# ELECTRON BEAM REMOVAL OF $SO_2$ AND $NO_x$ FROM COMBUSTION FLUE GASES IN BRAZIL - NATIONAL AND INTERNATIONAL COOPERATION


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## RESUMO

O estudo da viabilidade técnica e econômica do processo de tratamento de gases tóxicos $SO_2$ e $NO_x$, provenientes de combustão de óleo ou carvão, foi iniciado no IPEN-CNEN/SP, em colaboração com a CETESB, com suporte da Agência Internacional de Energia Atômica - AIEA e do Conselho Nacional de Pesquisa e Desenvolvimento - CNPq,o que permitiu a construção de uma planta piloto de laboratório. No desenvolvimento do projeto, receberam-se visitas de especialistas neste processo e realizaram-se visitas técnicas a laboratórios e plantas pilotos em diferentes países, com discuções técnicas e troca de experiências. Além disso, teve-se a oportunidade de se discutir problemas ambientais com pesquisadores de alguns países da América Latina, onde existem problemas de poluição atmosferica similares aos existentes no Brazil.

## ABSTRACT

A feasibility study of the electron beam dry scrubbing process for removal $SO_2$ and $NO_x$ from combustion flue gases was initiated in Brazil in colaboration with CETESB under International Atomic Energy Agency - IAEA support, from now on Conselho Nacional de Pesquisa e Desenvolvimento - CNPq and what has lead to the construction of a laboratory pilot plant. During this time we had visits of experts in this process and also we make technical visits to some laboratories and pilot plants in different countries, where we had the opportunity to discuss techniques and exchange experiences. Additional we also had the opporunity to discuss about environmental problems with researches of some Latin-American countries where they have similar air pollution problems as we have in Brazil.


## 1. INTRODUCTION

Sulfur oxides are created and exhausted into the air when fossil fuels that contain sulfur (coal, oil and natural gas) are burned. Nitrogen oxides are formed when the nitrogen and oxygen are burned with fossil fuels at high temperature. Latter acids are being formed in the atmosphere and fall to earth as acid rain or snow. In results lakes and forests are being damaged in certain part of Central Europe, China, Northeastern United States and Eastern Canada. Some acid can be transported far away from industrialized zones and cross international borders to ruin environment in less urban areas. Trees, crops, and plants may be hurt. Acid rain affect building and monuments what can be seen in many cities in Europe. That are the reasons why strict control of $SO_2$ and $NO_X$ emissions is became internationally recognized as a global problem and many countries have set limits for the discharge of pollutants and $SO_2$ and $NO_X$ are listed among them ( 5 ).

In the past years, the use of fossil fuels with high sulfur content in Brazilian industrial installations has grown. In addition, estimates indicate such growing will be continuous. Due to environmental regulations enacted, the development of a technique able to remove toxic gases has become essential.


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Among the flue gas treatment methods, the process of electron beam irradiation has shown to be promissing. Under irradiation, those gases are simultaneously removed from the combustion gases. In the presence of ammonia, the by-product of the process is ammonium sulfate and ammonium nitrate that after filtration can be used as fertilizers. This process has been investigated in Japan( 3 ), Germany( 8 ), USA( 4 ) and Poland ( 2 ).

## 2. PRINCIPLE OF THE ELECTRON BEAM PROCESS

Research on flue gas treatment by radiation was initiated by Ebara Corp. in 1970. Fundamental work and pilot scale experiments have been performed in Japan, USA, Germany, Poland and other countries since then. It was founded in a basic and experimental way that EB technology for flue gas treatment has following advantages: Simultaneous removal of $SO_2$ and $NO_x$; dry process without wastewater; by product can be used as fertilize; no need for catalyst and low capital and operating costs compared with conventional methods (4 ).

The process is based on three stages. In the first one flue gas is irradiated which leads to the radical formation like OH, O, $HO_2$. In the second stage $SO_2$ and $NO_x$ are being oxidized to $H_2SO_4$ and $HNO_3$ in presence of water through a number concurrent of chemical reactions. In third stage the intermediate product react with ammonia presence to form ammonium sulfate and ammonium nitrate. Ammonia in near stoichiometric quantity is injected into the vessel prior to flue gas entry into the process vessel. This dry powdery ammonium salts are collected by filtering units (ESP or bag filters) and can be used as agricultural fertilizers ( 4 ).

