Cost assessment of e-beam wastewater treatment

Y. Kim[1], B. Han[1], J. K. Kim[1], K. Y. Jeong[2]

[1] EB TECH Co., Ltd., Daejeon, Korea
[2] Kongju National University, Korea

Email contact of main author: bshan@eb-tech.com

Abstract. To apply electron beam process to the treatment of industrial wastewater and disinfection of effluent from municipal wastewater plant, we accomplished the cost assessment together with the laboratory irradiation experiments. Cost assessments of industrial e-beam treatment plant for treating textile dyeing wastewater were carried out for the treatment capacity of 10,000 m^3 per day. The total construction cost for this plant was USD 4M and the operation cost was not more than USD 1M per year and it was about USD 0.3 per each m^3 of wastewater. Another study on the disinfection plant designed for the flow rate of 100,000m^3 effluent per day showed the overall cost for plant construction as approximately USD 4M, and the operation cost as around USD 1M per year. It is approximately USD 0.12/m^3 for construction and USD 0.03/m^3/yr for operation of above plant, and is quite applicable when compared to other advanced oxidation techniques such as Ozonation, UV techniques etc..

1. Introduction

Electron beam treatment of wastewater leads to purification by the decomposition of pollutants as a result of their reactions with highly reactive species formed from water radiolysis: hydrated electron, OH free radical and H atom. Sometimes such reactions are accompanied by the other processes, and the synergistic effect upon the use of combined methods such as electron beam with biological treatment, adsorption and others improves the effect of electron beam treatment of the wastewater purification. In the process of electron-beam treatment of wastewater there are utilized chemical transformations of pollutants induced by ionizing radiation.

The key to the successful implementation of electron beam process in environmental protection depends on how to manage the economics in its application. To compete with other processes in economic evaluation, the electron beam system should be operated with cost-effective manners. To result in complete decomposition of the pollutants, sufficiently high absorbed doses are required. However, in real conditions of rather high content of pollutants in wastewater, high absorbed doses are not economically acceptable, and it is better to utilize the partial decomposition of pollutant as well as transformations of pollutant molecules that result in improving subsequent purification stages.

2. Cost assessment for wastewater irradiation

The key to the successful implementation of electron beam process in environmental protection depends on how to manage the economics in its application. To compete with other processes in economic evaluation, the electron beam system should be operated with cost-effective manners. To result in complete decomposition (removal) of the substance, sufficiently high absorbed doses are required. However, in real conditions of rather high content of pollutants in wastewater, high absorbed doses are not economically acceptable, and it is better to utilize the partial decomposition of pollutant as well as transformations of pollutant molecules that result in improving subsequent purification stages. To apply electron beam process to the wastewater of Daegu Dyeing Industrial Complex (DDIC), a cost assessment for DDIC wastewater together with the laboratory irradiation experiments were accomplished.

2.1. Analysis of the cost of existing wastewater treatment process

Based on the data of the existing wastewater treatment plant [Park et al., 1996], the operation cost of existing process has calculated around USD 1.1 to 1.2 per cubic meter of wastewater including chemical and biological treatment.

2.2. Determining the target cost and target dose of electron beam process

When targeting the operation cost of new process below USD 1 per cubic meter of wastewater in total, the cost for electron beam process would be around USD 0.4, and it showed the maximum dose should be less than 2 kGy.

2.3. Finding the combining method to reduce the absorbed dose.

In the laboratory experiments, electron-beam treatment should not appreciably affect total biodegradability of pollutants if the main pollutant was biodegradable, but could improve biodegradation process at initial stages. Irradiation at comparatively low doses (several Grays) did not change total amount of biodegradable substances characterized by BOD_5 , but converted part of it into easier digestible form.

2.4. Construction and operation of pilot plan

Being convinced with the feasibility of laboratory scale tests, a pilot plant for a large-scale test (flow rate of 1,000m^3 per day) of wastewater has constructed with the electron accelerator of 1MeV, 40kW in 1998 (Figure 1). For the uniform irradiation of water, nozzle type injector with the width of 1500mm was introduced. The wastewater is injected under the e-beam irradiation area through the injector to obtain the adequate penetration depth.

