STUDY OF PLASMA - BASED STACK GASES CLEANING TECHNOLOGY TO REMOVE SO_X AND NO_X EMISSION FROM COAL-FIRED POWER PLANTS IN TURKEY

Ş. Turhan, T. Zengin, S. Ocak, S. Ünal, F. Parlaktürk, N. Tuğluoğlu, S. Karadeniz and D. Erçin

Ankara Nuclear Research and Training Center (ANRTC), Beşevler-Ankara-Turkey

Abstract

Environmental problems, which caused by the increased energy demands, have become a serious problem in Turkey. Air and environmental pollutants such as the SO_x (SO_2, SO_3) and NO_x (NO, NO_2) generated mainly by burning fossil fuels, especially coal with high sulfur contents turn ultimately into sulfuric/sulfurous acid and nitric/nitrous acid in the atmosphere. This acids affect forests, agricultural fields and flora by acidifying the soil and affects fish by acidifying land-borne water. Therefore, Turkey is seeking to install Flue Gas Desulfurization (FGD or $deSO_x$) technology on all newly commissioned coal fired thermal power plants units and to retrofit onto older units to reach introduced emission limits. In this study, both the current energy consumption and production and emission of these gases in Turkey is reviewed and plasma-based stack gas cleaning technologies such as electron beam flue gas treatment (e-beam FGT) and pulsed corona discharge FGT (pulsed CD-FGT) are compared with preferred limestone/gypsum wet-scrubbing (L/G-FGD) technology and evaluated for some coal fired power plants.

1. Introduction

Turkey has been one of the fastest growing power market in the world with a young and growing population, rapid urbanization and economic growth for nearly two decades. Also the electricity demand of Turkey is growing rapidly with the rate of increase of 8% in average for many years [1]. The emission of these pollutants depends on energy demand, energy sources, emission-control legislations, the kind of plant (new/old), the size of plant and the fossil fuel used [2]. In Turkey, the 1986 Regulation on Air Quality Control sets emission limits for different thermal power plants [3].

The main tools for reduction of pollutants or to reach introduced emission limits are emission-control technologies. In most developed countries, wet scrubbing FGD technology is a well-established process for removing SO_x and CTs are widespread technology for removing NO_x [4]. The wet-scrubbing

(L/G-FGD) technology was preferred. It was commissioned in the 2x150 MWe Cayirhan 1-2, 1x210 MWe Orhaneli, 2x160 MWe Cayirhan 3-4 (with plant), 1x157 MWe Kangal (with plant) and is under construction in the 3x210 MWe Kemerkoy, 2x210 MWe Yenikoy and 3x210 MWe Yatagan. CT is used to control NO_x emission from all existing power plants in Turkey [5]. But, wet scrubbing FGD equipment is of complex construction, contains a great many control elements, and necessitates a large–scale waste water treatment system needing much operation work. Moreover, SCR and CT involve very costly catalysts having only a short operation life.

On the other hand, new technologies are investigated and developed for industrial scale commercial viability by researchers, engineers and environmental firms. Especially e- beam and corona discharge (DC, AC or pulsed) FGT technologies are dry scrubbing, cost effective and simultaneously remove SO_2 and NO_x and the resulting by-product, i.e. ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate (NH_4NO_3) were used as a fertilizer.

2. Energy sources

Turkey's installed electricity generation capacity is 27264,1 mega-watt (MWe) (of this; 16052,5 MWe is thermal and 11175.2 MWe is hydro) and 28318,5 MWe (of this; 16626,2 MWe is thermal and 11673.4 MWe is hydro) in 2000 [5] and 2001 respectively. According to data of TEAS, Turkey's electricity generation growth to be 8.8% in average per year between 1975 and 2001 [6]. This could lead to building a total installed generating capacity of 65069 MWe by 2010, about two times the current capacity. To meet the demand the construction of new generation facilities and increasing the efficiency and availability at present power plants will be necessary. Primary energy resources, which are produced in Turkey, are hard coal, lignite, asphaltite, petroleum, natural gas, hydroelectric energy and geothermal energy. However energy resources are limited except coal and hydro. The existing installed capacity of coal fired thermal power plants of The Turkish Electricity Generation and Transmission Corporation (TEAS) and affiliated partnerships is 6390 MWe and production capacity is 45545,5 gigawatt-hours (GWh) (see Table 2). Turkey had 108 hydroelectric power plants, which have a combined capacity of 10503 MWe and produce 38878,5 GWh annually in operation.

