OVERVIEW OF FLUE GAS TREATMENT IN BRAZIL

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Abstract

The coal mines in Brazil are primarily located in southern part areas. The total coal reserves are approximately 32.8 billions tons, 89% of which are located in Rio Grande do Sul state. The Brazilian agriculture potentiality is very high, mainly due to the availability of flat land and the existence of industrial capacity to supply the main fertilizers needs. Electron beam flue gas treatment process ensures simultaneous removal of SO_2 and NO_X from flue gases by single process, requiring no additional wastewater treatment system and can produce useful nitrogen fertilizer consisting of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate NH_4NO_3 as by-products. During the TC Project BRA/8/021 - Pilot Plant for Electron Beam Purification of Flue Gas supported by IAEA (1995-1996), a laboratory facility for electron beam flue gas treatment was set at IPEN. In 1997, an official request from Brazilian Government, Ministry of Science & Technology (MCT) and IPEN was made for the Japan Consulting Institute (JCI) to prepare feasibility studies of air pollution control by electron beam flue gas treatment in three power generation companies. These companies are responsible for the power generation, the transmission and the supply of electricity to Brazil: Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A., Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE) and Piratininga – AES Eletropaulo Thermal Power Plants.

1. INTRODUCTION

1.1. Brazilian energy sources

The population of Brazil is 187 millions as of 2006, 81.3% of which is located in urban areas. The portion of total residences receiving supply of electricity and Liquefied Petroleum Gas (LPG) or Natural Gas is 82%, while the portion of residences using firewood as fuel is 18% in the country.

The Gross National Product (GNP) of Brazil is US$ 1100 billion with 3.7% annual growth in 2006. The proven petroleum reserve and natural gas reserve is 11.8 billions of barrels and 306.4 billion of cubic meters, respectively. The daily petroleum production averaged 1 718 000 barrels in 2006. The measured coal reserve is 32.8 billion of tons. The hydraulic electrical potential already inventoried is 260.1 GW in 2005 [1].

The electric energy produced in Brazil by hydroelectric power plants represented 73%, while coal and oil-fired power generations contributed with 2% and 1%, respectively, in 2006. The Ministry of Mine and Energy estimated the same participation of these generation sources in 2016 [2].

1.2. Environmental protection projects

The Institute for Nuclear and Energy Research (IPEN) is a Government of State of Sao Paulo owned institution, associated to the University of Sao Paulo (USP) and supported and operated technical and administratively by the National Nuclear Energy Commission (CNEN), a federal agency of the Ministry of Science and Technology (MCT). In Brazil, the Federal Government has the monopoly of the mining of radioactive resources, the production and the commerce of nuclear products. This monopoly is carried out by the National Nuclear Energy Commission (CNEN).

The IPEN is recognized as a national leader institution in areas like, radiopharmaceuticals, industrial applications of radiation, research nuclear reactor operation and utilization, material science and technology, laser technology and applications and also in nuclear technology education with its post-graduation program in Nuclear Technology. The IPEN's main radioactive and nuclear facilities are two research nuclear reactors (100 W and 5 MW), two cyclotron accelerators (18 MeV and 30 MeV), radiopharmaceuticals and nuclear fuel productions, two industrial electron beam accelerators, both with energy of 1.5 MeV (37.5 kW and 97.5 kW) and one multipurpose gamma irradiator (37 PBq) for research, development and contract services.

The mission of Radiation Technology Center (CTR) at IPEN is "to apply the radiation and radioisotope technologies in the Industry, Health, Agriculture and Environment, producing scientific knowledge, forming human resources, transferring technology and generating products and services for customers". In the environmental protection field applying radiation processing at CTR, the most important achievements were the coordination of the IAEA TC Project BRA/8/025 - Electron Beam Treatment of Wastewater (1993-1997), elected a Model Project by Agency in 1995 and the IAEA TC Project BRA/8/021 – Pilot Plant for Electron Beam Purification of Flue Gas (1995-1996).

