E-Beam Flue Gas Treatment Plant for "Sviloza Power Station"AD

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Abstract. After the successful operation of e-beam flue gas treatment pilot plant in Maritza East 2 power plant equipped with three electron accelerators (0.8 MeV, total power 90 kW) with a gas flow rate of 1.0 $\times 10^4$ m^3/h containing 5,600 ppm SO_2 and 390 ppm NO_X, the feasibility study for an industrial scale EBFGT facility for a 165 MW power plant in "Sviloza Power Station" AD in Svishtov, Bulgaria, treating a flue gas flow of 6.0×10^5 m^3/h (NTP) has carried out with a comprehensive engineering and cost study. The power of accelerators required is 4 × 350 kW, and expected efficiency of removal for SO_X is 90 % and 40% for NO_X. There are two reaction chambers each equipped with two accelerators, which have two irradiation windows each, installed in series irradiate each chamber. The applied dose is around 4kGy, and the by-product will be collected for fertilizer. This study showed that the large-scale EB plants for flue gas cleaning have cost advantages over conventional technologies.

1. 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 air pollution, and the activities to produce heat and electrical energy are responsible for emitting a large number and amount of pollutants. The electron beam flue gas treatment process is one of the most promising technologies in the modern environmental protection. Electrons interact with such pollutants in stack gases containing sulphur oxides (SO_2 and SO_3), nitrogen oxides ($NO_X = NO_2 + NO$) and volatile organic compounds to create divergent ions and radicals including oxidizing radicals and excited species. These excited species react in a various ways of neutralization reactions to convert SO_2 and NO_X into a dry product containing $(NH_4)_2SO_4$ and NH_4NO_3 that was usable as a fertilizer. The potential of using radiation to initiate the process aimed at the removal of the toxic gases SO_2 and NOx using accelerated electron beam was first investigated by Japanese institutes in the 1970s. The method has subsequently been developed, from pilot scale to commercial scale, by research and development projects in Germany, Japan, USA, Poland and China. There are 5 industrial scale demonstration installations completed or under construction all over the world, including 3 in China, one in Japan and another in Poland [3,10,11]. There is an experience with this technology also in Bulgaria – the pilot installation in "Maritza East -2" TPS[9].

2. TPS "Sviloza" EBFGT Project in Bulgaria

After the successful operation of e-beam flue gas treatment pilot plant in Maritza East 2 power plant equipped with three electron accelerators (0.8 MeV, total power 90 kW) with a gas flow rate of 1.0 $\times 10^4$ m^3/h containing 5,600 ppm SO_2 and 390 ppm NO_X, the feasibility study for an industrial scale EBFGT facility for a 165 MW power plant in "Sviloza Power Station" AD in Svishtov, Bulgaria, treating a flue gas flow of 6.0×10^5 m^3/h (NTP) has carried out with a comprehensive engineering and cost study. TPS "Sviloza" was generated flue gases from 4 working boilers – 600,000 Nm^3, with emission of SO_2 - 1,680ppm, NOx - 780ppm and dust - 400 mg/Nm^3. All 8 stacks from 4 boilers are connected to the chimney of 150m in height and planning to take by-pass lines from each stack to send the gases to EBFGT plant and connecting them to chimney after treatment. There is an empty space of over 50m X 60m for excursion of site. Flue gas condition in the flue gas treatment system for TPS ”Sviloza” are[9];

- Flue gas flow rate :	600,000 m^3/h
- Inlet flue gas temperature	160°C
- Inlet flue gas composition:	
SO_2	1,680 ppm
NOx	780 ppm
CO_2	10.4% vol.
O_2	8.3% vol.
H_2O	6.0% vol.
N_2	to the balance
Fly ash	< 400 mg/Nm^3
- SO_2 removal efficiency	85-90 %
- NOx removal efficiency	30-40 %
- Maximum dose	4 kGy
- Ammonia consumption	1,367-1,660kg/h
- By-product output	5,413-6,400kg/h

The developed basic technological design of two-stream EBI for purification of flue gases at TPS “Sviloza” is presented on FIG.1. The design takes in account the conditions, requirements, and limitations of the chosen technology. The limitations due to the existing infrastructure are illustrated on the Figure.