Coal (hard coal and lignite) is the dominant source of energy produced in Turkey. In 2000, lignite 36,58%, hard coal 4,06%, natural gas 49,2% fuel oil 7,94% and motorin 1,04% of thermal electricity production [5]. Hard coal reserves are about 1100 million tons (Mt). The production of hard coal is about 2,5 Mt per year. The majority of hard coal production is sold to the Catalagzi thermal power plant and remainder of its sold to the iron and steel, the sugar and cement industries. Not all of the coal-consumed industry is indigenous and the remaining coal needs are imported. Turkey imports over 6 Mt of hard coal each year [7]. Lignite is the largest source produced in Turkey. Lignite recoverable reserves are estimated to be about 7300 Mt including about 1000 Mt of under ground. Lignite production increased quickly up to end of the 1980s but since remained, reaching about 70 Mt in 1999 [8]. The production of lignite is expected 108 Mt in 2010. Figure 1 shows production of lignite and hard coal. Turkish lignite has a very low calorific value and high sulfur, dust and ash content. About 75% of the reserves have a calorific value below 2500 cal/kg and less than 10% have a quality over 3000 kcal/kg. About 75% of lignite was consumed by the electricity sector.

Table 2. The existing coal-fired thermal power plants (end of 2000) [8].

Thermal power plants	Unit number x installed capacity MWe	Fuel type	Fuel capacity Ton/h	Sulfur Content (%)	Volumetric flow rate Nm^3/h
Yatagan	3x210	Lignite	3x235	1,63	1081373
Afsin-Elbistan	4x340	Lignite	4x559	1,23	1662440
Yenikoy	2x210	Lignite	2x303	1,75	1140153
Kemerkoy	3x210	Lignite	2x342	2,18	1482200
Seyitomer	4x150	Lignite	4x189	0,96	866000
Soma A	2x22	Lignite	2x21	0,78	111760
Soma B	6x165	Lignite	6x236	0,67	913260
Tuncbilek A	2x32+1x65	Lignite	82.25	1,46	770904
Tuncbilek B	2x150	Lignite	2x145	1,46	646702
Cayirhan*	2 x160	Lignite	4x152	2,63	601000
Kangal	2x150+1x157	Lignite	3x243	1,92	920800
Orhaneli	1x210	Lignite	1x188	1,44	991826
Catalagzi B	2x150	Hard coal	2x97	0,41	630200

- Operational rights of 1st and 2nd Cayirhan have been transferred to Park Termik A.Ş in jully 2000.

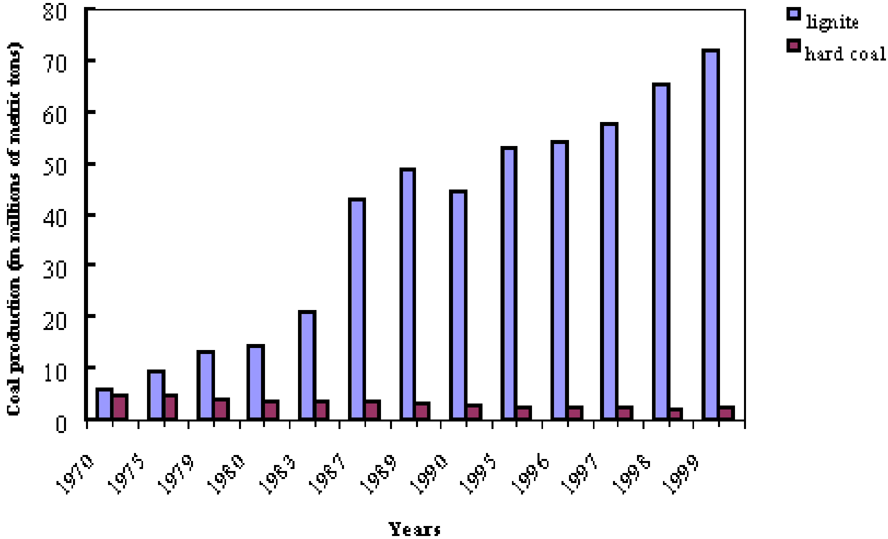

Figure 1. The production of lignite and hard coal of Turkey [9]