1.3. Coal power generation and coal industry

The coal mines in Brazil are primarily located in southern part areas including the States of Rio Grande do Sul, Santa Catarina, Parana and Sao Paulo. The total coal reserves in Brazil are approximately 32.8 billion tons, 89% of which are located in Rio Grande do Sul (RS) State. The total amount of the production in Rio Grande do Sul State occupies 58% of the national production, while the Company Rio Grande do Sul of Mining (CRM), the biggest coal production in Brazil based in RS State, produces 35% of the national's coal production.

At present, coal-fired thermal power generation does not have a share in total power generation, when compared on hydraulic power generation in Brazil. In the future, however, it is most likely that coal will be a major energy supply source in the coal-production regions in the south.

1.4. Demand and supply of fertilizer in Brazil

The Brazilian agriculture potential is very high, mainly due to the availability of flat land and the existence of industrial capacity to supply the main fertilizers needs. Also Brazilian agriculture can improve the productivity mainly by using more advantage technologies, by the application of more fertilizer and by the mechanization of the culture.

At present, forty three percent on the total export comes from the agro-business in Brazil. As the historical growth rate of the agro-vegetable production has been 4.1% per year, since 1970. The annual agro-vegetable production can be evaluated around 200 millions tons. Considering a consumption of 8.1% in weight of fertilizer per agro-vegetable production and the historical growth rate of 1.6% per year for NPK per cultivated hectare, the annual fertilizer consumption can be estimated in 20 million tons.

The Brazilian soil is poor in sulfur and the farmers use ammonium sulfate as nitrogen and sulfur source. The nitrogen participation in total fertilizer consumption is in average 10% and 20% of the consumed nitrogen is from ammonium sulfate. The ammonium sulfate consumption could be partially converter by the fertilizer produced from flue gas treatment by electron beam accelerator process, reducing the importation of ammonium sulfate and sulfur. There are also in Brazil two ammonia suppliers, which export the most products on the grounds.

2. ENVIRONMENTAL REGULATION ON AIR POLLUTION IN BRAZIL

The federal constitution in Brazil estipulate that the measures for environmental protection including air pollution control is concurrently conduced both by the federal government and by the governments in the level of state, city and town [3].

2.1. Environmental conservation policy

The basic pollution control and environmental conservation polices are set forth and being executed according the laws, licenses and regulations.

2.1.1. Law 6938/81

- Established the objectives and tools for the Environmental Policy Incorporated, for the first time, the concept of reconciling economic development with the preservation of the environment;
- Creation of the National Environmental System (SISNAMA), made up by the National Environmental Council (CONAMA) and by federal and state-level executive agencies. The SISNAMA includes not only the ministries and sectorial organizations of the federal administration directly responsible for the environment, but also state and municipal-level agencies, professional associations and non-governmental organizations; and
- The CONAMA is designed to advise, study and propose government policy guidelines for the environment and natural resources, as well as to consider rules and standards by the national Resolutions, compatible with environmental protection. It was commissioned to define the criteria to be adopted by Environmental Impact Assessments (EIA) for issuing those licenses, thereby ensuring public access to information on damage caused to the environment and environmental protection actions.

2.1.2. Licensing process

- Preliminary Licensing (LP) – requires the submission and approval of the plant mains characteristics and pollution control systems concept, the EIA, usually for major projects. The LP viabilities for one determined area;
- License to install the facilities (LI) – requires the projects documents of the pollution control systems, that must be consistent with the EIA and are used as basic reference for inspection during construction; and
- License to Operate (LO) – is obtained after inspections of the installed pollution control systems, operation condition and compliance with environmental regulations and effluent standards. The LO is periodically renewed, after annual inspection and compliance verification.

