SCIENTIFIC AND TECHNOLOGICAL PAPERS

PHYSICAL SCIENCES AND TECHNOLOGY

ADVANCED CONTROL-TECHNOLOGIES FOR SUPPRESSING HARMFUL EMISSIONS IN LIGNITIC COAL-FIRED POWER GENERATION

Surriaya Mir and
*S.M. Abdul Hai**

(Received on 25-10-1999 and, in *revised form,* 15-11-1999)

ABSTRACT

The production of sufficient amount of indigenous energy is a prerequisite for the prosperity of a nation. Pakistan's energy demand far exceeds its indigenous supplies. A cursory look at the energy situation in Pakistan reveals that there is an urgent need for the development of its energy-resources.

In this regard, coal can play a key role if its problems of high sulphur and high ash can be rectified through the adoption/adaptation of advanced technologies, like (i) clean coal technologies, and (ii) control technologies. A review on clean coal technologies for utilization of lignitic coals has already been published[1] and the present article describes the effect of harmful emissions from the combustion of high-sulphur coals, like the ones found in Pakistan, and their control through advanced control-technologies, to make a significant contribution in the total energy economics of Pakistan.

INTRODUCTION

As the world has progressed through the industrial age, energy in the forms of electricity and diesel & petrol has replaced people and animals in performing work in manufacturing, agriculture and transportation. In fact, energy has become an essential component of our daily life, as food is, and those societies with abudance of energy are at the pinnacle of the present civilization.

About 40 percent of the energy produced in Pakistan is consumed by industry, while the rest is being consumed by agriculture and for other purposes. As against a total estimated existing energy demand of 9.5 GWe, just 7.5 GWe is produced in the country (Giga watt is equal to one million Kilowatts), causing a shortfall of about 2 GWe (or about 20%). To reduce the gap between energy production and demand, as also the import bill of oil, the oil and gas reserves should be preserved for superor fuel use and indigenous coal-reserves should be developed/ utilized to supplement the energy needs. An estimate of energy-resource potential of oil, gas, coal and hydel is given in Table-I[1].

In Pakistan, the environmental pollution caused by combustion of coal has been a major impediment in its utilization. A substantial reduction in coal-combustion emissions is achieved through the development of suitable control-technologies. With the use of these technologies, even low-grade lignitic coals are utilized, all over the world, for energy production. Today, various countries like USA, Germany, China, Greece, Turkey, etc., use low-quality coals for production of energy. Following the example of other countries, concerted efforts have to be made in Pakistan to utilize these technologies for power-production from coal found in the country.

The energy-defficiency in Pakistan is not so much due to poor resource-endowment, as the inability to exploit the available resources. The per-capita availability of energy in Pakistan is very low, even when compared to the developing countries, see Table-II[2]. To achieve self reliance and to reduce the bills of imported energy, Pakistan too needs to produce additional energy from indigenous sources of coal. Coal can make a significant contribution in Pakistan, as we have extensive resources of lignitic and sub-bituminous coals, which are estimated at billions of tons. At present coal, in Pakistan, has a small share in the total energy-supply position, on account of its high sulphur and mineral contents.

THE COAL RESOURCES OF PAKISTAN

An account of the coal resources of Pakistan and their characteristics is given elsewhere; these reserves have been estimated at over 183 billion tonnes. The

* Pakistan Council of Scientific and Industrial Research, Fuel Research Centre, Karachi.

Table - I
Energy Resources Potential of Pakistan

	Probable	Possible
Oil (Billion Barrels)	13.2	97-404
Gas (TCF)	40	1443
Coal (Billion Tons)	2.94	22.13
Hydel (MW)	28,345	40,000

Source:

Oil	ECL Study, World Bank
Gas	ECL Study, World Bank
Coal	GSP (Geological Survey of Pakistan
Hydel	WAPDA and Working Group

Table - II
Energy Supplies and Per-Capita Availability

	Energy Supplies (mln TOE)	Per Capital Availability (TOE)
1991-92	30.793	0.262
1992-93	32.981	0.273
1993-94	34.784	0.279
1994-95	36.115	0.282
1995-96	38.750	0.292

Source: Hydrocarbon Development Institute of Pakistan

largest coal field discovered by Geological survey of Pakistan in 1992, is located in Thar Desert. During July 1996-March 1997, 2,366 thousand tonnes of coal was produced and consumed in the country. Major share of the production was consumed by brick-making sector (88.25%), followed by power sector (11.36%) and households (0.39%).