The process can be used for treatment of the gases from coal and oil fixed power stations, industrial boilers, furnaces and municipal solid waste incinerators. Also retrofitting of existing facilities to reduce $SO_2$ and $NO_x$ concentrations is possible regarding to low space requirement and location between ESP and stack where move space is available.

### 2.1 - PROCESS MECHANISM

When high energy electrons are applied for flue gas irradiation, quantities of radicals and free atoms are generated. The interaction of these electrons and flue gas molecules results in ionizing and dissociation. The fraction of energy absorbed by each gas component is proportional to its partial pressure. The most principal reaction in primary processes can be schematically represented by ( 4 ):

$N_2$ ---> $N_2$+ (2.27); e- (2.68); N+ (0.69); N (3.05); $N_2$* (0.29)

$O_2$ ---> $O_2$+ (2.07); e- (3.30); $O^+$ (1.23); O (1.41); $O_2^*$ (1.90)

$H_2O$ --> $H_2O$+ (2.56); e- (3.23); H (4.07); OH (4.17); O (0.45)

$CO_2$ --> $CO_2$+ (2.24); e- (2.96); CO+ (0.51); O+ (0.21); O (0.38)

Where number in parentheses represent the G values of the species. The G is the number of molecules produced per 100eV of energy absorbed in the system. This is the first stage of the process. In second stage the radicals and atoms containing the oxygen react with $SO_2$ and $NO_x$ to form (with the presence of water) sulfuric and nitric acids. There are the ion-molecules reactions mechanism for the decay of the primary species. Low concentration components have to compete with the primary radical decay processes. Above 760 reactions were listed in Agate Code to describe undergo processes. Some of secondary stage reaction where $SO_2$ and $NO_x$ are involved are listed bellow ( 4 ):

$$SO_2 + HO_2 \text{ ---------> } SO_3 + OH$$

$$SO_2 + OH \text{ ---------> } HSO_3$$

$$SO_2 + O \text{ ---------> } SO_3$$

$$SO_3 + H_2O \text{ ---------> } H_2SO_4$$

$$NO + OH \text{ ---------> } HNO_2$$

$$NO_2 + O_3 \text{ ---------> } NHO_3 + O_2$$

$$NO_2 + HO_2 \text{ ---------> } HNO_2 + O_2$$

$$NO_2 + OH \text{ ---------> } HNO_3$$

Most then 20% of NO is converted into free $N_2$ and are being released in the EB process with ammonia presence according to tests at JAERI and KFK. The last stage is the product formation. Finally the gas conversion process is initiated by the reaction of sulfuric and nitric acids in the presence of the water and stoichiometric amount of ammonia. This acids are converted into ammonium sulfate and ammonium nitrate to be collected by filtering system ( 4 ).

The efficiency of the EB process was analyzed in many experimental facilities to optimize process conditions. Last data shows that 95% of $SO_2$ removal efficiency can be obtained at dose rate 5kGy when water content and thermal reaction condition are optimized properly. Multistage irradiation can improve significantly $NO_x$ removal. The dose rate of 7kGy for two stage and 6kGy for three stage irradiation is required for the removal efficiency 80% ( 5 ).

## 2.2. ELECTRON BEAM FACILITY FOR FLUE GAS TREATMENT

The first experimental facility for EB process applied to flue gas treatment was build by Ebara Corp. in Japan. The batch tests where carried on in 1970-71 period. The experiments proved that $SO_2$ and $NO_x$ can be removed from irradiated flue gas in results of radiation chemical reactions. Subsequent development of the process has been continued by Ebara, JAERI, University of Tokyo, NKK in Japan Ebara, Research Cottvel, Department of Energy, Electric Power Research Institute, University of Karlsuhe, KFK, Badenwerk in Germany, Institute of Nuclear Chemistry and Technology, Warsaw Power Station in Poland ( 5 ).