2.1.3. Environmental regulation on air pollution

- The CONAMA Resolutions 018/88, 004/88, 003/89 and 010/89 – establishes maximum limits for polluting emissions from engines and new motor-propelled vehicles; The CONAMA Resolution 005/89 – describes the National Air Pollution Control Program and it classifies the territory into three area classes. Actually, the primary quality standard is in vigor for the area Classes II and III:

  Class I – areas to be preserved, such as, National Parks and Reserves, where the air quality is to be kept as natural as possible;

  Class II – areas where the level of deterioration is limited by the secondary air quality standard (minimum impact on welfare of the population and on the environment); and

  Class III – development areas, where the level of deterioration is limited by the primary air quality standard and can to affect the health of the population.

- The CONAMA Resolution 003/90 of 28/06/1990 – establishes the primary and secondary standards to be accomplished according to the area classification, for the pollutants, smoke, total suspended particulates (TSP), inhaler suspense particulates (ISP), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3) and nitrogen dioxide (NO_2) and criteria for acute air pollution episodes. The Environmental and Emission Standards and the Criteria for Acute Air Pollution Episodes at CONAMA Resolution 003/90 are illustrated in Tables I and II; and
- The CONAMA Resolution 008/90 of 06/12/1990 – establishes the emission standards to external combustion industrial equipment for opacity, TSP and SO_2. The Emission Standards at CONAMA Resolution 008/90 are illustrated in Table III. There is not NO_X and volatile organic compounds (VOC) emission limits from Stationary Sources in Brazil.

TABLE I. THE ENVIRONMENTAL AND EMISSION STANDARDS - CONAMA RESOLUTION 003/90 OF 06/28/1990.

Pollutant	**Primary Standards (µg/m^3)**		**Secondary Standards (µg/m^3)**	
Averaging Time	24 hours	1 year	24 hours	1 year
Smoke	150	60	100	40
Total Suspended Particulates (TSP)	240	80	150	60
Inhaler Suspense Particulates (ISP)	150	50	same as primary standards	
SO_2	365	80	100	40
CO	40 000*	10 000**	same as primary standards	
Ozone	160*	-	same as primary standards	
NO_2	320*	100	190*	100

Notes: * 1 hour; and
** 8 hours average.

TABLE II. THE CRITERIA FOR ACUTE AIR POLLUTION EPISODES - CONAMA RESOLUTION 003 OF 06/28/1990.

Parameter	**Levels**		
	Caution	**Alert**	**Emergency**
Sulfur Dioxide (µg/m^3)	800	1600	2100
Total Suspended Particle (TSP) (µg/m^3) - 24h	375	625	875
SO_2 x TPS	65 000	261 000	393 000
Carbon Monoxide (ppm) - 8 h	15	30	40
Ozone (µg/m^3) - 1 h	400	800	1,000
Inhalable Particles (µg/m^3) - 24 h	250	420	500
Smoke (µg/m^3)	250	420	500
Nitrogen Dioxide (µg/m^3) - 1 h	1130	2260	3000

TABLE III. EMISSION STANDARDS ON CONAMA RESOLUTION 008/90 OF 06/12/1990.

Fuel	**Output / Area Classification**	**Emission Limit ($g/10^8$ kcal)**	
COAL	< 70MW – Class I	Special Allowance	
	> 70 MW – Class I	Not Allowance	
	< 70 MW Classes I & II	TSP[*]	1500
		SO_2	5000
	> 70 MW Classes I & II	TSP	800
		SO_2	2000
OIL	> 70 MW – Class I	Not Allowance	
	< 70 MW Class I[**]	TSP	120
		SO_2	2000
	< 70 MW Classes II & III	TSP	350
		SO_2	5000
	> 70 MW Classes II & III	TSP	120
		SO_2	2000

Notes: [*] TSP - Total Suspended Particulates and

[**] Biggest annual consumption = 3000 ton. The emission limit for opacity is 20%, equivalent to Ringelmann #1.