Pakistan's coal reserves, which are distributed in the major coal fields of various provinces are briefly described below:

Baluchistan: The known coal-producing fields include Duki, Khost-Sharig, Harnai, Pir Ismail Ziarat, Mach-Abe-Gum, Sor-Range-Deghari and Ghamalong-Bahlol; the overall resource-potential is over 194 million tonnes, with measured reserves of 52.5 million tones. Average annual prodcution is about one million tonnes.

N.W.F.P: Hangu is the only coal-producing field in NWFP. Some sporadic mining is reported from Cherat. The resource-potential is over 44 million tonnes, with measured reserves of 0.5 million tonnes. The production is insignificant.

Punjab: Substantial resources of coal have been outlined in the Eastern and Central Salt Range and in Makerwal area of the Surghar Range. A coal resource potential of 234 million tonnes has been projected, with drill-proved reserves of 43 million tonnes. Although several coal-seams are developed, only one is being mined throughout the province. The average annual production is 450,000 tonnes.

Sindh: A very large coal-resource exists in the Sindh province. Coal-resource potential in excess of 183 billion tonnes has been outlined in Lakhra Sonda-Jherruck, Indus East, Thar and Badin coal fields. Measured reserves are over 73.4 million tonnes. The coal being produced is high in sulphur. The known coal-fields, from where mining is reported, include Lakhra and Meting-Jhimpir. Average annual production is about one million tones[2].

ADVANCED-TECHNOLOGIES FOR CONTROL OF EMISSIONS FROM COAL-COMBUSTION

The research and development efforts addressed to the environmental control of coal-combustion emissions are classified as under :

i) The advanced clean-coal technologies are the recently developed technologies that utilize low-grade lignitic coal, controlling environmental discharge during combustion without the use of outside scrubbers. Detailed perspective applications of these technologies in indigenous coal-fired power-production have already been discussed in an earlier paper[1].

ii) The advanced control-technologies are in practice for quite some time and are widely used in large pulverized-coal-fired power plants, the world over. These technologies use the techniques for NO_x removal and collect ash and sulphur oxides emissions through sophisticated techniques, converting them into useful products. The possible application of advanced control technologies in lignitic coal-fired power generation is being addressed in this paper.

Some of the hazardous pollutants produced by coal combustion and their effects on health/environment are first summarized, as under:-

1. The Hazardous Emissions Produced by Combusion of Coal

To achieve environmental safety, for using coal as a fuel, the emissions of three recognized atmospheric pollutants need to be suppressed:

(1) the oxides of sulphur,
(2) the oxides of nitrogen, and
(3) extremely fine particulate matter.

Each of these pollutants poses unique threats to ecological conditions and human health. Sulphur oxides, predominantly sulphur dioxide (SO_2), are formed from the combustion of the sulphur contained in the coal, whether in the form of iron pyrites (FeS_2) or as elemental sulphur. The emissions may travel in the upper atmosphere over long distances, depending on climatic conditions, and get oxidized to sulphur trioxide ($S0_3$), dissolve in atmospheric moisture and fall as acid rain, which adversely affect human health and cause fish in lakes to die and deteriorate forest vegetation.

Nitrogen oxides are formed in the combustion of all fossil fuels, the amount depending on the conditions of the combustion, particularly the temperature of the combustion. High-temperature combustion leads to the chemical combination of the nitrogen and oxygen in the air. Nitrogen-containing compounds are found along with the coal; this nitrogen upon liberation is chemically active and combines readily with available oxygen. Nitrogen oxides; or NO_x, are a mixture of several discrete nitrogen/oxygen compounds. In the upper atmosphere, they readily enter into complex chemical reactions with the ozone, catalyzed by ultraviolet radiation, to form a series of acrid compounds that make themselves felt as "smog" and atmospheric haze.

The third pollutant i.e. the particulate matter is especially specific to coal. It is composed of mineral and some unburnt combustible matter and trace elements. In addition to the obnoxious effect of the smoke formed by the combustion of aromatic hydrocarbons, the trace elements in particulate may be fine enough to be breathable. Some gaseous and particulate substances from coal combustion and their toxicity and environmental standards are shown in Table-III[4].