3. Environmental impacts

The growth in the use of fossil fuels in Turkey has led to a growth in emissions of pollutants. SO_x and NO_x emissions are increasing and total emission of SO_x, NO_x and non-methane volatile organic compounds (NMVOCs) are 1,765 Mt (of this; 1,278 Mt caused from thermal plants), 0,925 Mt (of this; 0.187 Mt caused from thermal plants) and 0,613 Mt respectively in 1999 [10]. This situation has created environmental problems. Turkish environmental policy considers that energy policy should take into account environmental problems and that a balance should be found between increase in energy demand that are required for economic development and environmental concerns. The Government, as well as municipalities, has taken several measures to reduce pollution from energy sources. Municipalities have attempted to replace lignite consumption in the residential sector of major towns by importing low sulfur coal and by promoting natural gas consumption. 1986 law on air quality requires the building of FGD facilities for all newly commissioned coal thermal power plants units and retrofitted onto older units.

4. E-beam FGT technology

E- beam FGT technology is very versatile and an effective process to remove simultaneously SO_x and NO_x from of the flue gas produced in the combustion of fossil fuel. The flue gas flows into the process vessel then gas mixture is subjected to an intense field of energized electrons, which collide with the flue gas molecules resulting in molecular ionization. These ions interact with flue gas constituents resulting in the creation of free atoms and active radical species such as $O^\bullet$, $OH^\bullet$, $HO_2^\bullet$ and $N^\bullet$. These are capable of rapid reaction with SO_2 and NO_x and water in the flue gas to ultimately yield a mixture of fine mist and vapor of sulfuric acid (H_2SO_4) and nitric acid (HNO_3). In the presence of ammonia (NH_3), these acids are converted to ammonium sulfate $(NH_4)_2SO_4$ and ammonium nitrate (NH_4NO_3) [11].

If e-beam FGT is used to remove SO_x and NO_x from flue gas of thermal power plants, there are four main systems. These are a flue gas cooling systems, an ammonia supply system, an electron beam irradiation system and a by-product collecting system as shown in Fig. 2.

By now, various tests and small pilot plants have been conducted around the world. The pilot plants, cleaning of flue gas from coal combustion, with volumetric flow rate exceeding 10000 Nm^3/h have been built in Indianapolis-USA; Badenwerk-Germany; Kaweczyn-Poland and Chubu-Japan [13]. Ebara Corporation, with the co-operation of the Chinese government, has completed the first commercial e-beam FGT-P installation in 1997, which is sited at the coal-fired Chengdu Power Station in China. Design conditions of this retrofit facility are: 300.000 Nm^3/h, 1800 ppm, 400 ppm, 80% and 10% and 2,470 kg/h (20,000 tons/year) are volumetric flow rate, initial SO_2 and NO_x, removal efficiency of SO_2 and NO_x and by-product output rate respectively [12]. Then e-beam FGT-P is proposed to be employed Pomorzany in Poland, with the co-operation of the Japanese Government and IAEA, for the gases emitted by two Benson type boilers of power about 100 MWe. 270.000 Nm^3/h, 5500 ppm, 390 ppm, up 80% and up 70% are volumetric flow rate, initial SO_2 and NO_x and removal efficiency of SO_2 and NO_x respectively [4]. In addition to the systems operation in China and Poland, a large, full-scale installation of the e-beam FGT-P at Nishi-Nagoya thermal power plant (220 MWe, flow rate: 620000 Nm^3/h, estimated the rate of by-product production: 4,5 tons/h) is now under construction at a major thermal power plant in Japan with startup in 1999 [12].