3. LABORATORY FACILITY FOR ELECTRON BEAM FLUE GAS TREATMENT

During the TC Project BRA/8/021 – Pilot Plant for Electron Beam Purification of Flue Gas supported by IAEA (1995-1996), a laboratory facility for electron beam flue gas treatment was set in the Radiation Technology Center at IPEN [4]. This facility was assembling together the Electron Beam Accelerator (EBA), model JOB-188, energy of 1.5 MeV, 37.5 kW, made by Radiation Dynamics, Inc. (RDI), which is presented in Figure 1.

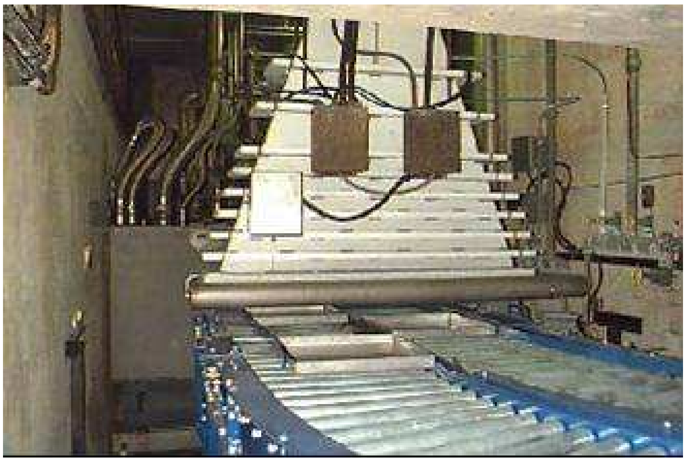

FIG. 1. Electron Beam Accelerator, RDI model JOB-188, 1.5 MeV and 37.5 kW at IPEN.

The maximum flow rate treated at IPEN's laboratory plant, applying the EBA was 1 Nm^3/h. Connected to the main line of this facility there were installed tubes to conduce steam and pure gases from the bottles (SO_2, NH_3, NO_2 and CO_2), thermocouples, flow meters, irradiation chamber with titanium foil window (40 µm), electrostatic precipitator, monitoring points and gas analyzer equipment for SO_2, NO and NH_3 measurements. All the line, tubes and irradiator chamber were assembled on stainless steel, with thermal isolation. The dosimetric studies of the flue gas treatment process were made by CTA film and N_2O. Figure 2 presents the Gas Analyzer equipment, model Radas 2 associated with a Gas Sampling Unit, model CFP-306 made by Hartman Braun and Shimadzu, respectively. The measured component are NO (0-100/1000 ppm) and SO_2 (0-300/3000 ppm).

The IPEN's laboratory facility of electron beam flue gas treatment demonstrated and also suggested that this technology was economic and a competitive alternative to combined wet flue gas desulphurization and selective catalytic reduction for coal fired power stations [5, 6].

FIG. 2. Gas Analyzer equipment, model Radas 2 associated with a Gas Sampling Unit, model CFP-306 made by Hartman Braun and Shimadzu, respectively, installed in the laboratory facility for electron beam flue gas treatment at IPEN.

4. FEASIBILITY STUDIES OF AIR POLLUTION CONTROL BY ELECTRON BEAM FLUE GAS TREATMENT PROCESS IN BRAZIL

4.1. Japan Consulting Institute support

Environmental problems have recently become a major issue for governments worldwide. Air pollution control, in particular, is on of the important areas that a great deal of their attentions has to be paid on governmental basis. With regard to power generation an expansion plan compatible with sound environment has to be developing, since a thermal power plant could be fixed source of a considerable amount of air pollutants.

Under this situation an official request from Brazilian Government, Ministry of Science & Technology (MCT) and Institute for Nuclear and Energy Research (IPEN) was made for the Japan Consulting Institute (JCI) to prepare feasibility studies of air pollution control by electron beam flue gas treatment in three power generation companies in 1997. These companies are responsible for the power generation, the transmission and the supply of electricity to Brazil: Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A., Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE) and Piratininga – AES Eletropaulo Thermal Power Plants (TPPs) in Brazil. These studies carried out by JCI, MCT and IPEN were to assess the feasibility of installing the Electron Beam

Accelerator (EBA) system to control sulfur oxides, nitrogen oxide and suspended particulates matters emission in those TPPs.