EB process is being used now to remove the other kind of gas pollutants. The results obtained from experimental works which have been already proved the capability of the do process gas, traffic tunnel ventilation gas and various VOC pollutants in gas phase ( 3 ).

In order to demonstrate capability of the EB process four pilot plant demonstration facility are being used in Poland and Japan now. They are based on Ebara process where ammonia is injected before process vessel where flue gas is irradiated. The table 1 shows the parameters of the pilot plants for the flue gas treatment which have been installed since 1991 and are being used now to demonstrate ca pability of the EB technology for commercial use ( 5 ).

TABLE 1.The major parameters of the pilot/demonstration plants for the flue gas treatment which have been installed since 1991.

| INSTITUTION | YEAR OF INSTAL. | VOLUME FLOW RATE ($NM^3/h$) | $SO_2/NO_x$ (ppm) | TEMP ($^oC$) | ACCELER. |
|---|---|---|---|---|---|
| INCT/KAWENCZYN POLAND | 1991 | 20.000 | 200/600 250 | 60 to 80 | 500 - 700 KeV 2 X 50 kW |
| EBARA / JAERI JAPAN | 1992 | 12.000 | 800 to 1000 or 150/300 | 65 | 800 KeV 3 x 36 kW |
| EBARA / TOKYO JAPAN | 1992 | 50.000 | ---- 0 - 5 | 20 | 500 KeV 2 x 12.5KW |
| NKK / JAERI MATSUDO-JAPAN | 1992 | 1000 | 100 100 HCl = 1000 | 150 | 400 - 350 KeV 15 kW |

In 1991, a 3 year, 14.3 million USD project was initiated in Japan by Ebara Corp. with Japan Atomic Energy Research Institute (JAERI, Takasaki) and the Chubu Eletric Power Company (Nagoya). The irradiation test were started in November 1992. The main objectives of the research carried out at this pilot plant are as follow: To recognize the quantities characteristics of the process; to test multistage irradiation; to optimize collecting (ESP/bag house) and by product handling systems; study and evaluation commercial characteristic of the process; to evaluate the reliability of the process for long duration operation and to improve necessary areas of the facility .

To confirm capability of the EB method in low $NO_x$ content gas, a Tokyo plant was build by Ebara Corp. and

Tokyo Metropolitan Government to treat ventilation exhaust gases from a highway Tokyo Bay Tunnel. The facility was finished in June 1992. The main parameters of the pilot plant are shows in Table 1.. 50.000$Nm^3$/h of the gas from ventilation exhaust is introducing into irradiation vessel for EB treatment with the ammonia presence. In results $NO_X$ is converted into powdery ammonia nitrate products. The activated carbon is used to remove ozone formed by irradiation. Target removal efficiency 80% is being obtained at 3ppm level of $NO_X$ in inlet parts.

To evaluate the EB process applied to flue gas from municipal waste incinerators a pilot plant was build by NKK, JAERI and Matsudo City Government Clean Center. The plant was completed in June 1992. The main parameters of the plant are shown in Table 1. The irradiation is being done where slurry of calcium hydroxide is sprayed at the temperature higher than 150$^oC$. The bag filter is used to collect powdery product (mixture of calcium nitrate, sulfate and chloride) formed by irradiation. During the process HCl and $SO_2$ are removed by spraying slurry of $Ca(OH)_2$ and $NO_X$ is effectively removed by EB irradiation (6 ).

The Polish Pilot Plant, of capacity 20000$Nm^3$/h, has been build at EPS Kavweczyr in Warsaw. The installation was constructed on the by pass at the main stream of the flue gas with total flow net 260000$Nm^3$/h from the WP-120 boiler (nominal heat output 120Gcal/h, efficiency 84%, coal consumption 26-32 t/h). The black coal is used with content 1.2% of sulfur, 18% of ash content and with calorific value 4700 Kcal/kg.

The Polish Pilot Plant is the first installation in which two stage irradiation by electron beam was applied resulting in a significant decrease of energy consumption. The other novelties of this construction are connected with process vessel where irradiation zones are located along the flue gas system flow and double window construction was applied with perpendicular streams of air for cooling the output windows at the accelerators and inlet windows of the process vessel.