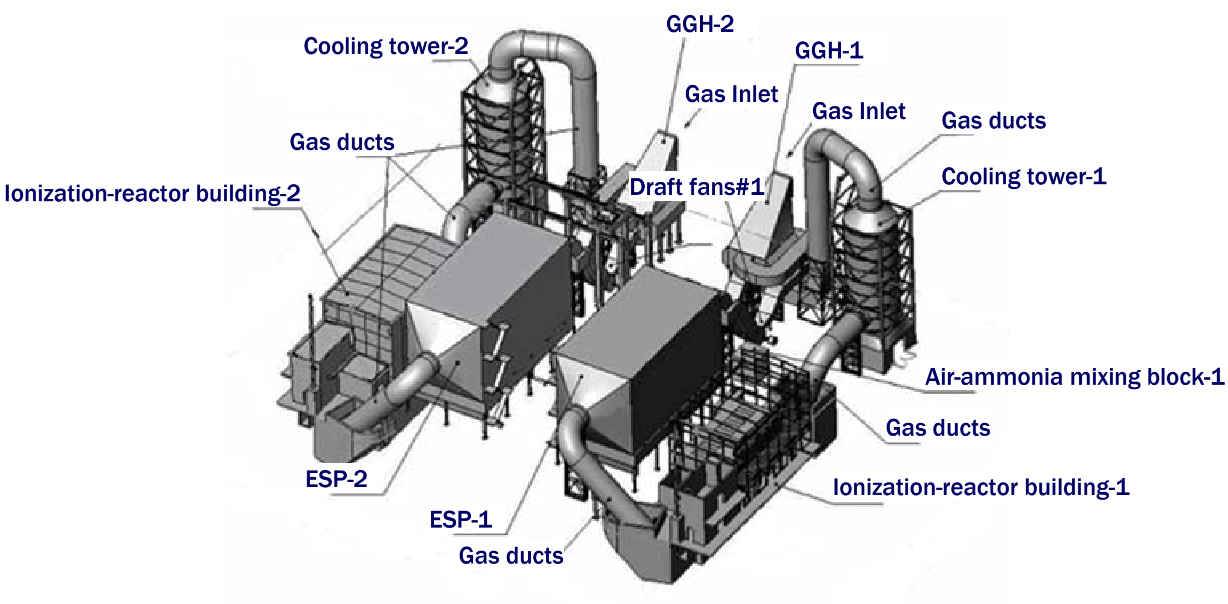

FIG.1. Basic design of two-stream EBI for flue gas purification [9].

EBFGT is concerned intensively by Bulgarian government and customers, but there are few limitations. The main limitations are that the capital cost is higher than Wet FGD at present; the process is not matured enough, especially the stability which can not meet the requirement of power plant customers, normally customers require a FGD installation operating at the rate of 95% of a power plant operation hours; power consumption occupied nearly 1- 2% of power plant capacity, which is higher than Wet FGD of about 1.5% or less.

3. Engineering Considerations for EBFGT Plant

There are several engineering considerations which selection of electron accelerators, irradiation method, sizing of process reactor and emergency operation etc.

3.1 High power accelerators

Accelerator manufacturers produce many different kinds of electron accelerators with an energy range from 0.5 to 10 MeV and beam power range from 50 to 600 kW. The beam power of medium energy accelerators reaches 600 kW, and there are several applications calling for manufacture of accelerators of beam power up to 1 MW[16]. To treat flue gas of 600,000Nm^3/hr with 4kGy, the accelerator power is required 1,200~1,400kW. The two accelerators of 400kW with double windows are installed for treating 300,000m^3/h of flue gas in TPS "Sviloza" EBFGT Project. Therefore, the four accelerators (2 irradiators each) operating 300~350kW at 0.9MeV. The accelerator, one extraction horn with multiple window inside supporters, is about theoretical 15%(75kW for 500kW) of too much power loss and requires huge cooling system because of heat generation. The power loss, multiple extraction horn with double window, is less than 1%(4~5kW for 400kW) because power loss concentrated on small beam jumping area. The solid connection is more stable and safety than cable connection in high voltage connection.