The EBA process is considered to be the process which is most suitable for the installation in the TPP under the present studies based on the following:

- Simultaneous removal of both SO_2 and NO_X by single process;
- Dry process requiring no additional wastewater treatment system;
- Simple system with less space required and easy operation; and
- Both SO_2 and NO_X pollutants are recovered as valuable nitrogen fertilizer which contains a certain portion of sulfur, which are imported in Brazil as intermediate raw material for production of ammonium sulfate, since no domestic sulfur resources are available.

The EBA system can transform SO_X (SO_2 and SO_3) and NO_X (NO_2 + NO) into a useful nitrogen fertilizer consisting of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate NH_4NO_3. The collected fertilizer can be used to cultivate such crops as vegetables, corn and wheat. Especially, the southern region of Brazil harboring the thermal power station in its center is one of the nation's major grain crop growing belts requiring large amounts of fertilizers.

4.2. Economical evaluation of the EBA system

The economic evaluations of the EBA systems proposed for the Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A., Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE) and Piratininga – AES Eletropaulo Thermal Power Plants (TPPs) in Brazil were carried out under the considerations:

- Variable cost - by-product income and utility cost (electrical power, process water, steam and ammonia);
- Fixed cost - depreciation, interest, maintenance and employee;
- Annual operation cost; and
- Annual electricity.

4.3. Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A.

The Jorge Lacerda Thermal Power Plant is located near Tubarao City, in Santa Catarina (SC) State of the south area of Brazil. This power plant presented in Figure 3 is a coal fired thermal power plant, and is managed by Eletrosul Centrais Eletricas do Sul do Brasil S.A. The ELETROSUL Company income was US$ 104.8 million in 2006. Jorge Lacerda is the biggest coal fired thermal power plant in South America.

This thermal power plant consists of seven units and the total capacity and amount of fuel used are 832 MW and 463.3 tons/h (2 395 377 tons/year), respectively. The UPLA A I (2x50 MW) and UPLA A II (2x66 MW) units were built in 1965 and 1973. The UPLB B III (2x125 MW) and UPLC C IV (350 MW) units were built in 1980 and 1997, respectively.

Coal used as fuel in this power plant is available in Santa Catarina State and transported to the storage yard by train. The sulfur content of this coal is 1.8 - 2.3 wt% and ash content is 39 - 44 wt%. The boiler flue gas is discharged through dry type electrostatic precipitator (ESP), in which about 98% of fly ash is collected. The collected fly ash in the ESP is transported to the storage silo by pneumatic conveyors and sold to the cement factories near the power plant. The bottom ash of boilers is transported by hydraulic conveyor to the ash pond, and the water used for this conveyor system is recycled.

In Brazil, hydroelectric power plants are in base load operation and thermal power plants are supplementary used. Thus the annual operation load of thermal plant is relatively low (50% – 60%). However, hydroelectric power plants reach to the limitation of construction and the demand for thermal power plants is increasing.

FIG. 3. Jorge Lacerda - ELETROSUL Thermal Power Plant (823MW).

4.3.1. Technical description of the proposed flue gas treatment system

Table IV shows the expected reduction of air pollutants at Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A. in 1997 [7]. The technical descriptions of the proposed flue gas treatment system were:

