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14 Industrial Wastewater Treatment with Electron Beam

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Abstract

Global withdrawals of water to satisfy human demands have grown dramatically in this century. Between 1900 and 1995, water consumption increased by over six times, more than double the rate of population growth. This rapid growth in water demand is due to the increasing reliance on irrigation to achieve food security, the growth of industrial uses, and the increasing use per capita for domestic purposes. Given the seriousness of the situation and future risk of crises, there is an urgent need to develop the water-efficient technologies including economical treatment methods of wastewater and polluted water.

In the Central Research Institute of Samsung Heavy Industries (SHI), many industrial wastewater including leachate from landfill area, wastewater from papermill, dyeing complex, petrochemical processes, etc. are under investigation with electron beam irradiation. For the study of treating dyeing wastewater combined with conventional facilities, an electron beam pilot plant for treating 1,000m^3/day of wastewater from 80,000m^3/day of total dyeing wastewater has constructed and operated in Taegu Dyeing Industrial Complex. A commercial plant for re-circulation of wastewater from Papermill Company is also designed for S-paper Co. in Cheongwon City, and after the successful installation, up to 80% of wastewater could be re-used in paper producing process.

1. Introduction

Samsung Heavy Industries (SHI) was established in 1974 and has managed to enter a wide range of successful business areas. These include plant engineering, Industrial machinery, shipbuilding, and constructions. The volume of annual sales is over 3 billion dollars with the 10,000 employees. The Central Research Institute of SHI is located in Daeduk Science Town, which is at the central part of Korea. The Accelerator Laboratory in this institute is devoted for the development of accelerator technologies and applications.

The research activities for the applications of accelerator include wastewater treatment, combustion flue gas purification, semi-conductor treatment, and other radio-chemical processing. The treatment of industrial wastewater with electron beam is one of the actively studied subjects for the environmental application in Central Research Institute. The method for the removal of heavy metals from wastewater and other technologies [1,2] are developed with the joint works of Central Research Institute of SHI and Institute of Physical Chemistry (IPC) of Russian Academy of Sciences.

2. Increase Of World Water Consumption

Actually 70% of the world is covered with water, however, the reality is that 97.5% of all water on earth is salt water, leaving only 2.5% as fresh water. Nearly 70% of that fresh water is frozen in the icecaps of Antarctica and Greenland, and most of the remainder is present as soil moisture, or lies in deep underground aquifers as groundwater not accessible for human use. As a result, less than one per cent of the world's fresh water, or about 0.007 per cent of all water on earth, is readily accessible for direct human uses [3]. This is the water found in lakes, rivers, reservoirs and those underground sources that are shallow enough to be tapped at an affordable cost. Only this amount is regularly renewed by rain and snowfall, and is therefore available on a sustainable basis.

It has been estimated that the amount of the fresh water that is readily accessible for human use at about 9,000 cubic kilometers a year, and another 3,500 cubic kilometers of water that is captured and stored by dams and reservoirs could be added. Harnessing the remaining water resources for human needs becomes increasingly costly, because of topography, distance and environmental impacts. Currently, humans are using about half the 12,500 cubic kilometers of water that is readily available. Given an expected population increase of about 50% in the next 25 years, coupled with expected increases in demand as a result of economic growth and life-style changes, this does not leave a great room for increased consumption (Fig.1). Water needs to be left in rivers to maintain healthy ecosystems, including fisheries. When global water picture is examined at a country level, some countries still have large amounts of water per capita, but others, however, are already facing serious difficulties. Future increases in demand due to population growth and increased economic activities will inevitably impinge further on the available water resources.