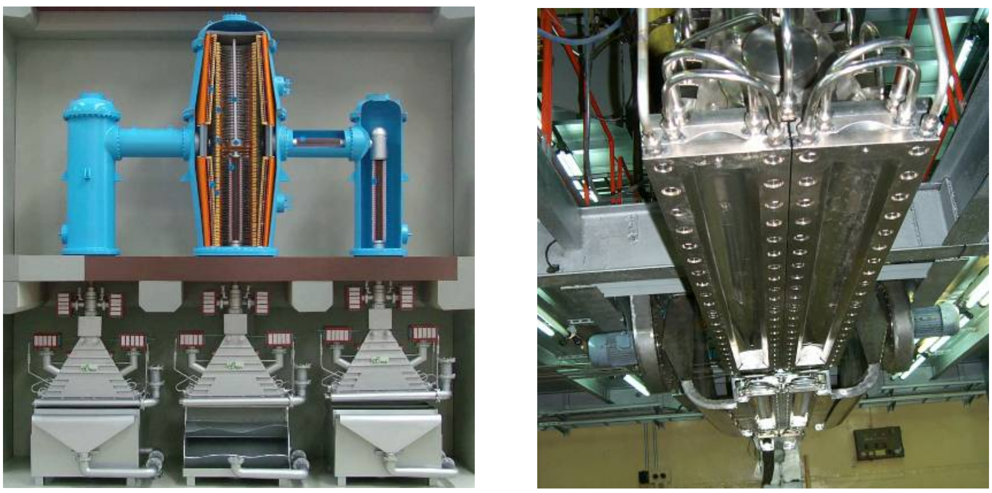

FIG. 2. ELV-12 High Power Accelerator (1MeV, 400kW)

Technical problems of EBFGT is reliability of facilities for year-round operation for electron accelerator, process reactor, technical lines and by-product recovery etc. Especially, Electron Accelerator' stability is very important in EBFGT Plant. The customers require operating at the rate of 95% of a power plant operation hours. High power accelerator, ELV-12 (FIG.2) has been operated without unusual troubles since 2005 in Korea and is proven multiple extraction horn with double window in wastewater treatment process.

3.2 Irradiation method

The multi-stage irradiation with two or three extraction horn, understood better than single-stage irradiation for NOx reduction. It shows two stage irradiation leads to remarkable energy saving and retains high NOx removal [1,2]. According to Ebara report, the accelerator power can be reduced by 35 to 40% by multi-stage irradiation [4]. Beam energy, 0.9MeV is better than 1.0MeV in considering of maximum Beam Power, and diameter of reactor is ranged 3.0~3.2m at 0.9MeV. It can be calculated to 10.4~11.8m/s of gas velocity in the process reactor. This velocity can reach level of Poland and Japan EBFGT Plant [6]. And the length(10~11m) of process reactor with two irradiator horn is similar to case of Poland and China [13]. The four accelerators of 400kW with double windows are installed for treating 600,000m^3/h of flue gas in TPS "Sviloza". The four accelerators are operating 300~350kW at 0.9MeV and dimension of process reactor is two sets of ø3.0~3.2m x 11m, as shown FIG.3. The three accelerators can be operated at 450kW for compensation of power loss in an emergency condition in this Project.