- Installation: one boiler of 125 MW (UPLB B III n^o 6);
- Gas flow rate: 480 000 Nm^3/h;
- Temperature inlet and outlet: 180^{o}C and 90^{o}C, respectively;
- Source of flue gas: coal firing boiler flue gas (sulfur content, dry base: 1.99%);
- Coal consumption: 74.7 ton/h;
- Calorific value: 4500 kcal/kg;
- Electron Beam Accelerators: 4 equipments, scanning type, 800 kV and 500mA;
- Power supplies: 2 equipments, D.C. high voltage (800 kV x 1,000 mA);
- By-product colleting equipment: dry type electrostatic precipitator;
- Efficiency removals of SO_X and NO_X: 80% and 25%, respectively;
- Operating and maintenance requirement: 13 persons;
- Total cost: US$ 37 000 000
- Finance: Long term soft bank loan of US$ 22 200 000;
- Coverage: 60% of the total project cost;
- Repayment period: 25 years, 1.8% per year; and
- Increase of electricity cost: 0.00109/kWh (3.6%).

The current electric charge by Jorge Lacerda – Eletrosul Centrais Eletricas do Sul do Brasil S.A. Thermal Power Plant of US$ 0.03/kWh will be increased to US$ 0.03109/kWh, by installation of the EBA System for 125 MW and its ratio is equivalent to 3.6% rise.

TABLE IV. EXPECTED REDUCTION OF AIR POLLUTANTS AT JORGE LACERDA - ELETROSUL CENTRAIS ELETRICAS DO SUL DO BRASIL S.A. LOCATES AT TUBARAO CITY, SANTA CATARINA STATE.

Parameters	Air Pollutants	EBA System Base (80% De-SO_X, 25% De-NO_X)
Inlet	Gas Flow Rate*	480 000 Nm^3/h (125 MW)
	SO_2	1.739 ppmv
	NO_X	446 ppmv
	Dust	1100 mg/Nm^3
	H_2O	7.3%v
Outlet	SO_2	347 ppmv
	NO_X	334 ppmv
	Dust	50 mg/Nm^3
Reduction	SO_2	1,769 kg/h
	NO_X	103 kg/h
	Dust	467 kg/h

Note: * Wet base.

4.4. Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE)

The Presidente Medici Thermal Power Plant is located in Candiota City, in Rio Grande do Sul (RS) State of the south area of Brazil. This power plant presented in Figure 4 is a coal fired thermal power plant, and is manager by Companhia Estadual de Energia Eletrica. The CEEE Company income was US$ 96.3 million in 2006.

This thermal power plant consists of two units - Phase A (2x63 MW) and Phase B (2x160 MW) and the total capacity and amount of fuel used are 446 MW and 185.6 tons/h (1,307,789 tons/year), respectively. The Phase C (1x350 MW) will be concluded in 2009, when the new total capacity will be 796 MW.

Coal used as fuel in this power plant is available on the Candiota deposit, near the installation in Rio Grande do Sul State. The sulfur content of this coal is 1.61 wt% and ash content is 55 wt%, with causes ash handling trouble. The boiler flue gas is discharged through dry type electrostatic precipitator (ESP), in which about 98% of fly ash is collected. The collected fly ash in the ESP is transported to the storage silo by pneumatic conveyors and sold to the cement factories near the power plant. The bottom ash of boilers is transported by hydraulic conveyor to the ash pond, and the water used for this conveyor system is recycled.

In Brazil, hydroelectric power plants are in base load operation and thermal power plants are supplementary used. Thus the annual average operation load of thermal plant is relatively low (40%). However, hydroelectric power plants reach to the limitation of construction and the demand for thermal power plants is increasing. The load factor of the Presidente Medici Thermal Power Plant is 35%-40% and 60%-70%, Phases A and B, respectively.

FIG. 4. Presidente Medici - CEEE Thermal Power Plant (446 MW).