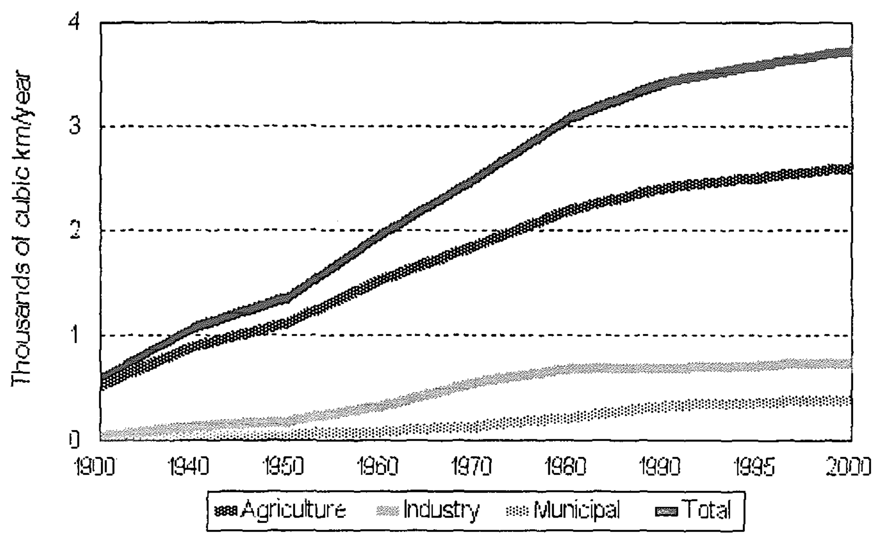

FIG. 1 Increase in world water consumption [3]

Despite improvement in the efficiency of water use in many developed countries, the demand for fresh water has continued to climb as the world's population and economic activities have expanded. From 1900 to 1995, withdrawals of fresh water from rivers, lakes, reservoirs, underground aquifers, and other sources increased by more than a factor of six. Increases in irrigation and, to a lesser extent, industrial uses of water have been the largest sources of this growing demand. At the same time, contamination by pollutants has seriously degraded water quality, effectively decreasing the supply of fresh water.

The results have been increased pressure on fresh water resources in most regions of the world and a lack of adequate supplies in some localities. Water experts and international institutions warn that water shortages could become critical in some regions.

In Korea, The annual average rainfall is 1.3 times greater than that of world, but it varies too much with season and area to control for withdrawal. Only 24% of rainfall could be accessible for human uses. If in the absence of far more effective management of water resources, this could be a pose serious long-term obstacle to sustainable development of Korea.

3. Electron Beam Treatment of Wastewater

People have used water as a convenient sink into which to dump wastes. The pollution comes from many sources, including untreated sewage, chemical discharges, petroleum leaks and spills, agricultural chemicals, etc.. The wastewater discharged has outstripped nature's ability to break them into less harmful elements. Pollution spoils large quantities of water, which then cannot be used. Virtually all pollutants can be removed from water, especially in the case of toxic substances, is very expensive, and requires sophisticated techniques.

The treatment of municipal and industrial wastewater becomes a more important subject in the field of environment engineering. The treatment of the industrial wastewater containing refractory pollutant with electron beam is actively studied in Samsung Heavy Industries. Electron beam treatment of wastewater often 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).

TABLE I. Supply and Demand of Fresh Water in Korea (in billion tons)

Year	1994	2001	2006	2011
Demand	2.990	3,364	3,499	3,665
Supply	3,222	3,429	3,454	3,465
Shortage	-	-	45	200

TABLE II. Amount of Wastewater Generated/Discharged in Korea [4] (in 1,000m^3/day)

	Number of Companies (%)	Amount of waste-water generated (%)	Amount of waste-water discharged (%)
Textile co.	1,423 (5.6)	473 (5.4)	457 (19.2)
Papermill	268 (1.1)	711 (8.1)	364 (15.3)
Light Ind.	511 (2.0)	390 (4.5)	243 (10.2)
Processing Ind.	3,376 (13.3)	439 (5.0)	200 (8.4)
Metal fabrication	437 (1.7)	5,346 (61.1)	169 (7.1)
Others	19,284 (76.2)	1,382 (15.8)	942 (39.7)
Total	25,299 (100)	8,741 (100)	2,375 (100)

Sometimes such reactions are accompanied by the other processes, and the synergistic effect upon the use of combined methods such as electron beam treatment with ozonation, electron beam and adsorption and others improves the effect of electron beam treatment of the wastewater purification.