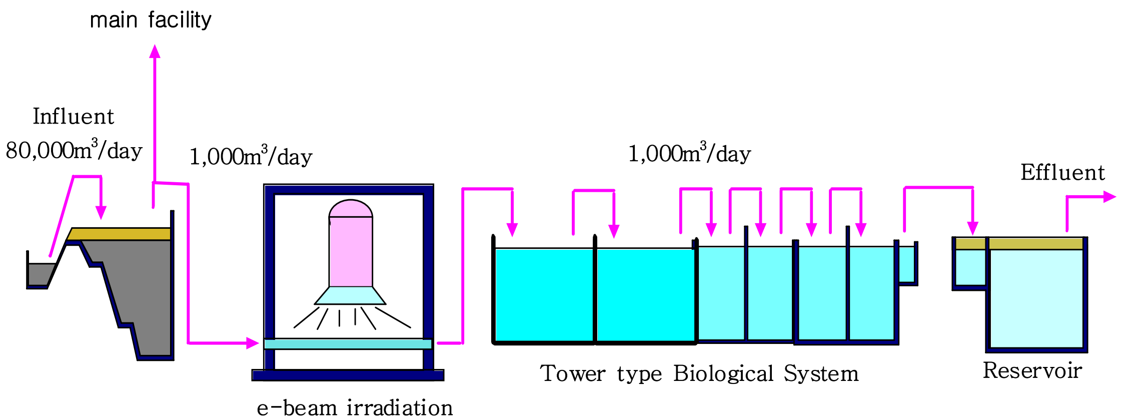

FIG. 1. Schematic diagram of Pilot Plant with e-beam

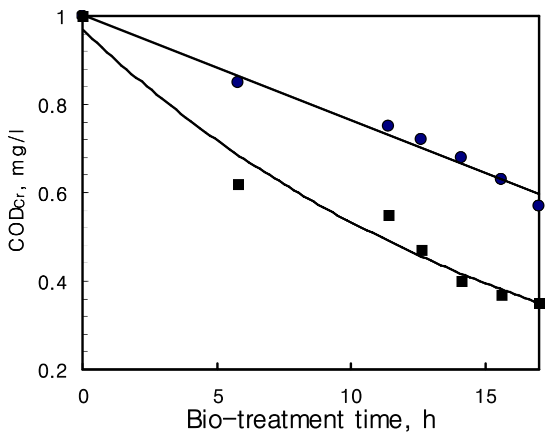

FIG. 2. Effect of irradiation on biological treatment of DDIC wastewater
■- *after EB treatment;* ●- *without EB treatment*

From the operation data of pilot plant at around 1 kGy, the improvement of biological treatment of wastewater after preliminary electron-beam treatment was found, and it is proved by radiolytical transformations of biodegradable compound. Electron-beam treatment should not appreciably affect total biodegradability of pollutants if the main pollutant is biodegradable, but can improve biodegradation process at initial stages. In other words, irradiation at comparatively low doses (several Grays) for this case does not change total amount of biodegradable substance characterized by BOD_5 , but convert part of it into easier digestible form. This is confirmed, also, by the data presented in Figure 2 where one can see that decrease in TOC, COD_{Cr}, and BOD_5 during biological treatment is close to linear one for non-irradiated wastewater, while for electron beam treated wastewater the decrease is faster at the beginning of bio-treatment and decelerates during the process [Han et al., 2002]

3. Economical evaluation of commercial plant

3.1. Construction of Industrial Plant

Based on the cost assessment and removal efficiency of pilot scale electron beam treatment facility, an industrial scale plant for treating 10,000m^3 effluent per day of DDIC wastewater has constructed from 2003 and finished in 2005 [Han et al., 2005] for
- decreasing the amount of chemical reagent up to 50%
- improving the removal efficiency of harmful organic impurities by 30%
- decreasing the retention time in Bio-treatment facility