The main objectives of research carried out at the pilot plant are: Testing all parts of the installation under industrial conditions; optimizing of the process parameters leading to reduction of energy consumption with high efficiency of $SO_2$ and $NO_X$ removal; selecting and testing filter devices and filtration process; developing of the monitoring and control systems at industrial plant for flue gas cleaning; preparation of the design for industrial scale facility ( 2 ).

## 2.3. PRESENT STATUS OF EB PROCESS

EB process apply to flue gases treatment is suitable for full scale commercial application. It was determined by basic experiments and operation of pilot plant facilities. This is a dry process with usable by-product which can offset the operating and investment costs. EB technology was recognized as flexible and adaptable with excellent turndown ratios. The process can be easy control for different removal efficiency and adjust for the utilization of different fuels. Major conclusion regarding EB process for flue gas treatment are as follow:

- More than 95% of $SO_2$ and 85% of $NO_x$ can be simultaneously removed from the flue gas under optimal operating conditions;

- Ammonia should be injected into the process in near stoichiometry amount, upstream injection was found more efficient;

- $SO_2$ removal efficiency depends on temperature injection, filter condition and EB dose rate;

- The quantity of $SO_2$ removed by EB is relatively independent of the inlet $SO_2$ concentration;

- $NO_x$ removal occurs almost entirely under EB application and depends strongly on dose rate, gas temperature and ammonia stoichiometry are the second order effect;

- $NO_x$ removal efficiency is increased as inlet $SO_2$ concentration increases. This occurs as a result of the formation of nitrosulfuric compounds;

- 5kGy is required for 95% of $SO_2$ removal efficiency and 7kGy is required for 80% of $NO_x$ removal efficiency in two stage irradiation facility in optimal conditions;

- Good reliability of the long time operation was demonstrated in pilot plant facilities;

- By-product collected during the process consist of ammonium sulfate and ammonium nitrate can be effectively used as fertilizer. The small amounts contaminants does not effect the quality of the product;

- No waste water in the process are being produced;

- Relatively low capital investment and operating Cost of EB process facility can rate this method as equivalent or preferable to compare with FED/SCR ones;

- Low space requirements what makes significant advantage in retrofit installations;

To complete present data of the EB process intense experiments are being done in Japan, Poland and Germany. The number of the most interesting subject one listed bellow:

- Experimental study of quantitative characteristics of the process at the pilot plant level;
- Design study and evaluation commercial characteristics of the process;
- Experimental study to apply this method for other kind of gases treated by radiation;
- Wet and dry ESP, baghouse, gravel bag filter experimental study to optimize by-product collecting system;
- Optimization of the spray cooler construction to obtain dry bottom and reduction of power consumption;
- Optimization of the systems preventing or removing duct clogging by-product;
- Duct configuration (rectangular, cylindrical) and gas velocity in duct and process vessel are investigated;
- Multistage irradiation (two and three zones);
- Ammonia slip and ammonia injecting (location, quantity);
- By-product handling studies (granulation, liquid, storage, fertilizer tests).

Electron Beam process for flue gas treatment could be used beneficially in the future. Experimental studies describe above perfecting the technology and promote it for future application.

## 3. EQUIPMENT'S SPECIFICATION

BOILER - Oil or coal fired to produce thermal or electric energy.

ESP - Electrostatic precipitator to reduce the fly ash content downstream to the boiler.

HEAT EXCHANGER - To reduce inlet or increase outlet gas temperature by additional stream of air or water.

SPRAY COOLER - Vertically install down to boiler and ESP is used to increase water content in flue gas and describe its temperature by complete evaporation injected water.

AMMONIA INJECTION - To keep stoichometric quantity of $NH_3$ in flue gas stream.

PROCESS VESSEL - Horizontally mounted with multistage irradiation capability.

ACCELERATOR - To initiate radiation chemical process of flue gas treatment.

ANALYTICAL AND CONTROL SYSTEM - to keep automatic control over the process.

COLLECTOR - as baghouse/ ESP/gravel bed filter to collect by-product.

BY-PRODUCT HANDLING SYSTEM - To prepare powder, granules or wet sort of by-product.