In Korea, where the industries are concentrated in near urban areas, resulting in severe water pollution problems in most large cities. Major sources of water pollution include chemical-intensive industries such as textiles, metal plating, electronics, papermill and refineries. Typical contaminants include non-biodegradable substances, grease and oils, acids and caustics, heavy metals such as cadmium and lead, sludge and a long list of synthetic organic compounds. The amounts of wastewater generated and discharged in Korea are summarized in TABLE II.

TABLE III. Wastewater under study at SHI

Wastewater (from)	Purpose of investigation	Results
Dyeing company	Removal of color and organic Impurities	Pilot plant constructed. Improve removal efficiencies
Papermill	Decrease COD, color Increase re-use rate	Reduction in impurities Commercial plant designed
Petrochemical co.	Removal of organic residues after processing	Removal of TCE,PCE,PVA, HEC and other substances
Leachate from landfill area	Removal of organic impurities Improvement of Bio-treatment	Bio-treatment efficiency improved
Heavy metals	Decrease the content of heavy metal ions in water	Removal of Cd,Cr^{+6},Hg up to 98% (95% in Pb)
Power plant Clean-up	Decrease the content of organic acid and detergent	Decrease the content of organic substance

The wastewater under current investigation at SHI are from dyeing companies, petrochemical processes, papermill and leachate from sanitary landfill area etc.. Those are also summarized in TABLE III. Two electron accelerators of energy 1 MeV each in continuous mode at Daeduk (SHI) and one accelerator of 5 MeV in pulsed mode at Moscow (IPC) are used in experiments. Applied sets of dose for the experiments were measured with an ordinary or modified Fricke dosimeter and dichromatic dosimeter.

4. Pilot Plant for Wastewater from Dyeing Process

An electron beam pilot plant for treating 1,000m^3/day of dyeing wastewater from 80,000m^3/day of total wastewater has constructed in Taegu Dyeing Industrial Complex (TDIC). TDIC includes now more than 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 colored industrial wastewater. Therefore, intensive and effective purification of the wastewater is one of the most complicated and actual problems of TDIC's current activities.

Purification of the wastewater is performed by Union wastewater treatment facilities in Fig.2 using conventional methods schematically described in Fig.3. Current facility treats up to 78,000m^3 of wastewater per day, extracting thereby up to 730 m^3 of sludge.