According to the data obtained in laboratory and pilot plant experiments with DDIC wastewater, the optimum absorbed dose for electron-beam treatment was chosen to be near 1 kGy, and required electron beam power was determined as 400kW for the flow rate of 10,000m^3 effluent per day. For this purpose, an electron accelerator of 1 MeV, 400kW with three separate irradiators was developed together with EB TECH Co. Korea and Russian institute BINP. [Han et al 2007] The plant is located on the area of existing wastewater treatment facility in DDIC combined with existing bio-treatment facility. The process of wastewater treatment consists of the following steps
- collecting the inflow wastewater in primary basin;

- pumping the wastewater from primary basin to reactor;
- irradiating the wastewater through injection nozzle;
- collecting irradiated wastewater in secondary basin;
- pumping wastewater from secondary basin to outlet line for biological treatment

Total technological scheme of the installation on of electron-beam treatment is presented in Figure 3. It includes three principal technological chains: wastewater flow, cooling air flow, and ventilating air flow. Coordinated functioning of those chains is assured by monitoring and control systems. To have treatment capacity 10,000 m^3 of wastewater a day, nozzle-type injectors were installed under the irradiation windows (Figure 4).

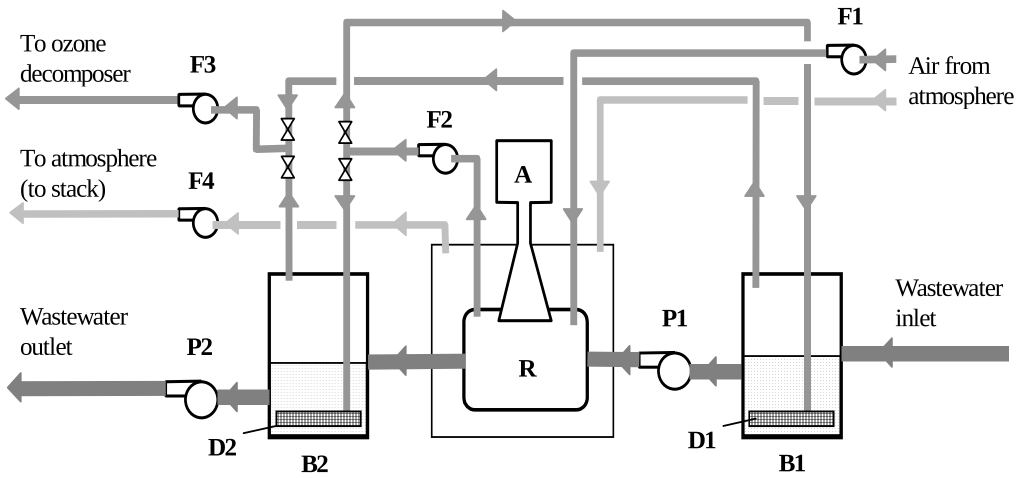

FIG. 3. Technological scheme of industrial plant.

F1~F4 – fans, P1/P2 – pumps, D1/D2 – Diffusers, A – Accelerator, R – Reactor, B1/B2 –basins

3.2 Economic Evaluation

Based on data obtained from the construction and operation of industrial plant, the cost assessment for treatment of DDIC wastewater was estimated. Cost for high power accelerator is around USD 2.0 and building, piping, other equipment and construction works were about USD 1.5M. Even by considering the additional cost for tax, insurance and documentation as to be USD 0.5M, the overall capital cost for plant construction is approximately USD 4.0M as shown in Table 1.

Above estimation doesn't include the cost for land, R & D and the cost for the approval form authorities. Construction period includes 17 months in civil and installation works and 3 months for trial operation. To estimate the operation cost, the electricity consumption of accelerator and other equipment is calculated as 500kW (80% efficiency) and 300kW to the total of 800kW. Based on the year round operation (8000hr/yr), it costs USD 320,000 per year when the cost of electricity (kWh) was assumed to be USD 0.05. The labor cost of operator is calculated on 3-shift work and is approximately USD 100,000 per year. Therefore, the actual operation cost for 10,000 m^3/day plant comes up to less than USD 1.0M$ per year including the interest and depreciation of investment as shown in Table 2, and the operation cost of electron beam process for DDIC wastewater is USD 0.3 per cubic meter of wastewater which was close to the targeting cost.