INDUCED DRAFT FAN - To overcome pressure drop in ducts and by-product collector.

### 3.1. GENERAL ARRAIGNMENT OF THE TECHNOLOGICAL PROCESS

Flue gas generated by the coal heated boilers enters EB process after ESP where ash content is reduced in order to improve the quality of the fertilizer by product. No such filter is foreseen after oil-fired boiler. The initial concentration of $SO_2$ depends on sulfur content of the applied fuel. $NO_x$ concentration depends on the combustion process temperature and is different for different burner and boiler construction.

Heat exchanger is usually used to reduce the gas temperature in initial cooling stage up to 150-250$^{o}$C level. Then flue gas enters the spray cooler where the temperature is reduce to 65-80$^{o}$C by atomized water injection. Usually dry bottom principle is applied operate spray cooler facility, to eliminate a residual waste water stream. Water is totally evaporated by a heat exchange with the hot flue gas due to dew point of the gas is approximately 50$^{o}$C. Water content in the flue gas should be increase up to 8-12% in this stage.

Ammonia in stoichiometric quantity is injected before flue gas enters the process vessel where it is irradiated by electron-beam to promote the reaction of the ammonia and flue gas. The beams interact with nitrogen, oxygen, water and others substances in the flue gas to produce active free radicals such as OH, O, $HO_2$. In results $SO_2$ and $NO_x$ are converted to sulfuric and nitric acids and finally forms a by-product consisting of ammonium sulfate and ammonium nitrate. The ammonium sulfate and the ammonium nitrate are collected by electrostatic precipitator or bag filters and the cleaned flue gas is released through the fan into the stack ( 6 ).

### 3.2. MAJOR EQUIPMENT

### 3.2.1. ACCELERATORS

The present estimation of the required dose level for the efficient $NO_x$ removal (80%) shows that the radiation dose should be in the range of 10kGy for low sulfur content coals. Multistage irradiation can reduce this figure up to 7kGy. It is necessary to add that 95% of $SO_2$ removal can be obtained with the dose rate 5kGy. Significant improvement in $NO_x$ removal can be made where the high sulfur coal is applied. If it is assumed that gas absorbs 85% of the total beam energy then 1MW accelerator facility will be sufficient for 100MW generator with the dose range described above.

Many factors should be considered when specifying the location of the accelerator/scanner relative to the process vessel. The most important are: dose uniformity, cost and easy access to maintenance. The best position of the scanner is to found at the top of process vessel with the irradiation zones along the gas stream flow. The multistage irradiation is recommended to increase process efficiency.

The process vessel location in horizontal position at underground level can reduce shielding costs and allows to have easy access and remotion of certain components of scanner/process vessel systems. The Table 2 shows the basic electron beam parameters which have been applied in laboratory and pilot plant facilities for flue gas treatment. The TABLE 3 shows producers and accelerators which are suitable for flue gas treatment in capacity 10 - 20.000 $Nm^3/h$ ( 9 ).

**TABLE 2.** The basic parameters of the electron accelerators applied in facilities for flue gas treatment.

| TYPE OF FACILITY | ENERGY (MeV) | B.POWER (kW) | TYPE OF ACCELERATOR | REMARKS |
|---|---|---|---|---|
| | 12 | 1.2 | linear | Ebara, Japan |
| LABORATORY | 3 | 15 | Cockrft-Walton | JAERI, Japan |
| | 1.2 | 1.2 | Dynamiton | Tokyo Univ. |
| FACILITY | 1.5 | 30 | ---- | JAERI, Japan |
| | 0.22 | 22 | Transformer | Karlsh.,Germ |
| < 1000 $Nm^3/h$ | 0.3 | 3.6 | " | KFK, Germany |
| | 0.7 | 5 | Resonance | INCT, Poland |
| | 0.75 | 30 | ---- | Ebara, Japan |
| PILOT | 0.75 | 2 x 45 | ---- | Ebara, Japan |
| | 0.8 | 2 x 40 | ---- | Res. Cott.US |
| DEMONSTRATION | 0.8 | 2 x 80 | ---- | Ebara, USA |
| | 0.3 | 2 x 90 | Electrocurtain | Badenwerk,GE |
| FACILITY | 0.5 | 15 | Cockrft-Walton | KFK, Germany |
| | 0.5 | 15 | " | Ebara, Japan |
| 1000 - 20.000 | 0.7 | 2 x 50 | Transformer | INCT, Poland |
| | 0.8 | 3 x 36 | Cockrft-Walton | Ebara,Japan |
| ($Nm^3/h$) | 0.5 | 2 x 12.5 | " | Ebara, Japan |
| INDUSTRIAL PLANT 300.000 $Nm^3/h$ | 0.8<br>1.0 | 8 x 150<br>4 x 400 | Transtormer<br>Induction linear | |