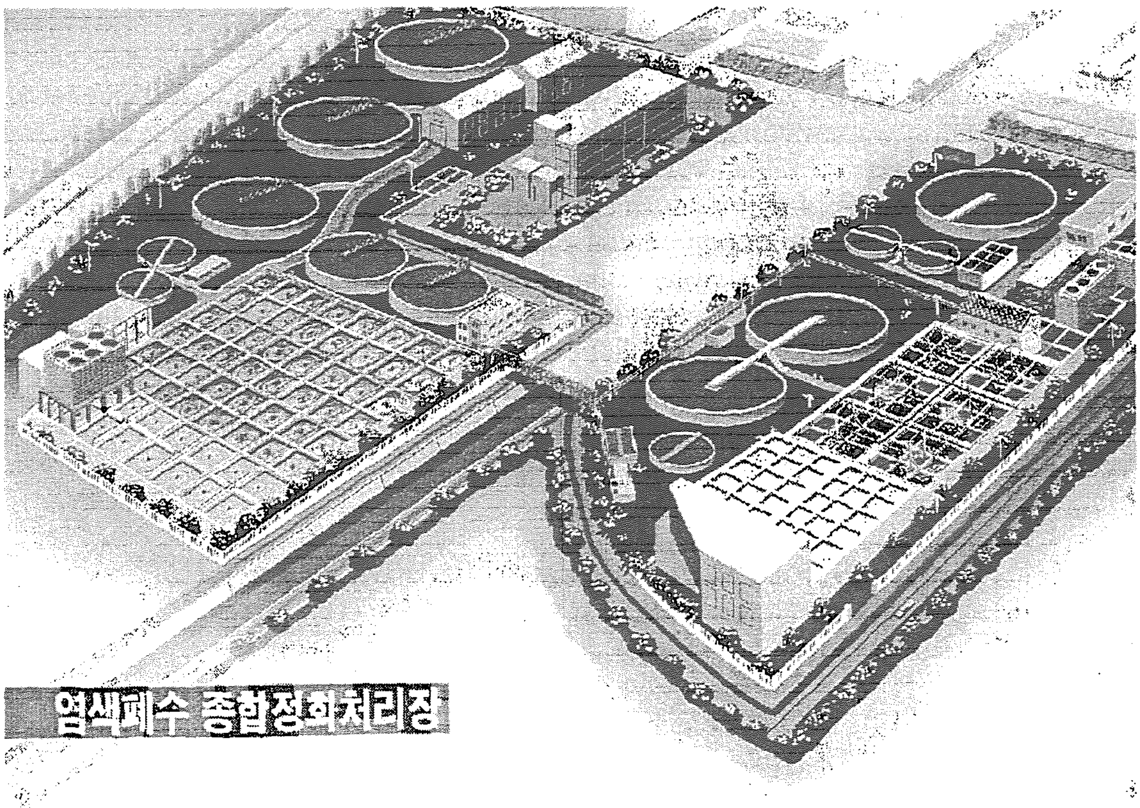

FIG. 2 Wastewater treatment Facility in TDIC

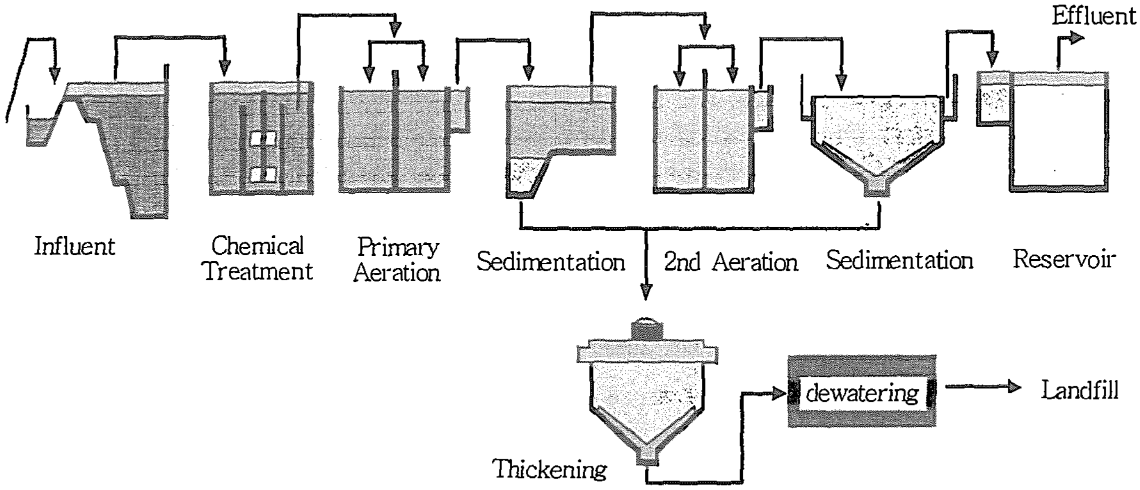

FIG.3 Process flow in dyeing wastewater

Rather high cost of purification results from high contamination of water with various dyes and ultra-dispersed solids. Because of increase in productivity of factories and increased assortment of dyes and other chemicals, substantial necessity appears in re-equipment of purification facilities by application of efficient methods of wastewater treatment. The existing purification system is close to its limit ability in treatment of incoming wastewater. Some characteristics of raw wastewater as well as characteristics of treated water after several treatment stages and of effluent are listed in the TABLE IV.

