HIGH POWER ACCELERATOR FOR ENVIRONMENTAL APPLICATION

Bumsoo Han, Sung Myun Kim, Rustam A. Salimov*, Nikolai K. Kuksanov*

EB TECH Co., Ltd. 550 Yongsan-dong Yuseong-gu, Daejeon 305-500 Korea, bshan@eb-tech.com
**Budker Institute of Nuclear Physic, Lavrentiev prospect 11, Novosibirsk 630090Russia, N.K.Kuksanov@INP.nsk.su*

High power accelerator (1MeV, 400kW) has developed for environmental application together with EB TECH Co. and BINP. This accelerator can deliver maximum 400kW of electron beam through 3 irradiators which has the double extraction windows. Titanium foils are used for window materials and are cooled by water and air jet blow. High voltages are generated through the inductions of coils in main body and SF6 gases are used for protecting electrical discharges. The first accelerator of this figure has installed in 2005 at Daegu Dyeing Industrial Complex, Korea for treating industrial wastewater form textile dyeing industries.

I. INTRODUCTION

The problems of environmental damage and degradation of natural resources are receiving increasing attention throughout the world. The increased population, higher living standards, increased urbanization and enhanced industrial activities of humankind are all leading to degradation of the environment. Increasing urbanization has been accompanied by significant water pollution. Given the seriousness of the situation and future risk of crises, there is an urgent need to develop the efficient technologies including economical treatment methods of pollutants. However, to have advantages over existing processes, the electron beam process should have cost-effective and reliable in operation. Therefore high power accelerator has developed for environmental application and they show the decrease in the cost of construction and operation of electron beam plant.

I.A. Accelerator Required for Environmental Application

Most important factor to control the economics of the e-beam plant is the cost of electron accelerator in use. Accelerator manufacturers produce many kinds of electron accelerators with energy range from 0.5 to 10 MeV and beam power range from 50 to 400 kW. For flue gas treatment, electron energies around 0.7 ~1.0MeV is enough to use, but electron beams at energy more than 1.0 MeV are useful for wastewater treatment and sludge hygienisation. Such energy provides enough penetration of accelerated electrons into wastewater and sludge at admissible hydrodynamic regimes of wastewater flow and sludge. The accelerators with beam energy more than 5 MeV are being produced at low beam power (less than 50 kW). Low beam power is enough acceptable for experimental and pilot plants but not for large-scale treatment of industrial uses. Therefore, the medium energy accelerators obtained the maximum practical use for flue gas and wastewater treatment. The beam power of such accelerators reaches 400 kW and there are several projects for production of accelerators at beam power up to 1 MW. Therefore, the basic criterions of accelerator for environmental application are

- High beam power to increase productivity and reduce unit operation cost,
- High electrical efficiency to reduce exploitation and unit operation costs,
- High beam utilization to increase productivity and reduce unit operation cost.

I.B. Environmental Application of Accelerator

EB-treatment gives essential change of various properties of pollutants - solubility, volatility, reactivity, absorptivity etc. It stimulates the development of productive combination of e-beam method and various conventional methods. At present the e-beam treatment has not wide application and spreads less than conventional methods. However, first experience of the industrial application shows that e-beam process can occupy the quite essential place at future. Already now the e-beam technology and its combination with conventional ones provide noticeable economy of time, area and industrial power to pollutant treatment. [1~4] Continuous reinforcement of ecological standards is additional motivation for elaboration and industrial application of e-beam treatment.

High-energy irradiation produces instantaneous radiolytical transformations by energy transfer from accelerated electrons to orbital electrons of water molecules. Absorbed energy disturbs the electron system of the molecule and results in breakage of inter-atomic bonds [5,6]. Hydrated electron e_{aq}^-, H atom, $^{\bullet}OH$ and $HO_2^{\bullet}$ radicals and hydrogen peroxide H_2O_2 and H_2 are the most important products of the primary interactions (radiolysis products). Electron beam processing of wastewater is non-chemical, and uses fast formation of short-lived reactive radicals that can interact with a wide range of pollutants. Such reactive radicals are strong oxidizing or reducing agents that can transform the pollutants in the liquids wastes. The first studies on the radiation treatment of wastes were carried out in the 1950s principally for disinfection. In the 1960s, these studies were extended to the purification of water and wastewater. After some laboratory research on industrial wastewaters and polluted groundwater in 1970s and 1980s, several pilot plants were built for extended research in the 1990s