We may define the environmentally safe, the clean use of coal, as the use of coal under such combustion conditions that the excessive emissions of sulphur oxides, nitrogen oxides, and particulate matter are avoided. In many countries, the term "excessive" is defined legally by regulatory agencies, and compliance by coal consumers with these definitions has the force of law. The developmental lending agencies, such as the World Bank, have adopted conditions for their lending that ensure compliance with their own regulations for permitted emissions. The solution of the problems that arise in connection with the "Clean" use of coal are thus not simple. The combustion-equipment must be capable of suppression of sulphur oxides and nitrogen oxides emissions, and the particulates must be captured to the extent that law or good environmental practice requires[5]. In Pakistan, the problems are intensified because the sulphur-content of almost all the coal deposits is unusually high and the same is true for their mineral content.

USE OF TECHNOLOGIES IN COAL-COMBUSTION EMISSION

The control-technologies utilized in power generation by pulverized coal-firing involve (a) the collection/utilization of the particulate matter i.e. ash, and (b) the capture of gaseous emissions, mainly sulphur dioxide, and the proper utilization of the products without polluting the environment and the removal of NO_x produced by coal-combustion. These are described below in some detail.

(a) Ash Collection/Utilization Through Control Technologies

(i) Ash Collection Technologies: Large coal-burning boilers usually fire pulverized coal. The components of the fuel that cannot be burned or gasified are obtained as ash. The bottom-ash collected in the furnace has found little use and is generally put in the landfill. The ash that is present in the dust form and carried out with the gas is called "fly ash". The composition of fly ash is essentially the same as the bulk composition of the ash in the coal from which it comes. The principal difference is that the fly ash consists of particles that have been heated to temperatures ranging from about 1400 to 1700°C. This "fly ash" pollutes the atmosphere when released with the combustion-gas and the ground-water if removed from the gas and discarded in land disposal area. Many advances in the understanding of the behaviour of ash in coal have been made and effective techniques for ash collection/utilization have been developed. Finely divided "fly ash" is usually removed by cyclonic separation, electrostatic precipitation, filtration and wet scrubbing techniques.

Electrostatic precipitation is, by far, the most widely used ash-collection method[6]. Low pressure drop, high collection efficiency and dependable operation make it the standard choice for large boilers and, quite often, for small ones. Electrostatic precipitation is a very complicated phenomenon. The basic principle is of suspending electrodes in the gas-stream and imposing a potential difference between the electrodes and a ground collection surface. Ionization of the gas by the high potential causes the particles to pick up a charge They are thus attracted to the collection area; the collector plates are vibrated to shake off the collected particulates into a hopper.

ii) Utilization of Fly Ash: The major market for "fly ash" has been in concrete. Addition of Ash to concrete reuslts in lower water-requirement, higher ultimate strength, improved workability, lower permeability and less heat-generation during curing. In cement-manufacture, "fly ash", added to the raw batch before burning, can provide an inexpensive source of silica and alumina[7].

Soil stabilization with "fly ash" for road areas, airport runways, parking areas and foundations has been practised fairly extensively and, in many cases, lime is also added[8].

Table - III: Toxicity of Some Gaseous and Particulate Substances from Coal-Combustion

Substance	Toxicity	
	Acute	Chronic
Particulates: total suspended particulates	With SO_2 in episode conditions, contributes to mortality and morbidity.	Pulmonary irritation, chronic obstructive & restrictive lung disease
Sulphur Oxide	Increased respiratory disease; breathing difficulty in asthmatics	Respiratory disease and increased mortality suspected.
Nitrogen oxide	Increases infant susceptibility to lower respiratory infection due to conversion of nitrates into nitrites	May combine with amines to form carcinogenic nitrosamines; also mutagenic & teratogenic Nitrites constitute a direct animal carcinogen

Table - IV: Products of Flue-Gas Sulphur removal, in a 600 MW Power-Plant, Opeating 4000 hr/year and using 2% Sulphur Bituminous Coal; heating value 29.3 x 10^3 KJ/Kg and 80% Removal Efficiency; Yields Depend on Process Used