5. Pulsed CD-FGT technology

Pulsed CD FGT is also a dry scrubbing process and cost-effective means for many gaseous pollutants such as SO_x, NO_x and other organic compounds and the by-products are $(NH_4)_2SO_4$ and (NH_4NO_3) which are used as a fertilizer [14]. Same as e-beam FGT except that the electrons are created and energized inside the reactor by a pulsed high voltage supply with extremely short rise time. Corona discharges generate low energy electrons, about 20 eV, as compared to electron beam discharges where high energy electrons, keV or MeV are produced [15]. The low energy electrons are accelerated from very low level of kinetic energy as they drift along the high voltage region (corona region) until they collide with a gas molecule and immediately lose energy by excitation, attachment, dissociation or ionization.

Recently, pulse CD FGT has been investigated in lab-scale and pilot test facility by China, Japan and U.S.A., Italy, etc. as one of the most promising technologies for $deSO_x$, and $deNO_x$ [15].

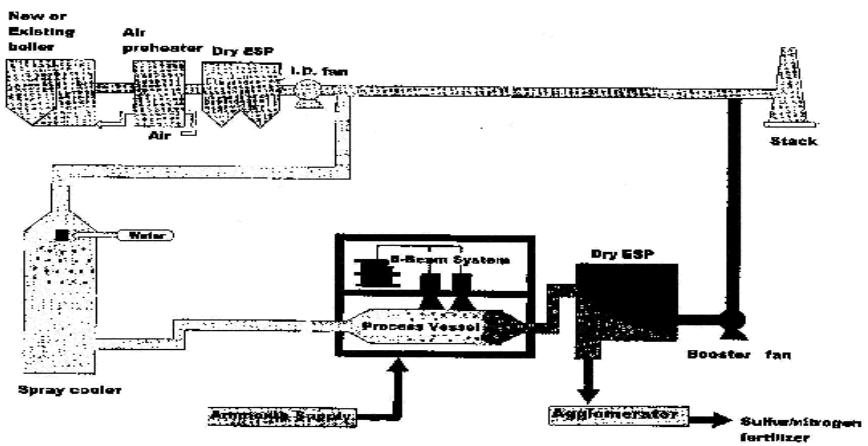

Figure 2. The flow diagram of e- beam FGT for power plant [12]

6. The economical aspects of E-beam and pulsed CD FGT

Researchers, companies and consultants have been made many costs of analyses. It is very different to make comparisons of these analyses because the different people doing the estimates make many different assumptions. One of the assumptions is always the cost of the accelerators. The prices of electron accelerators depend on electron energy, beam power, electrical efficiency, physical size and etc. Relation between the required power of electron beam and the capacity of generating station (MWe) may be presented as follows: 1) In case a single step irradiation, the required power of electron beam is about 2% of the capacity of generating station; 2) In case circumstances of an irradiation in several, successive steps, the required power of electron beam is reduced to values less than 1% of the generation station capacity or of other industrial SO_2 and NO_x generating plants [16]. The cost of electron beam power decreased from about 25 DM/W, in 1980s, to 3,5 DM/W in 1995 [17], and at present is about 2$/W (for NISIN accelerator unit of 800 KeV, 800 kW). After year 2000 it might be possible that this price will decrease due to the new acceleration technologies and equipment improvements for industrial applications [17].

Frank estimated that the investment cost of projected e-beam FGT is on the level $190-$210/kW for 300 MWe installed electrical power and 2,6% sulfur [16]. For instance, in Poland, for 100 MWe, the total cost is about 20 millions $ [18]. Now, the cost of electron beam power is about 12% of the total investment cost. For 550 MWe, the total cost will be about 80 millions $, and the electron beam power cost of about 10% (4000 kW).

According to estimate done by Civitano and Masuda, the investment of the pulsed CD FGT is $23.5 million for a 320 MW power station and $50 million for 300 MW boiler (a brand new pulsed CD) respectively [19, 20]. The NO_x would be removed at the same cost, whereas an additional SCR unit would be required with any of the system shown for a capital cost of 80-100 $/kW to remove NO_x.