II. HIGH POWER ACCELERATOR

The key to the successful implementation of electron beam 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 accelerator with enough low doses. Therefore accelerator of 1MeV, 400kW has produced together with EB-TECH Co. and BINP, Russia (Fig. 1)

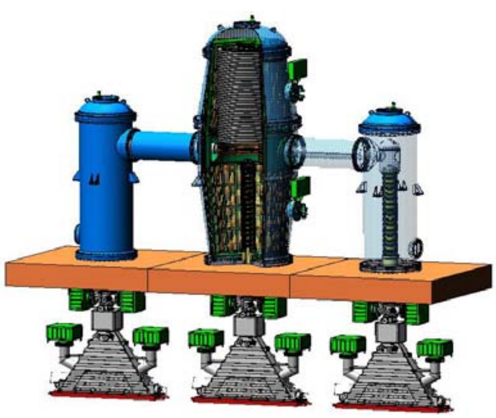

Fig. 1 Accelerator of 1MeV, 400kW in assembly

This accelerator can deliver the maximum 400kw of electron beam power through 3 irradiators which has the double extraction windows (Fig. 2) Titanium foils are used for window materials and are cooled by air jet blow and water. High voltages are generated through the inductions of coils in main body and SF6 gases are used for protecting electrical discharges. The first accelerator of this figure has installed in Daegu Dyeing Industrial Complex (DDIC), Korea for treating textile dyeing wastewater.

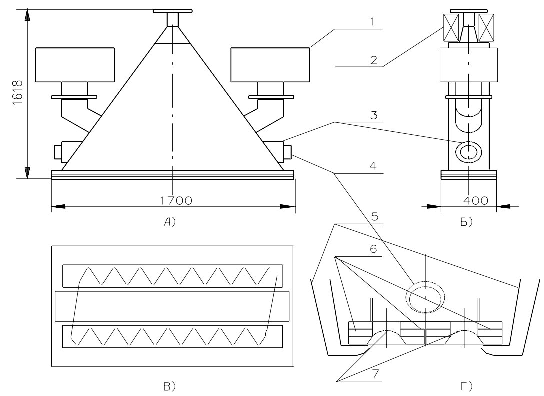

Fig. 2 Double extraction window: 1 ion pumps, 2 scanning system, 3 cylinder flange, 4 protection cylinders, 5 foil blower, 6 foil frame, 7-extraction foils.

Electron accelerators for radiation processing are classified on the basis of the mode of operation, into direct current (DC) and radio-frequency (RF) – powered machines. With DC voltage accelerators a DC voltage is used to accelerate the electrons, either applied directly between the electron source and an electrode as with electrostatic machines, or transferred to the electrons inductively as with machines of the transformer type. The final energy of the electrons in DC accelerators is numerically equal to the potential difference across the accelerating tube [7]. DC voltage is used to accelerate electrons in direct acceleration method. DC voltage power supplies as high voltage sources are usually based on the use of oil or gas filled transformers with rectifier circuit. They are relatively simple and the most reliable accelerator component. Medium energy (0.5-5 MeV) can be obtained by high voltage generator. Different type of inductance or capacitance coupling makes possible to multiply AC primary voltage and obtain up to 5 MV of output voltage. The main parameter of High power accelerator is shown in TABLE I.

TABLE I. Parameter of High Power Accelerator

Items	Parameter
Nominal energy	0.6-1,0 MeV
Energy stability	± 1%
Nominal beam current	500 mA
Beam current stability	± 2%
Beam power	400 kW
Scan width	200 cm
Dose uniformity	<± 5%
Mode of operation:	continuous
No of accelerating heads	3 heads (*1)
Total beam power	400 kW
Power consumption	500 kW
Electrical efficiency	80 %

High voltage coreless transformer concept was applied in this high power accelerator. The certain number of secondary coils is needed to obtain required output voltage. There is no central magnetic guide what simplifies the high voltage source design. The central pressure tank is used to install HV transformer, accelerating section and scanner. Two more tanks are used with additional accelerating tube and scanning devices. SF_6 gas insulating system is used. Coreless accelerators are usually operated at AC voltage with frequency 0.4-1 kHz to reduce the accelerator dimensions. Electron energy 0.2-2.5 MeV can be obtained in such accelerators.

