APPLICATION OF ELECTRON ACCELERATOR FOR TEXTILE DYEING WASTEWATER TREATMENT

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Textile dyeing processes consume large amount of water, steam and discharge filthy and colored wastewater. Increased use of assorted dyes and other chemicals hurries in re-equipment of purification facilities by application of efficient methods based on radiation technology. Based on the laboratory data, a pilot scale e-beam plant had constructed at Daegu Dyeing Industrial Complex (DDIC) in 1998. Electron accelerator of 1MeV, 40kW was used for 1,000m^3 per day. Continuous operation of this plant showed the preliminary e-beam treatment reduced bio-treatment time and resulted in more significant decreasing TOC, COD_{Cr}, and BOD_5. Convinced of the economics and efficiency of the process, a commercial plant with 400kW electron accelerator has constructed in 2005. This plant improves the removal efficiency of wastewater by decreasing the retention time in bio-treatment facility with approximately 1 kGy. This plant is located on the area of existing wastewater treatment facility in DDIC and the treatment capacity is 10,000 m^3 of wastewater per day.

I. INTRODUCTION

Electron beam treatment of wastewater leads to their purification from various pollutants. It is caused 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 [1]. 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. At sufficiently high absorbed doses these transformations can result in complete decomposition (removal) of the substance. Under real conditions, i.e., at rather high content of pollutants in a wastewater and economically acceptable doses, partial decomposition of pollutant takes place as well as transformations of pollutant molecules that result in improving subsequent purification stages, efficiency of the process being notably influenced by irradiation conditions and wastewater composition [2].

I.A. Wastewaters from textile dyeing companies

The complex wastewater from textile dyeing companies in Daegu Dyeing Industrial Complex (DDIC) was investigated in this study. DDIC includes about hundred factories occupying the area of 600,000m^2 with 13,000 employees in total. A majority of the factories has equipment used for dip dyeing, printing, and yarn dyeing. The production requires high consumption of water (90,000m^3/day), steam, and electric power, being characterized by large amount of highly colour industrial wastewater. Purification of the wastewater is performed by union wastewater treatment facilities (chemical treatment and 2 steps of biological treatment). Current facility treats up to 80,000m^3 of wastewater per day, extracting thereby up to 500m^3 of sludge. Rather high cost of purification results from high contamination of water with various dyes and ultra-dispersed solids.

Characteristics of DDIC wastewater undergo both short-term and long-term variations, the former being equal to 10-13 % while the latter amounting up to 20 % of mean value. Overall characteristics of influent wastewater, 5 day's biological oxygen demand (BOD_5), chemical oxygen demand measured by permanganate method (COD_{Mn}), suspended solid (S/S) are presented in Table I.

TABLE I. Typical characteristics of DDIC wastewater

Parameter	pH	BOD_5 (mg/l)	COD_{Mn} (mg/l)	S/S (mg/l)	Color units
Raw	12	2,000	900	100	1,000
Chemical	6.8~7.5	1,700	450	50	500
After 1st Bio	7.0~8.0	1,300	250	50	400
After 2nd Bio	7.0~8.0	50	80	50	250

Chemical composition of the wastewater also is not constant. Data of chemical analysis showed the composition of dissolved organic impurities in influent wastewater consist of organic compounds, organic dyes, surfactants and other organic compounds. In the organic compounds, TerePhtalic Acid (TPA) and ethylene glycol (EG) are the major components of the pollutants. Organic dyes and surfactants, even at comparatively low concentration, determine such objectionable properties of the wastewater as color and foaming, so concentration of these compounds should be substantially reduced. Among other organic compounds there are: hexane, carboxyl-methyl and hydroxyl-methyl cellulose, phenols, starch, waxes, etc. Inorganic compounds are presented mainly by sulfate anion and sodium cation and small amounts of chlorides and carbonates. Besides, some amount of hydrogen peroxide may be present. The latter, unlike other inorganic compounds, can take part in radiation induced transformations of organic compounds.

II. PILOT PLANT TEST

II.A. Laboratory-scale Test

The laboratory scale studies had been carried out regarding the possibility of electron beam application for purification of wastewater. With the co-works of EB-TECH Co., Korea Dyeing Technology Center (DYETEC) and Institute of Physical Chemistry of Russian Academy of Sciences in Moscow, Russia (IPC), the experiments on irradiation of model dye solutions and real wastewater samples (from various stages) had been performed.