The studies have been carried out regarding the possibility of electron beam application for purification of wastewater. With the co-works of SHI Central research Institute and IPC, the experiments on irradiation of model dye solutions and real wastewater samples (from various stages of current treatment process) have been performed. [4] 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 (Fig. 4). 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%.

TABLE IV. Typical Characteristics of Wastewater

Parameter	pH	BOD_5 (mg/l)	COD_{Mn} (mg/l)	Suspended solids (mg/l)	Color units
Raw wastewater	12	2,000	900	100	1,000
After chemical treat	6.8-7.5	1,700	450	50	500
After 1st Bio-treat	7.0-8.0	1,300	250	50	400
After 2nd Bio-treat	7.0-8.0	30	60	50	250

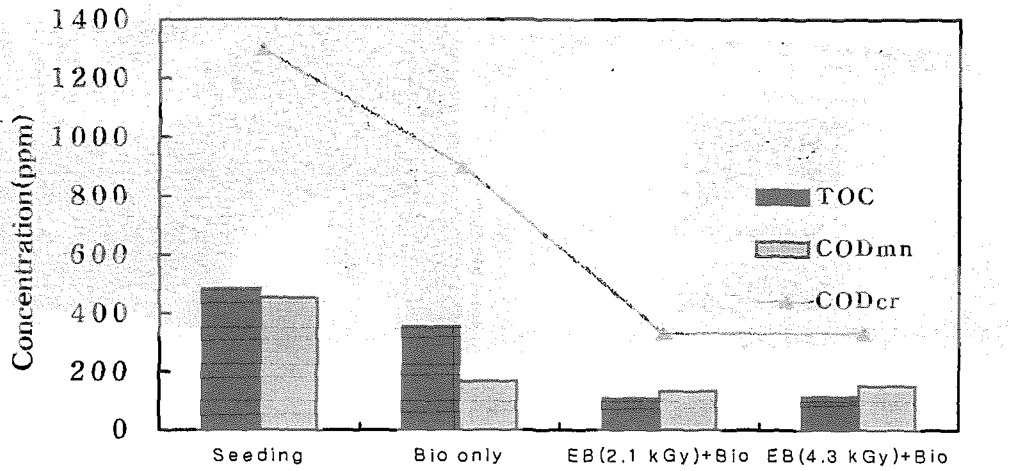

FIG. 4 Combined effect of e-beam and biological treatment.

A pilot plant for a large-scale test (flow rate of 1,000m^3 per day) of wastewater starts operation with the electron accelerator of 1MeV, 40kW (Fig. 5). The accelerator was installed in Feb. 1998 and the technical lines are finished in May. The Tower Style Biological treatment facility (TSB) which could treat up to 1,000m^3 per day has also installed in October. The wastewater from various stages of the existing purification process can be treated with electron beam in this plant to investigate the experimental possibilities of the pilot plant, and it will give rise to elaborate the optimal technology of the electron beam treatment of wastewater with increased reliability at instant changes in the composition of wastewater. The wastewater is injected under the e-beam irradiation area through the nozzle type injector to obtain the adequate penetration depth. The speed of injection could be varied upon the dose and dose rate.(Fig.6)