4.4.1. Technical description of the proposed flue gas treatment system

Table V shows the expected reduction of air pollutants at Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE) Thermal Power Plant in 1997 [8]. The technical descriptions of the proposed flue gas treatment system were:

- Installation: one boiler of 160 MW (Phase B);
- Gas flow rate: 884 380 Nm^3/h;
- Temperature inlet and outlet: 180°C and 90°C, respectively;
- Source of flue gas: coal firing boiler flue gas (sulfur content, dry base: 1.61%);
- Coal consumption: 185.6 ton/h;
- Calorific value: 3078 kcal/kg;
- Electron Beam Accelerators: 7 equipments, scanning type, 800 kV and 500mA;
- Power supplies: 4 equipments, D.C. high voltage (3 units 800 kV x 1,000 mA, 1 unit 800 kV x 500 mA);
- By-product colleting equipment: dry type electrostatic precipitator;
- Efficiency removals of SO_X and NO_X: 80% and 50%, respectively;
- Operating and maintenance requirement: 13 persons;
- Total cost: US$ 47 700 000
- Finance: Long term soft bank loan of US$ 28 620 000;
- Coverage: 60% of the total project cost;
- Repayment period: 25 years, 1.8% per year; and
- Increase of electricity cost: 0.00055 kWh (1.7%).

The current electric charge by Presidente Medici – Companhia Estadual de Energia Eletrica (CEEE) Thermal Power Plant of US$ 0.032/kWh will be increased to US$ 0.03255/kWh, by installation of the EBA System for 160 MW and its ratio is equivalent to 1.7% rise.

TABLE V. EXPECTED REDUCTION OF AIR POLLUTANTS AT PRESIDENTE MEDICI – COMPANHIA ESTADUAL DE ENERGIA ELETRICA (CEEE) THERMAL POWER PLANT LOCATES AT CANDIOTA CITY, RIO GRANDE DO SUL STATE.

Parameters	**Air Pollutants**	**EBA System Base (80% De-SO_X, 50% De-NO_X)**
Inlet	Gas Flow Rate*	884 380 Nm^3/h (160 MW)
	SO_2	1680 ppmv
	NO_X	260 ppmv
	Dust	3000 mg/Nm^3
	H_2O	9.4%v
Outlet	SO_2	336 ppmv
	NO_X	130 ppmv
	Dust	50 mg/Nm^3
Reduction	SO_2	3 076 kg/h
	NO_X	214 kg/h
	Dust	2 364 kg/h

Note: * Wet base.

4.5. Piratininga – AES Eletropaulo

This feasibility study concerned the development and application of a SO_2 and NO_X simultaneous gas treatment was carried out through a 135 MW electron beam flue gas treatment demonstration plant at Piratininga-AES Eletropaulo Thermal Power Plant locate at Sao Paulo, the biggest city in Brazil, around 16 million inhabitants in 1997. This power plant belongs to a service electric utility necessary for the supply of energy to more than 5800.00 customers, covering an area of 21.168 km^2 where approximately 20.2 million people live. This plant was a 470 MW, 2x100 MW built in 1954 and 2x135 MW erected in 1960, oil fueled (at full load, 2800 tons/day). The oil was low sulfur content, less then 1%, but the feasibility study had considered the mode of operation and another cheaper fuel supply, with sulfur content till 3.0%. It was estimated to use a flue gas rate of 370 000 Nm^3/h for 135 MW generated by the plant.

The Electron Beam Accelerator (EBA) process had aimed to reduce SO_2 and NO_X gas pollutant emissions attending the Brazilian environmental laws including the expected law for NO_X levels. The process consisted in electron beam irradiation (above 0.8 MeV) of burning gas from the plant at ammonia presence forming as reaction product ammonium sulfate and nitrate that were collected as dry dust at an electrostatic precipitator. This was economically useful to the plant and to Brazil, a mainly agricultural country. Figure 5 presents Piratininga-AES Eletropaulo Thermal Power Plant locates at Sao Paulo City. The AES Eletropaulo Company income was US$ 186.7 millions in 2006.

FIG. 5. Piratininga - AES Eletropaulo Thermal Power Plant (470MW).