7. The comprasion of the E-beam and CD FGT with preferred L/G FGD

In this section, we have compared e-beam and pulsed CD FGT with the wet scrubbing L/G FGD, which was commissioned in the 1x210 MWe Orhaneli coal, fired power plant in aspects of capital cost, operating cost and by-product's value. **Capital cost:** As indicated above, the total initial investments cost for 210 MWe Orhaneli plant is $36.750.000 million to construct e-beam FGT technology (by taking account of plant size, lower cost of labor, etc.) and is $15.500.000 million ($35 million) to construct pulsed CD FGT. According to data, which is taken from TEAS for the wet scrubbing L/G technology on these power plants, total initial investment cost is $43,3 million [8]. **Operating cost:** For the operating cost, we consider only the cost of electricity and chemical materials injected into process vessel. For e-beam and pulsed CD FGT, stoichiometric amount of ammonia is calculated as 2,3 tons NH_3/ hour and the total cost of ammonia is $2,4 million per year. The needed limestone for wet scrubbing is 79135 ton per year and the cost of limestone is $475 thousands per year [8]. For e-beam and pulsed CD FGT, if the overall energy cost of 7 Wh/Nm^3 is assumed and total cost of electricity is $2,9 million per year. The cost of electricity for wet process also is $2,2 million per year [8]. **For value of the by-product:** We consider only ammonium sulfate for e-beam and pulsed CD FGT and gypsum for L/G FGD. For Orhaneli, it can be expect that 4.3 tons of SO_2 is removed per hour and this corresponds 8.9 ton ammonium sulfate per hour and annually 58000 tons ammonium sulfate. Their annual income is $3.2 million. For wet scrubbing L/G FGD, there is no economic value of obtained by-product as gypsum in Turkey. Results of the other plants are summarized Table 3. Parameters used for above calculation are: 210 MWe power output, initial concentration 2100 ppm, removal efficiency 80%, the price of electricity \$0,064/kWh, limestone \$6/ton, ammonia \$160/ton, ammonium sulfate \$55/ton, 6500 operation hour/year and data in given Table 2.

8. Conclusion

Turkey is a party to many international environmental agreements such as Air Pollution, Hazardous wastes, Ozone Layer Protection and etc. Turkey is seeking admission on the European Union (EU) and trying to meet EU standards. Therefore Turkey is requiring FGD units all newly commissioned coal power plants and is retrofitting FGD onto older units.

Table 3. Economic evaluation of the wet scrubbing L/G FGD and e- beam FGT and pulsed CD FGT (unit: million US dollars).

	Yatagan (1x210 MWe)			Kemerkoy (1x210 MWe)			Yenikoy (1x210 MWe)			Kangal (1x157 MWe)		
	Wet L/G*	E-B FGT	Pulsed CD FGT	Wet L/G**	E-B FGT	Pulsed CD FGT	Wet L/G***	E-B FGT	Pulsed CD FGT	Wet L/G	E-B FGT	Pulsed CD FGT
Capital Cost	25.9	36.8	15.5/35	28.9	36.8	15.5/35	25.7	36.8	15.5/35	37.0	27.8	12/26
Chem. Cost	0.6	3.4	3.4	0.6	6.6	6.6	0.8	4.7	4.7	0.8	4.1	4.1
Elect. Cost	2.5	3.1	3.1	2.5	5.2	5.2	2.7	3.3	3.3	1.5	2.7	2.7
By-product Value	-	4.5	4.5	-	8.8	8.8	-	6.3	6.3	-	5.5	5.5

* Total capital cost of 3x210: \$77.8 million
** Total capital cost of 3x210: \$84.1 million
*** Total capital cost of 2x210: \$51.4 million

This study has shown that the pulsed-based FGT technologies are most promising second-generation system and offer many potential attractive features for simultaneous removal of SO_2 and NO_x from the flue gas. Also, it is rated equivalent or preferable to wet scrubbing FGD+SCR for retrofits. But there are two negative aspects of the pulsed-based FGT technologies for Turkey. Firstly, it can be seen from Table 3 if deNO_x is not required, these technologies have not advantage over wet scrubbing L/G FGD technology as related the capital cost and energy cost except Orhaneli. Secondly, ammonia is not produced in Turkey and is imported Russia and Israel; therefore its cost can be frequently changed. Another problem related to ammonia is transport of ammonia to power plants. However, if the capital cost and energy cost of plasma based-technologies is reduced in future, a retrofit for small to mid-sized existing plants these can be easily configured especially pulsed CD FGT which are relatively easy to install because of equipped with ESP facilities, to meet emission regulations in Turkey since the area needed is far less than conventional wet scrubbing L/P FGD.

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