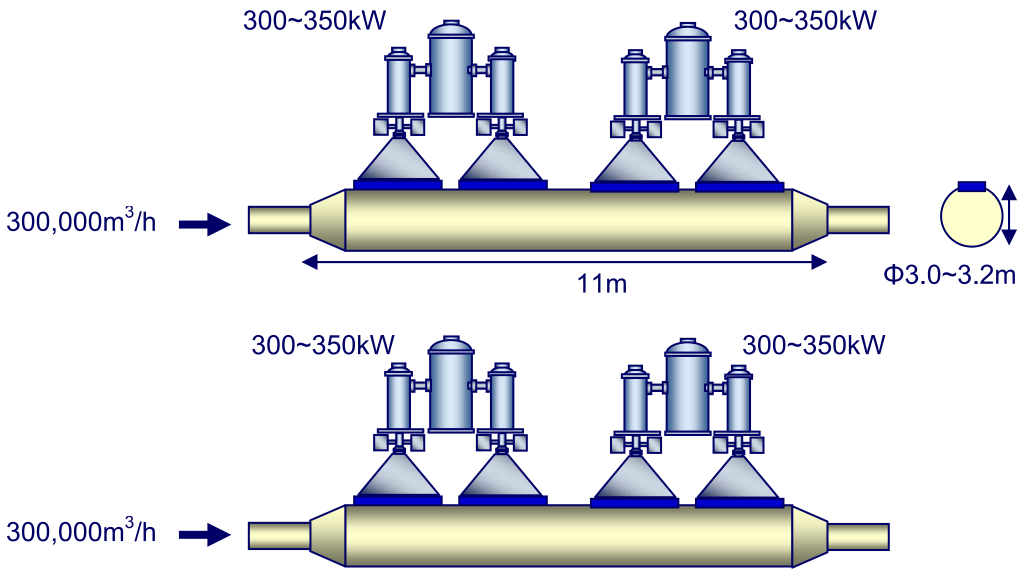

FIG.3. Optimum combination for accelerator at EBFGT "Sviloza"

3.3 Process Reactor Size

The reactors typical dimension is 2.4-2.6m at 0.8MeV at the existing EBFGT plant in the world[13]. The energy of the electron beam should not be greater than 1MeV because the shielding required at higher energies negates any advantages. For flue gas treatment, electron energies of approximately 0.7-1.0MeV are adequate, but electron beams of energy more than 1.0 MeV are useful for wastewater treatment and sewage sludge treatment. Such energy levels provide enough penetration of accelerated electrons into wastes when applied to admissible regimes. The maximum range of accelerated electrons is about 4m at 1MeV [5]. The process reactor size depends on target e-beam utilization efficiency. If reactor size is too large, the removal efficiency decrease with increasing depth to the bottom of reactor, but on the other it need a cooling for overheated bottom by e-beam. According to Mao et al., optimum size is ranged 2.6-2.9m in 0.8MeV, 2.9-3.2m in 0.9MeV and 3.1-3.3m in 1.0MeV[13].

And the other thing, EBFGT should consider on optimizing for the engineering technology and equipment to improve installation's stability. The main works focus on ESP, anti-corrosion and adhesion of by-product on reaction vessel, duct and electrodes of ESP, etc.

4. Cost Evaluation for TPS "Sviloza" EBFGT Project

The project are simultaneous removal of NOx by 40% and simultaneous removal of SOx by 90%; reduction annual emission of NOx from 3,040 ton/year up to 610 ton/year; the economical benefit will expect after commissioning of industrial EBFGT plant, and sales the by products to agriculture market - ammonium sulphate, ammonium nitrate, which a fertilizers - 28,000 ton/year, at total amount of 2,000,000 Euro/year. By-product of ammonium sulfate and ammonium nitrate sales to agriculture market, with this will decrease operation cost with about 50% [9].

TABLE 1. COMPARISON WITH UNIT COST FOR EB FGT [9, 10, 11]

Item	Chengdu, China(1998) [10]	Pomorzany, Poland(1999) [11]	TPS Sviloza, Bulgaria [9]
Boiler Power	90MW	130MW	165MW
Flue gas flow rate	300,000Nm^3/h	270,000Nm^3/h	600,000 Nm^3/hr
Inlet SO_2 / NOx	1800ppm/400ppm	525ppm/292ppm	1680ppm/780ppm
SO_2/NOx removal	80% / 10%	90% / 70%	90% / 40%
Absorbed Dose	3kGy	8-12kGy	4kGy
Inlet gas temp.	132℃	130-150℃	160℃
Outlet PM conc.	≤200mg/Nm^3	≤190mg/Nm^3	≤100mg/Nm^3
By-products	2.3ton/hr	300kg/h	5.7ton/hr
EB Accelerator	800kV/400mA×2	800kV×300mA×4	1000kV/400mA×4
Total Power	640kW/1,900 kW	1,000kW	1400kW/1800kW
Total Capital Cost	11.4 M$	21 M$	37.4M$
Unit Capital Cost	126.5$/kWe	160$/kWe	227$/kWe
Unit Operation Cost	16.5$/kWe (120$/t SO_2)	7.35$/kWe (1061$/t SO_2)	21.2$/kWe (157$/t SO_2)