In order to develop the most efficient method for re-circulation of wastewater, the experiments were conducted with samples in various stages of treatment. In the experiments, electron accelerator of 1 MeV, 40kW with the dose rate of 40kGy/s is used. To carry out the experiments, the laboratory unit was constructed for irradiation under flow conditions. The initial water is placed in storage vessel, which serves as saturator-equalizer. Wastewater from the vessel was moved with controlled consumption by pump to multi-jet nozzle. Diameter of each jet was equal to 4 min; it is equal to the range of 1 MeV electrons in water. The rate of wastewater moving at the exit of the nozzle was controlled within the range of 2-4 m/s. The wastewater injected directed in parallel each other in horizontal plane; their flight length was equal to ~1.5 m (at the initial rate 3m/s). The wastewater injected along horizontal part of their flight was treated by electron beam. Then irradiated wastewater was collected into the special container.

The results of laboratory investigations of representative sets of samples showed the application of electron beam treatment of wastewater to be perspective for its purification. The most significant improvements result in decolorizing and destructive oxidation of organic impurities in wastewater. Installation of the radiation treatment on the stage of chemical treatment or immediately before biological treatment may results in appreciable reduction of chemical reagent consumption, in reduction of the treatment time, and in increase in flow rate limit of existing facilities by 30-40%.

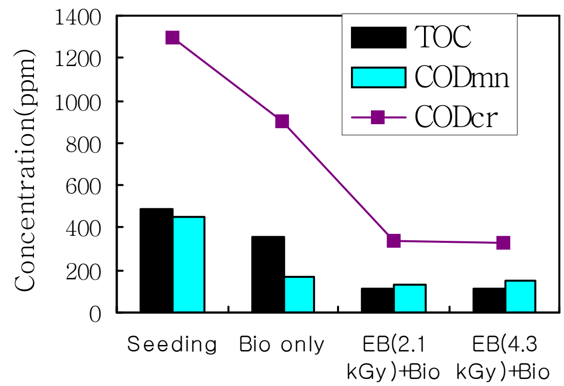

Fig. 1 Combined effect of e-beam and bio-treatment

II.B. Construction 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 and is now under operation with the electron accelerator of 1MeV, 40kW (Figure 2). The size of extraction window is 1500mm in width and Titanium foil is used for window material. The accelerator was installed in Feb. 1998 and the technical lines are finished in May 1998. 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. The speed of injection could be varied upon the dose and dose rate. Once the wastewater has passed under the irradiation area, then directly into the biological treatment system. The Tower Style Biological treatment facility (TSB) which could treat up to 1,000m^3 per day has also installed in October 1998. TSB is composed of equalizer, neutralizer, and 6 steps of contact aeration media. Each aeration basins are filled with floating or fixed bio-media to increase the contact area.

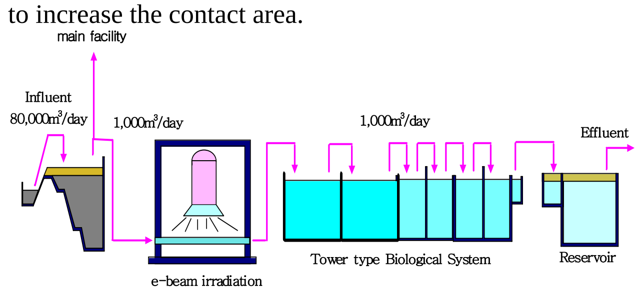

Fig. 2 Schematic diagram of Pilot Plant with e-beam

II.C. Result of pilot plant operation

Pilot plant inlet flow is a mixture of two flows: raw wastewater from dyeing process and wastewater from polyester fiber production enriched with TerePhtalic acid (TPA) and Ethylene glycol (EG); relative flow rate of the latter being 6-8% of total inlet flow rate. TPA concentration of influent is about $2 \cdot 10^{-2}$mol/l that is much higher than total concentration of all other dissolved pollutants. This concentration corresponds to electron fraction of TPA about 0.2% that makes direct action of radiation on TPA (or other pollutant) be negligible when treating the wastewater by electron beam. On the other hand, this concentration is high enough to prevent recombination of radical products of water radiolysis in the bulk of solution, taking into account high rate constants of reactions of both reducing (hydrated electrons, hydrogen atoms) and oxidizing (hydroxyl radicals) particles with TerePhtalate anion [5]:

$$e^-_{aq} + 1,4\text{-}C_6H_4(COO^-)_2 \rightarrow R^1 \quad k = 7.3\times10^9 \text{ l mol}^{-1} \text{ s}^{-1}$$
$$H + 1,4\text{-}C_6H_4(COO^-)_2 \rightarrow R^2 \quad k \cong 1\times10^9 \text{ l mol}^{-1} \text{ s}^{-1}$$
$$OH + 1,4\text{-}C_6H_4(COO^-)_2 \rightarrow R^3 \quad k = 3.3\times10^9 \text{ l mol}^{-1} \text{ s}^{-1}$$

Besides, because of high relative concentration of TPA comparing to other polluting compounds, competition between listed reactions and reactions of radical products from water with other compounds appears to be much in favor of the former ones.