III. ECONOMICAL EVALUATION OF COMMERCIAL PLANT WITH HIGH POWER ACCELERATOR

An industrial plant for treating 10,000 m^3/d of textile dyeing wastewater with high power electron accelerator (1MeV, 400kW) has been constructed and operated continuously since 2005. This plant demonstrated a reduction of chemical reagent consumption and the reduction in retention time with the increase in efficiency of removal of COD_{Cr} and BOD_5 up to 30~40%. Increase in removal efficiency after radiation treatment is due to radiolytical transformation of biodegradable compounds to more readily digestible forms (Fig. 3).

Fig. 3 High power accelerator in wastewater process

Based on the pilot plant experiments, the suitable doses cost-effective electron beam plant are determined as around 1~2 kGy for the flow rate of 10,000m^3 effluent per day. Thus, the cost assessment of radiation processing plant with e-beam is accomplished based on 1kGy and 400kW electron accelerator.

Cost for such high power accelerator is around 2.0 M$ for installation and building, piping, other equipment and construction works could be estimated 1.5 M$. Even by considering the additional cost for tax, insurance and documentation as 0.5M$, the overall capital cost for plant construction and operating are approximately 4.0M$ and 1.0M$ as stipulated in TABLE II and TABLE III.

TABLE II. Construction cost of industrial plant

	Cost	Remarks
Accelerator - 1MeV, 400kW	2.0	Cost for Land, R&D, Approval from Authorities are not included
Water reactor & raw material	1.5	
Installation cost – welding/piping/inspection etc.		
Design		
Shield Room & Construction		
transportation, tax, others	0.5	
Total	4.0	4M$

TABLE III. Operating cost of industrial plant

Items		Addition of E-beam	Remarks
Operating Cost	Invest (k$)	(4,000)	
	Interest	240	6%
	Depreciation	200	20yrs
	Electricity	320	800kW
	Labor	100	3 shift
	Maintenance, etc.	80	2%
Total cost		940	~ 1M$/yr

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 320,000$/yr when the cost of electricity (kWh) was assumed to be 0.05$. The labor cost of operator is calculated on 3-shift work and is approximately 100,000 $/yr. Therefore, the actual operation cost for 10,000 m^3/day plant comes up to around 1.0M$/yr including the interest and depreciation of investment and is 0.3$ for each m^3/day of wastewater.

IV. CONCLUSIONS

A DC-type high power accelerator of 1MeV, 400kW has developed and has been in use for wastewater treatment since 2005. This accelerator can also be used for gas and sludge treatment.

Accelerators for environmental application should have strong and firm configuration for year round operation, and economics in power consumption.

REFERENCES

1. HAN B., et al. “Combined electron-beam and biological treatment of dyeing complex wastewater. Pilot plant experiments”, *Radiation Physics and Chemistry*, Vol.64, pp 53-59 (2002)
2. PIKAEV, A. K., et. al. "Combined electron beam and coagulation method of purification of water from dyes", *Mendeleyev Communication*, June 1997 pp176-178 (1997)
3. HAN B., et. al “Application of Electron Beam to Wastewater from Papermill”, *XIIth IMRP*, Avignon, France (2001)
4. PIKAEV, A. K. *Modern Radiation Chemistry. Radiolysis of Gases and Liquids*, Nauka, Moscow, pp.440 (1986) (in Russian)
5. BUXTON, G. V., GREENSTOCK, C. L., HELMAN, W. P., ROSS, A. B. 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 (1988)
6. WOODS, R. J., PIKAEV, A. K. *Applied Radiation Chemistry: Radiation Processing*, Wiley-Interscience, New York, pp.535 (1994)
7. S. Humphries, Jr., *Principles of Charged Particle Acceleration*, John Wiley and Sons (1999)