Product	Amounts (10^3 kg/year)	Process
Sulphur	128,000	Bergbau-Forschung, IFP, Wellmand-Lord SFGD
Sulphuric acid (100%)	390,000	Wellman-Lord, Sumitomo, Monsanto, Lurgi-Sulphacid, Bergbau-Forschung
Sulphur dioxide	256,000	Wellman-Lord, Chemico, Sumitomo, Bergbau-Forschung
Gypsum ($CaSO_4 . 2H_2O$)	692,000	Chiyoda-Holter, Mitsubishi-Jecco, Chemico
Sludge (e.g. 70% $CaSO_3$ 1/2 H_2O) 15% $CaSO_4 . 2H_2O$ 15% $CaCO_3$		Bischoff, Bahco, Combustion Engineering, Chemico

iii) Removal of the Fine Particulate from Fly Ash: The fine particulates escaping from "fly ash", although in minor concentration, cause pollution from contained trace-elements. They are collected through many collection equipments, like electrified filters, sonic agglomeration, charged droplet scrubbers, wetted mesh filter and high-pressure nozzle.

(b) Control of Gaseous Emissions from Coal Combustion

(i) Control of Sulphur Oxide: Most of the processes for removing sulphur oxides from the gases involve contacting the gas with a material that combines with the sulphur oxides, thus converting them to a liquid or solid that can be removed and utilized. Most of the processes for removal of sulphur dioxide use limestone or lime, through wet-scrubbing or dry-scrubbing processes.

Use of the wet-scrubbing operation, with lime or limestone as the absorbent, is by far the most popular method for removing SO_2 from waste gases[4]. A high degree of removal can be attained, with good utilization of the absorbent. Despite several unresolved design and operating problems, the advantages are such that companies operating large boilers seldom give much attention (in planning) to any process other than lime or limestone scrubbing.

Many other processes, like sodium, ammonia and magnesia-based scrubbing and metal-oxides absorption, are now developed and success is being achieved.

(ii) The Useful By-Products of Flue Gas Desulphurization: Depending on the process, the sulphur dioxide removed from flue gas can be obtained in the form of a variety of chemical compounds. These can be converted into final saleable products, like gypsum, sulphuric acid, liquid SO_2 and elemental sulphur. Such compounds may be a sludge that contains $CaSO_3$ in addition to gypsum. Table-IV shows the annual quantities of these different products obtained in a 600 MW power-plant fired with bituminous coal containing 2% sulphur. The plant removes 8% of the sulphur and operates 4,000 hours/year. The table also shows the most important flue-gas sulphur removal processes that yield these products. In various countries of the world, different interests exist for the manufacture and use of individual products[4]. In the United States, lime and limestone-scrubbing processes contribute 80% to all flue-gas desulphurization (FGD) and produce gypsum of gas sludge as a final product[4]. It has become possible to convert sludge into material strong enough to be used in the building sector and in highway building.

A major adantage of the FGD system is that the reagent (limestone) is inexpensive and generally available. There are about 120 GGD systems in USA, 100 in West Germany and 56 in Japan and a few dozens in Europe, in operation based on lime or limestone. FGD systems for SO_2 removal may be sucessfully employed for Pakistan coals for future power plants.

(iii) Control of Nitrogen Oxides: There are several differences between controlling nitrogen oxides emissions from coal-combustion and controlling emission of particulates of sulphur oxides. The first difference is that a smaller amount of NO_x is emitted compared to other emissions. In addition, there is not much that can be done about the amount of ash and sulphur involved, both are present in the coal and must come out as the waste product, whereas much of the NO_x comes from the air and is produced by the reaction of nitrogen and oxygen at elevated temepratures. Thus, the amounts of NO_x vary with the boiler conditions and the emission is generally a direct function of flame temperature, excess air, nitrogen content in coal, percentage of boiler-load and rate of gas cooling.

The general approach in reducing NO_x emission is to alter the combustion conditions. The control of combustion to reduce formation of NO_x is more economical than the removal methods. The combustion-control either utilizes the modifiction in boiler or burner-design, staged combustion and re-circulation of the combustion gas to avoid the formation of NO_x, or uses the treatment of NO_x with ammonia or a catalyst to convert it into nitrogen and carbon dioxide[4].