Fig. 3 Pilot plant with electron accelerator

Figure 4 shows that TPA enriched wastewater can be efficiently purified by biological treatment. However, preliminary electron-beam treatment improves the process, resulting in more significant decreasing TOC, COD_{Cr}, and BOD_5. As concerns changes in TOC, COD_{Cr}, and BOD_5 during biological treatment, from the data presented in Figure 4 it follows that preliminary electron-beam treatment make it possible to reduce bio-treatment time twice at the same degree of removal. Coincident results were obtained in a separate set of experiments on the same pilot plant but with reduced wastewater flow rate (~130 l/day). In this case inlet flow was divided into two flows: the first one passed only biological treatment while the second one passed electron-beam treatment, then biological treatment with reduced hydraulic retention time (HRT). Averaged for one month's period decrease in TOC values amounted 72%, for the first flow (48h HRT bio-treatment), and 78%, for the second flow (1 kGy electron-beam treatment followed by 24 h HRT bio-treatment).

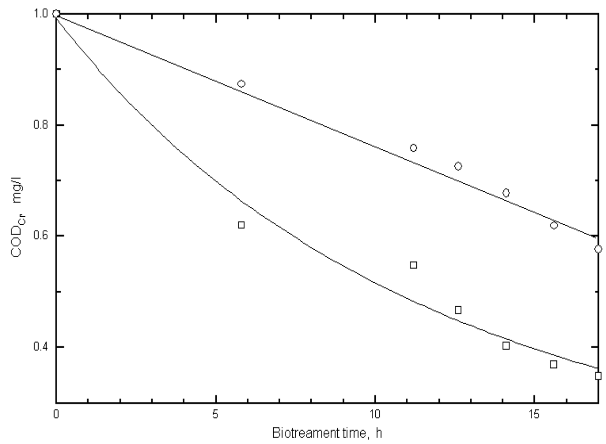

Fig. 4 Effect of irradiation and biological treatment
□- after EB treatment; ○- without EB treatment

In present experiments the improvement of biological treatment of wastewater after preliminary electron-beam treatment was found to be caused 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 4 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 [3].

III. CONSTRUCTION OF INDUSTRIAL PLANT

On the evaluation of economies and efficiency of pilot scale electron beam treatment facility, industrial scale plant for treating textile dyeing wastewater has constructed from 2003 to 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. For those purpose 400 kW electron accelerators with three separate irradiators was installed as a source of ionizing radiation. The plant is located on the area of existing wastewater treatment facility in DDIC and to have treatment capacity 10,000 m^3 of wastewater a day using one 1MeV, 400kW accelerator, and combined with existing bio-treatment facility. The process of wastewater treatment consists of the following steps [4]
- 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

Total technological scheme of the installation on of electron-beam treatment is presented in Fig. 5. 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.

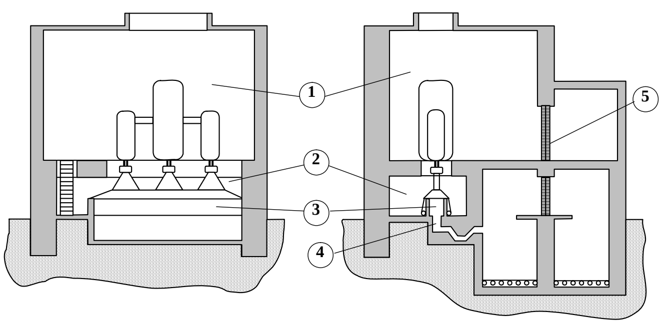

Fig. 5 Schematic diagram of industrial plant
1- Accelerator room, 2- Irradiation room,
3-Water injection, 4-Water tank, 5- Shield door

IV. CONCLUSION

An industrial plant for treating 10,000m^3 of textile dyeing wastewater per day with electron beam 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.

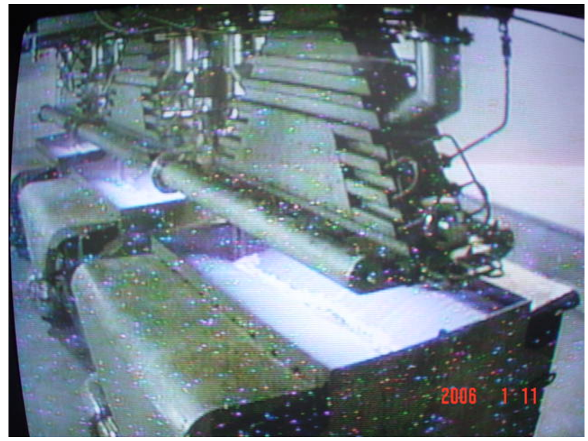

Fig. 6 Wastewater under treatment with e-beam

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