TABLE 1. CAPITAL REQUIRED FOR 10,000m^3 OF DDIC WASTEWATER PER DAY

Items	Cost in k$	Remarks
Electron accelerator - 1MeV, 400kW, 3 windows	2000	Cost for Land, R&D, Approval from Authorities are not included
Shielded Room (concrete) Auxiliary equipment Transportation and Installation Water handling system	1500	
Others – documentation, tax, insurance etc.	500	
Total Capital Requirement	4000	

4. Conclusion

An industrial plant with an electron accelerator of 1MeV, 400kW for treating 10,000m^3 of textile dyeing wastewater per day from DDIC has constructed and operated continuously since December 2005. This plant is combined with biological treatment system and it shows the reduction of chemical reagent consumption, and also the reduction in retention time with the increase in removal efficiencies of COD_{Cr} and BOD_5 up to 30~40%. Increase in biodegradability after electron beam treatment of aqueous-organic systems is due to radiolytical conversions of non-biodegradable compounds.

The total construction cost for this plant was about USD 4M and the operation cost has been obtained approximately USD 0.5M per year. Even with including the depreciation and interest, it is not more than USD 1M per year and it is about USD 0.3 per each cubic meter of wastewater.

Acknowledgements

The authors would like to thank for the support of the Korea Science and Engineering Foundation ; Ministry of Education, Science and Technology, City of Daegu and International Atomic Energy Agency

TABLE 2. OPERATION COST OF DDIC WASTEWATER TREATMENT

Items		Cost in k$/year	Remarks
Fixed Cost	Interest	240	6%
	Depreciation	200	20yrs
Variable Cost	Electricity ((0.05$/kWh)	320	800kW
	Labor	100	3 shift
	Maintenance, etc.	60	1.5% of Capital cost
Total Operation Cost		920	
Operation cost (8000hr/year) is about USD 0.3 per m^3			

REFERENCES

[1] Pikaev, A. K., 1986. Modern Radiation Chemistry. Radiolysis of Gases and Liquids. Nauka, Moscow , pp.440 (in Russian).
[2] Buxton, G. V., Greenstock, C. L., Helman, W. P., Ross, A. B., 1988. Critical review of rate constants for reactions of hydrated electrons, hydrogen atoms and hydroxyl radicals (OH/O^-) in aqueous solutions. J. Phys. Chem. Ref. Data, 17, 513-886.
[3] Makarov, I. E., Ponomarev A. V., Han, B., 2003. Demonstration plant for electron beam treatment of Daegu Dye Industrial Complex wastewater. Report from a technical meeting on emerging applications of radiation processing for 21st century, IAEA
[4] Park, Y. K., Lee, C. H., Kim, C. H., 1996. Advanced treatment of dyeing industrial complex wastewater by a combination of biological treatment and ultra-filtration. Environ. Eng. Res., 1, 31-36.
[5] Han, B., Ko, J., Kim, J., Kim, Y., Chung, W., Makarov, I. E., Ponomarev, A. V., Pikaev, A. K., 2002. Combined electron-beam and biological treatment of dyeing complex wastewater. pilot plant experiments. Radiat. Phys. Chem., 64, 53-59.
[6] Han, B., Kim J., Kim Y., Choi, J.S., Makarov, I.E. and Ponomarev, A.V., 2005. Electron beam treatment of textile dyeing wastewater : Operation of Pilot plant and Industrial plant construction. Water Science and Technology Vol. 52 No 10-11, 317-324.
[7] Han, B., Kim, S.M., Salimov, R.A., Kuksanov, N.K., 2007. High power accelerator for environmental application. Proceedings of Eighth International Topical meetings on Nuclear Applications and Utilization of Accelerators. American Nuclear Society, 1038-1041.