4.5.1. Technical description of the proposed flue gas treatment system

Table VI shows the expected reduction of air pollutants at Piratininga-AES Eletropaulo Thermal Power Plant in 1997 [9, 10]. The technical descriptions of the proposed flue gas treatment system were:

- Installation: one boiler of 135 MW (n^o 3 or 4);
- Gas flow rate: 370 000 Nm^3/h;
- Temperature inlet and outlet: 150^{o}C and 90^{o}C, respectively;
- Source of flue gas: heavy oil firing boiler flue gas (sulfur content: 3%);
- Oil consumption: 0.25 ton/h;
- Calorific value: 10 000 kcal/kg;
- Electron Beam Accelerators: 3 equipments, scanning type, 800 kV and 500mA;
- Power supplies: 2 equipments, D.C. high voltage (800 kV x 1000 mA, 800 kV x 500 mA);
- By-product colleting equipment: dry type electrostatic precipitator;
- Efficiency removals of SO_X and NO_X: 80% and 65%, respectively;
- Operating and maintenance requirement: 13 persons;
- Total cost: US$ 30 800 000;
- Finance: Long term soft bank loan of US$ 18 480 000;
- Coverage: 60% of the total project cost;
- Repayment period: 25 years, 1.8% per year; and
- Increase of electricity cost: 0.00102/kWh (2.4%).

The current electric charge by Piratininga-AES Eletropaulo Thermal Power Plant of US$ 0.042/kWh will be increased to US$ 0.04302/kWh, by installation of the EBA System for 135 MW and its ratio is equivalent to 2.4% rise.

TABLE VI. EXPECTED REDUCTION OF AIR POLLUTANTS AT PIRATININGA-AES ELETROPAULO THERMAL POWER PLANT LOCATES AT SAO PAULO CITY.

Parameters	Air Pollutants	EBA System Base (80% De-SO_X, 65% De-NO_X)
Inlet	Gas Flow Rate*	370 000 Nm^3/h (135 MW)
	SO_2	2040 ppmv
	NO_X	160 ppmv
	Dust	400 mg/Nm^3
	H_2O	10%v
Outlet	SO_2	408 ppmv
	NO_X	56 ppmv
	Dust	50 mg/Nm^3
Reduction	SO_2	1553 kg/h
	NO_X	71 kg/h
	Dust	117 kg/h

Note: * Wet base.

Air pollutants conversion study of combustion gas generating by oil fueled thermoelectric power plant to fertilizer by-product was presented to obtain a Master of Science, as well as, the socioeconomic and environmental consequences of the substitution of fuel oil for natural gas at the Piratininga-AES Eletropaulo Thermal Power Plant were also carried out on a Doctorate in Nuclear Technology – Applications at IPEN, in 2001 and 2005 respectively [11, 12].

5. CONCLUSIONS

Electron beam flue gas treatment process ensures simultaneous removal of SO_2 and NO_X from flue gases by single process. It is a dry process requiring no additional wastewater treatment system, most suitable for the installation in the thermal power plants under the present studies. The EBA process can transform SO_X (SO_2 and SO_3) and NO_X (NO_2 + NO) into a useful nitrogen fertilizer consisting of ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate NH_4NO_3. The valuable collected fertilizer can be used to cultivate such crops as vegetables, corn and wheat in Brazil.

The future of the electron beam application for flue gas treatment depends on technical developments to make the radiation technology very competitive for environmental applications. Due to this fact it is necessary:

- To establish new applications for EBA process in petrochemical complexes, incinerators and mines;
- To carry out R&D works in EBA systems and power supplies (capacity) supported by IAEA, including interregional projects;
- To promote fertilizer marketing for the valuable collected fertilizer (by-products); and
- To reach reliability, decreasing the power consumption and capital cost, optimizing the engineering technology and equipment to improve installation's stability.

The overview of flue gas treatment in Brazil demonstrates the importance of reestablishing the partnership and works with the Thermal Power Plants in the South of Brazil, after the privatization process: Presidente Medici - CEEE (446 MW) and Jorge Lacerda - ELETROSUL (823MW).
The profitable experience from Japan and Poland in EBA process and IAEA collaborations will be very important.

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