### 3.2.2. FILTERS, BY PRODUCT HANDLING

Process of particles formation and filtration has been intense investigated during recent years. The mass median aerodynamic diameter of the product aerosol facilities around $1_u$m depending on dose and flue gas parameters. A baghouse was initially selected as a by-product collector. A pre-coating system is used to protect the bag' surface from direct contact with hydroscopic by-product. To avoid decreasing property of by-product by neutral precaution material diatomaceous earth can be used.

TABLE 3. The basic parameters of the electron accelerators offered by the different producers for flue gas treatment in the capacity 10 - 20000 $Nm^3/h$.

| TYPE OF ACCELERATOR | PRODUCER | ELECTRON ENERGY (keV) | BEAM CURRENT (mA) | OUTPUT WINDOW (mm) |
|---|---|---|---|---|
| 600/200/1830, Dynamitron | Radiation Dynamics, USA/Japan | 500/600 | 200 | 1830 |
| ESI 0.3/90 Electrocurtain | Energy Scien. Corp., USA/Japan | 300 | 300 | 1400 |
| ELW3A Transformer | Inst. of Nucl. Phys., Russia/Japan | 500/700 | 100 | 1500 |
| UW-075-2-2-W, Transformer | NIIEFA, Russia | 750 | 2 x 60 | 2000 |
| EPS-500 Cascade | Nissin High Volt., Japan | 500 | 80 | 1600 |
| ESH, Transformer | Polimer Physics, Germany | 280 | 220 | 700 |

To remove by-product deposition from the bag filter and reduce baghouse pressure drops several method can be applied: Pulse jet cleaning; Reverse flow cleaning or Mechanical shaking. Acrylic and Teflon covered bags are the best in this application. It was found that other method can be used effectively in collection process. Wet and dry ESP and c bed filters are being used to optimize by-product collecting system.

ESP and baghouse can be install in series to increase efficiency of by-product collection, but at the significantly higher cost of installation. The usable by-product is one of major features of EB process for flue gas treatment. The concentration of ammonium sulfate and ammonium nitrate depends on fuel composition, but its quality was estimated on

75% of regular product. The sale of this by-product can be used to offset the cost of the ammonia which is applied in the process. This can decrease c the operating costs.

Depending on the coal sulfur content and the level of nitrogen oxides in flue gas, the nitrogen content of the by-product mixture will be between 20 - 30%. For the facility using 2.5% sulfur coal by-product production can be estimated on 800 Kg/day/MWe. With nitrogen content of approximately 25% fly ash is one of the significant compound of the by-product. Usually it is removed efficiently by ESP located before process vessel. Presently flyash is not recognized as hazardous waste material, but high flyash content in by product makes lower nitrogen content and increases the distribution and application costs per nitrogen unit (4 ).

Some trace of heave metals are present in fly ash. Usually the amounts of trace metal in the by product can be controlled at levels equal to or less than are being found in commercial fertilizers. Typically no more than 10%, by weight, of flyash by-product is accepted. This level of preremoval can be easily obtained by use of relatively low efficient collectors.

### 3.3. COST ESTIMATION

The costs including capital investment cost, operating and maintenance cost and by-product credit should be taken in to account to evaluate EB process from economic point of view. For 100 MWe power plant 1000kW electron beam power should be applied to achieve 90% of $SO_2$ removal efficiency and 80% of $NO_x$ removal efficiency at the dose rate 7kGy. The present status of accelerator development allow to build 500 kW units at the cost rate 2-5 US$/W of beam power wich depends on accelerator construction and its producer. The capital cost estimation depends on cost of the accelerator: 225USD/kWe to 350USD/kWe. Up to 25% of capital cost is apply to buy accelerators what is slightly less then typical cost of construction work (building, ducts) ( 4 ).