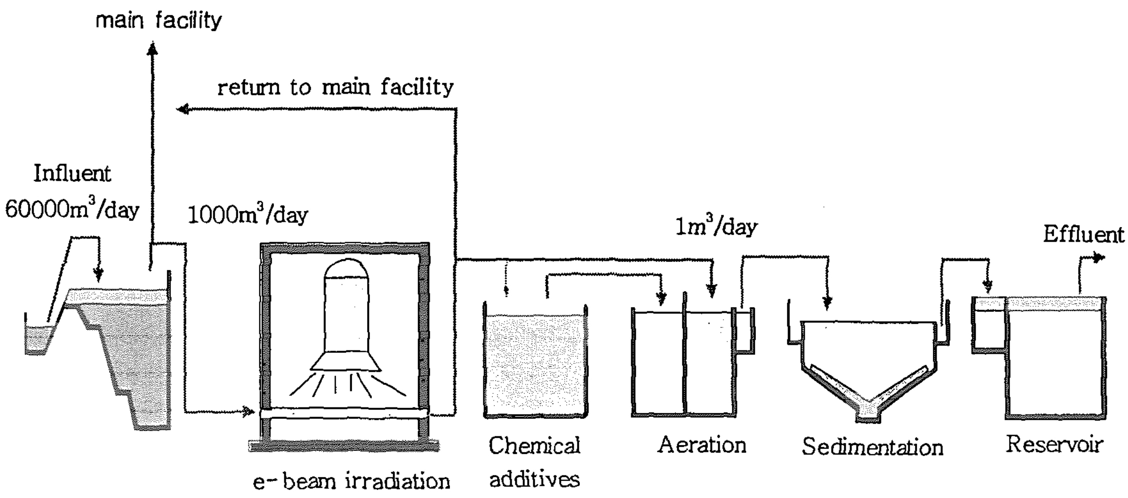

FIG.5 Schematic diagram of pilot plant at Taegu dyeing complex

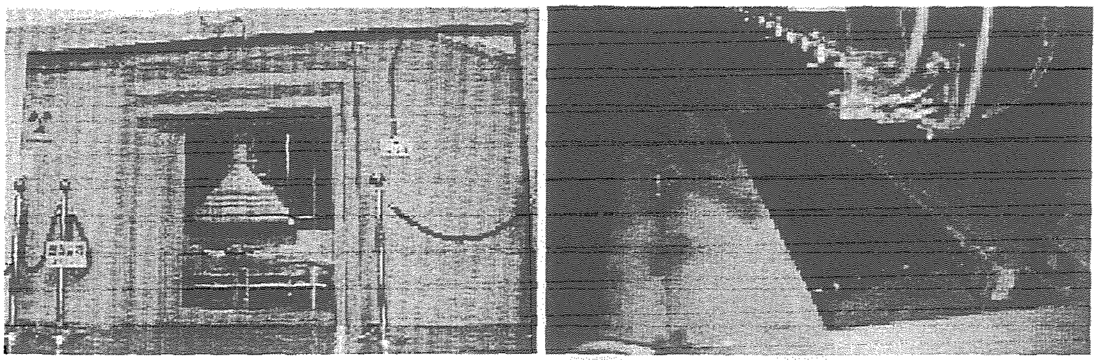

FIG.6 Electron Accelerator and Wastewater under Injection

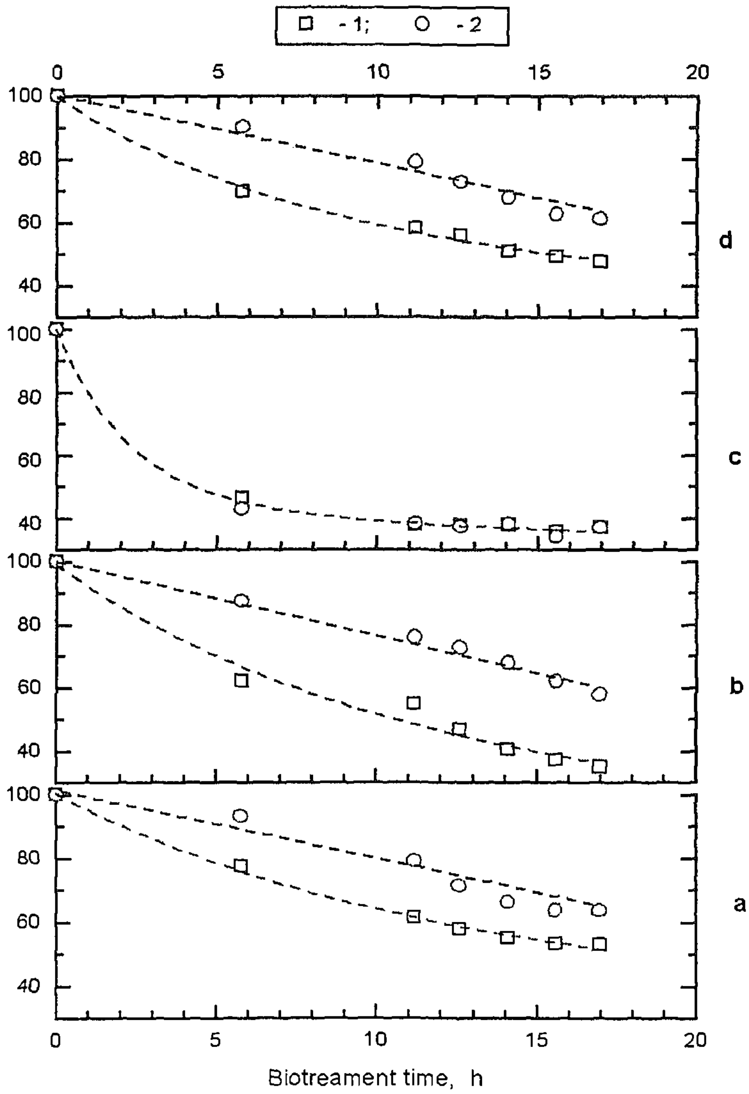

FIG.7 Effect of irradiation and biological treatment on wastewater parameters: a-TOC; b-COD_{Cr}; c-COD_{Mn}; and d-BOD. 1- after EB treatment; 2-without EB treatment

5. Commercial Plant Design for Wastewater from Papermill

A commercial plant for re-circulation of wastewater with electron beam from Papermill Company is also under planning in S-paper Co. and SHI. S-paper co. is located in Cheongwon City, 120km south of Seoul, and consumes 18,000 m^3 of water per day. The major products of this company are papers for newsprint (450t/day) and are mainly made of recycled paper (91%) and pulps. Purification of wastewater is now performed by 2-stages of chemical and biological treatment facilities.