Economics evaluation results of EBFGT as comparison with 3 Cases EB plant are carried out as summarized at Table 1. The total capital cost is about 37.4 million US dollars (26M Euro), which is about corresponding to 227$/kWe. The operation cost is about 21.2$/kWe(157$/ton SO_2). The unit capital cost is corresponding to unit capital cost in the EBARA final report[4], USEPA report[14] and IAEA report[15] based on a price of 2$/W for accelerator cost . The technology is competitive to conventional ones from removal efficiency and economical points of views. Even if the capital cost of EBFGT is higher than Wet FGD(Flue Gas desulfurization) at present, considering the denitration, the EBFGT process will be competitive compared with present Wet FGD and SCR process for de-NOx[4,5,7,14,15].

To have advantages over existing processes, the electron beam process should have cost-effective and reliable in operation. The most important factor in controlling the economics is the cost of the electron accelerator in use. Therefore, it should be developed high power accelerators(400kW~1MW) for environmental application and they can the decrease in the cost of construction and operation of electron beam plant. With the process applied in larger capacity power plant, such as 300MW or more, the capital cost will be decreased more. More significantly, the number of units can be reduced drastically with more high power accelerator [4]. This would reduce construction costs, thus reducing the capital costs. The basic criteria for accelerators for flue gas treatment are high beam power, high electrical efficiency and high beam utilization to increase productivity and reduce unit operational cost. As is shown in Table 2, the cost of accelerators is governed by their beam power, and the accelerator with the highest power has the lowest unit cost for power generation and is the most economical in environmental application[16]. As is shown in Table 3, The accelerator applied in this project is the main equipment and its capital cost occupied about 30% of total capital cost at Sviloza Plant[9]. According to our estimation, the accelerator capital cost can be decreased to about 21% of total capital cost. And also ESP cost can be decreased to 15% of total cost.

TABLE 2. UNIT COST FOR POWER OF ACCELERATORS [16]

Beam Power	20kW	40kW	100kW	200kW	400kW	1MW*
Total Cost (M$)	0.5	0.8	1.0	1.5	2	2.2
Unit Cost ($/W)	25	20	10	7.5	5	2.2

* Target data

TABLE 3. SUMMARY OF COST FOR EBFGT PLAN [9,11]

Item	Pomorzany (Poland)	Sviloza (Bulgaria)
Spray cooler	3%	2%
Reaction Chamber	2%	3%
Ammonia handling	3%	3%
ESP	10%	32%
EB Accelerator	25%	30%
By-Products handling	20%	3%
Civil Works & Others	37%	27%
Total	100% (21M$)	100%(37.4M$)

Further development of EB technology can significantly reduce the costs of construction and operation of the plant, especially for accelerators and ESP with the technology development. The main investment and operating costs of EBFGT are associated with the electron accelerators and ESP, the process will become more viable for large-scale treatment of industrial flue gases if accelerator costs fall.

At present, by constructing more and more industrial scale demonstration plants with good quality to enhance customer's confidence and win more development opportunity for EBFGT. This need extensive help and support of international organization and government. "Sviloza" TPS JSC, a 165MW scale industrial demonstration installation, has been planning, which will be supported by Bulgarian and Korean government.

5. Summary

The construction of a new "Industrial Electron Beam Flue Gas Purification plant", for simultaneous removal of sulphur and nitrogen oxides from the flue gases generated by the units of "Sviloza" TPS were very important solution for Bulgaria.

The industrial EB plants have proven the ability of the technology for efficient removal of SO_2 and NOx from flue gases from coal combustion processes. The Sviloza EB Plant may achieve high removal efficiency by simultaneous removal of SOx 90% and NOx 40%. The technology is competitive to conventional ones from removal efficiency and economical points of views.

The EB flue gas treatment technology is a new one and still needs development works. Further development of EB technology can significantly reduce the costs of construction and operation of the plant, especially for accelerators and ESP with the technology development.

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