive removal of BOD and COD from industrial wastewater. The microbiological and physicochemical effects of gamma radiation on industrial wastewater can be observed in this research and the optimum dose for disinfection and BOD, COD reduction to an acceptable level is obtained. The reliable disinfection dose is 7 kGy and the successive BOD, COD reduction dose was 18 kGy. 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 preservation point of view.
Gamma irradiation is an ecological and technological advantage compared to physiochemical and biological methods, because it breaks down organic compounds, generating substances that are easily biodegraded with very few usage of chemical reagents and never left residues, that is why mentioned as clean and cost effective technology.

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