For the economical point of view, this company tried to recycle the treated water to production lines, but used only 20-30% at total water since the amount of organic impurities after treatment are high and some of them are accumulated during re-circulation. In order to develop the most efficient method for re-circulation of wastewater, the experiments were conducted with samples in various stages of treatment. The best result obtained is irradiation of water after biological treatment combined with coagulation and filtration (Fig. 8). Irradiation in this stage, the additional removal of impurities is up to 80% in TOC (Total Organic Carbon) values.

On the base of data obtained by SHI and IPC the suitable doses in this case are determined as around 1 kGy for the flow rate of 15,000 m^3 wastewater per day (since the 3,000m^3 of wastewater is returned to initial stage with sludge). Therefore, three accelerators with the total power of 300kW and treating systems are designed. After the successful installation of electron beam treatment facilities, up to 80% of wastewater could be re-used in paper producing process (Fig. 9).

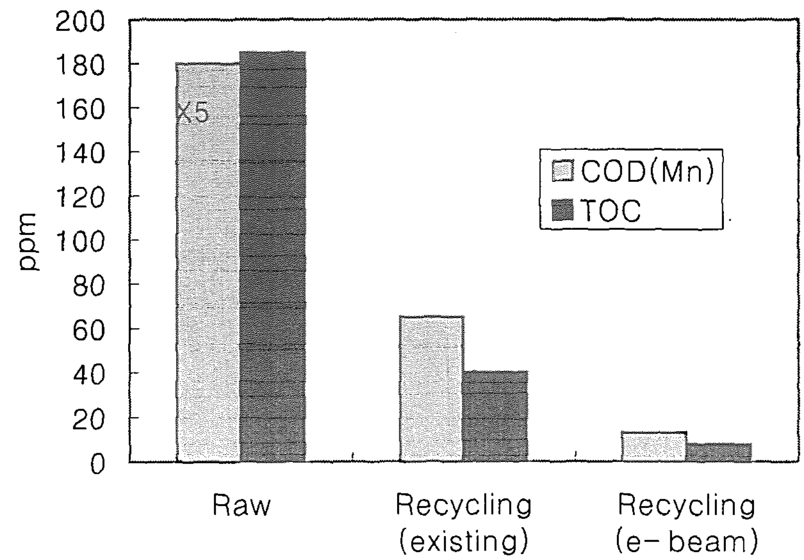

FIG.8 Treatment of wastewater from papermill.