NATIONAL SCENARIO

The development of the coal-sector, particularly of Lakhra and Thar, needs to be stepped up in order to provide fuel for WAPDA power projects. For utilizing Lakhra coal in power-generation, various feasibility studies were made for installing Lakhra coal fired power-plants, using control technologies by GSP, USGS, JICA. Detailed feasibility study was performed by John T. Boyed and Co. (USA), on behalf of USAID/WAPDA, for utilizing Lakhra coal for power-generation. Capital cost of mining and installation of power-plant was determined. Lakhra coal was tested for boiler design and assessment of environmental-impact was made by US consultants. Following the World Bank Guidelines, proper studies were made to establish that Lakhra power-plant was a component of the least-cost power-generation programme of WAPDA and the cost of coal from Lakhra mine was able to produce electricity that was more economical than any other available source of fuel, like imported coal or imported oil. Under the Energy Planning and Development Programme, with the assistance of the World Bank, Asian Development Bank and USAID, these investigations were completed. It was concluded that the Lakhra coal mine power-generation project, using Lakhra coal would be technically, financially and economically feasible and will be socially and environmentally sound, using flue-gas desulphurization technique[9-10].

Environmental-impact assessment by US experts has suggestd that 3x50 M.W. plants should be preferred at Lakhra, and that would not exceed the maximum limit of SO_2 impact in the environment, as set by World Bank standards. Inthis regard, Lakhra coal-development Co, which is a joint-venture company, having equity share of PMDC (30%), WAPDA (20%), Government of Sindh (20%), while the remaining 30 percent is reserved for the private sector participation, has pledged to supply 750,000 tonnes of coal per annum to WAPDA for its 3x50 MW coal-fired plant at Khanote (Sindh). LCDC produced 258,055 tonnes of coal from its small coal-mines during July-March 1996-97[2].

Beside the production of indigenous energy from the power plant, other factors like domestic, economic and industrial development in an undeveloped area of the province of Sind, providing jobs for workers, increasing energy, self-sufficiency and reducing foreign-exchange expneses are some of the advantages that favour the developemnt of a coal-based technology at Lakhra. It may be envisaged that, with the use of control-technologies, the generation cost with indigenous coal, even after providing for environmental-control cost due to its high sulphur and ash content, may still be considerably less than the oil-based generation plant.

Concerted efforts are being made for the prospective utilization of Thar coal for power generation. USGS have performed studies on the characterization of the coal and progress is being made for its evaluation as a source of power generation.

CONCLUSION

For a nation to prosper, it is imperative that the nation should be able to effectually exploit its natural resources. Pakistan is endowed with huge reserves of low-rank coal, which, due to their high sulphur and ash content, so far have a meagre share in the total overall energy-supply of the country. These resources, if exploited properly, can make a significant contribution in narrowing down the gap between the supply and demand of energy. The control technologies, as are being utilized in the world in a manner that protect the environment to generally accepted world-wide standards, can be adopted in Pakistan. Thus, Pakistan coals may be utilzied in power-generation, resulting in the partial substitution of natural gas and oil, and making a visible impact on the future energy-economy of Pakistan.

REFERENCES

1. Surriaya Mir, M. Zahid Raza and A.R. Abbasi, "The clean coal technologies for lignitic coal power generation in Pakistan". Science, Technology and Development, 16 (2), April-June, 1997.
2. Economic Review, 1996-97, Government of Pakistan, Islamabad.
3. Eighth Five-year Plan 1988-93 and perspective plan 1988-2003, Planning Commission, Government of Pakistan, Islamabad (1988).
4. Chemistry of Coal-utilization, supplementary volume, H.H. Lowy, Ed. John Wiley and Sons, New York, 1963, 1449-1491.
5. Public law, 91-604, (1970) Clean Air Amendment Act, 1970, 42 USC 1851 et seq, 1975.
6. Roy E. Bickelhaupt, (1965) "Surface Reactivity and the Chemical Composition of Fly Ash" Proc. Symp. Electrostatic Precipitators for the Control of Fine Particles, January, EPA-6502-75-016.
7. Ash utilization, EEI-NCA-BM Symp., Pittsburgh, 1976, U.S. Bur, Mines, Inf. Circ, No. 8488, 1970, 351 pp.
8. Tentative Specifications for "Fly Ash, For use in Portland Cement Concrete", ASTM paper No. C618-72, Part 10, 1973 pp. 354-358.
9. Gilbert Conman Wealther, Inc (1985) Lakhra Power Feasibility Report.
10. J.T. Boyd (1985) Coal Mine Project Feasibility Report.