### 3.4. LABORATORY INSTALLATION

A laboratory units batch type and with flow system have been build in Japan, Germany, Poland and some others countries to investigate experimental characteristics of EB flue gas treatment process. Batch type facility can be easily adopted to local experimental condition. This type of laboratory unit was applied in Ebara during first test of performed in 1970-71 period to establish chemical reactions induced by radiation, responsible for $SO_2$ and $NO_x$ removal from the flue gas ( 2 ).

The flow system incorporate flow gas stream bellow rate 1000 $Nm^3/h$, generated by oil or city gas burners. The gas flow can be arranged by use of pressure tanks containing NO, $SO_2$, $O_2$ and $N_2$ at the moderate flow rate. Additional amount of water should be incorporate to keep adequate water contents. Flue gas generated by both oil and gas burners needs additional injection $SO_2$ and NO to meet appropriate experimental conditions. The choice between oil burner, city

gas burner or gas mixing device depends mainly on financial condition or possibility of adaptation existing facilities. The highest flow rate can be obtained in system equipped with the boiler.

The analytical equipment should allow to measure number of process parameters: Inlet and outlet $SO_2$, $NO_x$, $O_3$, $H_2O$, $NH_3$ concentration; dose rate; $NH_3$, $SO_2$, NOx injection flow rate; flue gas flow rate; temperature in dedicated points of facility and aerosol parameters. The accelerator is used to provide stream of electrons which is applied in the process. Electron beam parameters are not critical in laboratory installation due to experimental requirements. Energy of electron varied from 0.22 to 12 MeV and energy beam power from 1.2 - 30 kW in laboratory installation which has been used to investigate EB process.

The process vessel should stand long time irradiation with appropriate temperature due to nature of experimental condition. Stainless steel and other corrosion resistant materials are preferable. Thermal isolation and additional heating system could be used to stabilize experimental conditions.

The heating equipment is required to provide proper temperature condition for the process vessel and analyzed gas paths. Process vessel temperature 60 - 100$^{o}$C is being used for various experiments. The temperature of the gas paths is recommended by analytical instrument producers and usually is in 150$^{o}$C range.

Retention chamber located downstream of the process vessel is sometime use to stimulate product formation. The prefilter is sometime used after the burner to stop particles coming from combustion process. The heat exchanger is sometime used before process vessel to control temperature of EB process.

The spray cooler is used for water injection from an air-assisted mainfield of spray nozzles. The quantity of water injected is under control to cover temperature of the flue gas by evaporation process and increase its relative humidity. The ammonia injection is supplied from the pressure tank after conversion from liquid to gas phase. The amount of injected ammonia should be controlled carefully according to experimental requirements. Injection point is usually located before process vessel. The collector of the product is being used to analyzed product formation. Different of bag filter and ESP are being applied. FAN located before the stack is necessary to keep proper flow rate of the gas through process vessel and collector of the product.The stack and duct line is used to extract flue gas out of the building. Corrosion effect and deposition of the by product may occur when filter collector units is not applied.

A laboratory pilot plant has been built at IPEN-CNEN/SP using an electron beam accelerator from Radiation Dynamics Inc. having the following parameters ( 7 ):

- Electron energy ..... 0.5 - 1.5 MeV
- Beam current ..... up to 25 mA
- Scan length ..... 0.6 - 1.2m
- Scan frequency ..... 100 Hz

The irradiation device allows a four-turn irradiation and it was already used for dosimetric studies ( 1 ). The gas flow rate will be 25l/min and a synthetic mixture of $SO_2$ and $NO_x$ will be used in preliminary studies. The carrier gas will be normal cooking gas, that is burned at a proper burner. $NH_3$ will also be injected and the fertilizer will be collected at a bag filter. Several sample points will allow the measurement an control of gas rate, temperature and humidity and also the analysis of the gases to calculate the eficiency of their removal.

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