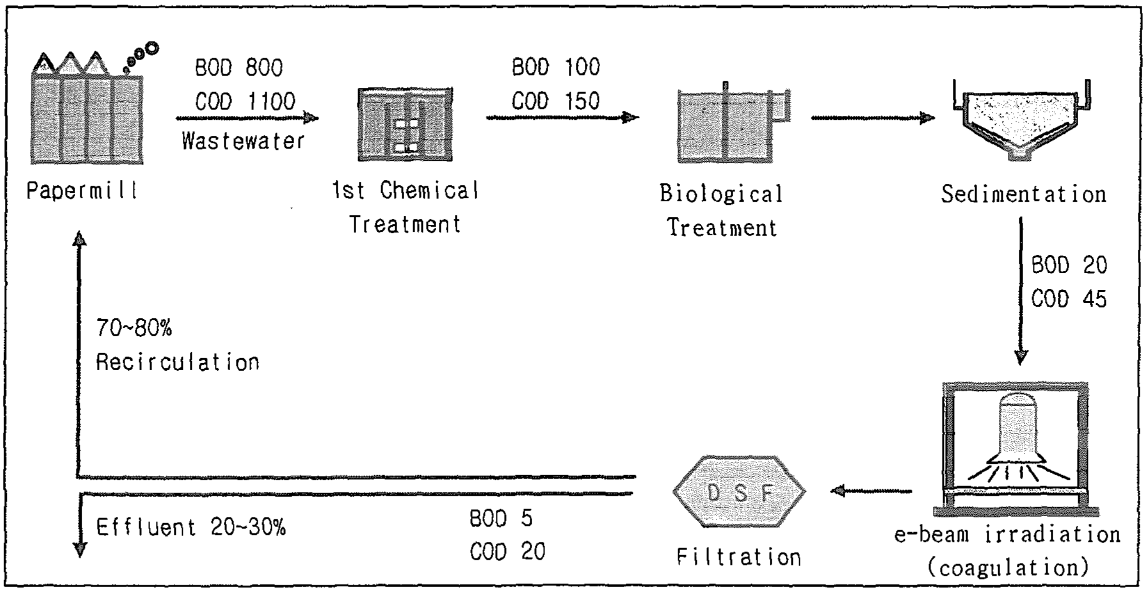

FIG. 9 Process flow of e-beam facility for wastewater from papermill.

6. Summaries and Conclusion

6.1 General

6.1.1 Electron beam treatment of industrial wastewater is under development in Samsung Heavy Industries for the removal of non-degradable wastes, and also for the re-use of wastewater to production process.
6.1.2 For industrial wastewater with low impurity levels such as contaminated ground water, cleaning water and etc., purification only with electron beam is possible, but requires high amount of irradiation doses.
6.1.3 For industrial wastewater with high impurity levels such as dyeing wastewater, leachate and etc., purification only with electron beam requires high amount of doses and far beyond economies.
6.1.4 Electron beam treatment combined with conventional purification methods such as coagulation, biological treatment etc. is suitable for reduction of non-biodegradable impurities in wastewater and will extend the application area of electron beam.

6.2 Experimental

6.2.1 A pilot plant with electron beam for treating 1,000m^3/day of wastewater from dyeing industries has constructed and operated continuously since Oct 1998.
Electron beam irradiation instead of chemical treatment shows much improvement in removing impurities and increases the efficiency of biological treatment.
Actual plant is under consideration based upon the experimental results.
6.2.2 Commercial plant for re-circulation of 15,000m^3/day of wastewater from papermill is also investigated, and after the successful installation, up to 80% of wastewater could be re-used in paper producing process.

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