A REVIEW ON DEVELOPMENT OF CLEAN COAL TECHNOLOGIES AND APPLICATION TO INDIAN COAL

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ABSTRACT

Coal is the most abundant fossil fuel available far and wide in the world. It continues to occupy a pivotal role in the world energy scene. Many countries are heavily dependent on coal for meeting their energy requirements. Conventional methods for utilization of coal lead to environmental pollution. It is therefore essential to control pollution from use of coal. Clean coal technologies have been under development to use coal on a large scale, more efficiently and cleanly. India too needs them to meet energy demands by utilizing inferior grade coals. Thus, the present effort on development of a Hot Gas Clean Up system to be a part of the Integrated Gasification Combined Cycle for Power Generation from Coal is in line with the National priorities and requirements.

Keywords: Coal, Clean Coal Technology, Integrated Gasification Combine Cycle, Fuel Gas Cleanup,

I. INTRODUCTION

1.1 Role of Coal in World Energy Scene

Coal is by far the most plentiful fossil fuel in the world. It has been estimated in 1996 that, there are around one thousand billion tonnes of global coal reserves economically accessible using current mining technology. At 1998 level of production, coal reserves are sufficient to last over 200 years. Current reserves to production (R/P) ratios of coal in terms of energy content are approximately four times the reserves of oil (life 45 years) and six times that of gas (life 65 years). The countries dependent on coal to meet a high percentage of their total energy needs and power generation are shown inTable-1.

Table-1: Countries Using High Percentage of Coal

Country	Coal in total energy, %	Coal in total percentage
China	73	80
United States	25	55
India	57	73
Russia	40	60
South Africa	75	90
Australia	39	84
Poland	65	97

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II. DEPENDENCE ON COAL IN INDIA

Major energy resources particularly for thermal & hydropower are unevenly distributed in the country. Bulk of the coal reserves i.e. 73% is located in the eastern states of Bihar, Orissa and Bengal. 73% of the hydro potential is available only in north & northeastern parts of the country. 80% of the lignite resources are located in southern India. The uneven distribution of energy resources has to be managed by either transportation of raw material (i.e. coal in this case) or transmission of power over long distances. Due to lack of a national power grid, coal is being transported over long distances from eastern to southern parts of the country.

There are problems in case of hydro & nuclear power generation. The total hydro potential in the country at 60% load factor is estimated as 84044 MW. About 25% of the potential is developed so far. India has very limited reserves of oil and natural gas. The demand of oil is being met through large imports. Quite often than not, the imports exceed indigenous production. For example, in the year 1997-98 the imports were 345 mt as against a domestic production of 338 mt. It is noteworthy a fact that, the geologically known reserves of coal in India are of the order of 211.6 billion tonnes as on 1-1-2000, likely to last over 200 years. Another important reason for dependence on coal is that the cost of power generation using domestic coal is found to be cheaper than imported naphtha, fuel oil and LNG.

III. COAL AND THE ENVIRONMENT: POLLUTANTS FROM COMBUSTION OF COAL

Coal contains carbon, hydrogen, volatile matter, mineral matter, nitrogen, sulfur, and moisture etc. It is known that during combustion of coal, these elements are converted to their oxides followed by the release of energy. The main elements, carbon and hydrogen, are converted into carbon dioxide and water. If the combustion is incomplete, the reactions may result in the formation of carbon monoxide and some hydrocarbons. The incombustible mineral matter is removed as ash and may contain some carbon if the carbon conversion is not completed.

Nearly all the sulfur in coal is converted into sulfur dioxide except for a small proportion that ends up as sulfates in the ash during combustion. Sulfur dioxide is slowly oxidized to sulfur trioxide and reacts with water particles in clouds to form sulfuric acid, resulting in acid precipitation. The increased concentration of carbon dioxide in the atmosphere has a warming effect known as greenhouse effect. Nitrogen in coal is converted into gaseous pollutants known as NOX consisting of oxides of nitrogen. The worst environmental impact of NOX is the greenhouse effect and the possible formation of photochemical smog. NOX has a global warming potential of 270 times compared to CO2. Coal is more carbon intensive than oil and gas as shown in Table-2. Therefore the greenhouse effect is enhanced by increased use of coal.

TABLE-2: CARBON INTENSITY OF FOSSIL FUELS (T. OF C PER T. OF OIL EQUIV.)

Fuel	Carbon Intensity, t./t.oe
Coal	1.08
Oil	0.84
Natural Gas	0.64

Source: Richard C Dorf (2001)

Coal can be utilized cleanly and efficiently, using improved technologies, particularly the Clean Coal Technologies. One of the primary objectives for development of cleaner technologies for utilization of coal is to

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reduce its contribution to the greenhouse effect. Combustion of all fossil fuels (oil, gas and coal) results in emission of CO2, SO2 and NOX. CO2 emissions from fossil fuel combustion worldwide increased from 3,811 million tones of carbon equivalent in 1970 to 5,821 million in 1990 and are projected to reach 9,762 million in 2020. Approximately 67% of these are projected to come from the developing countries.

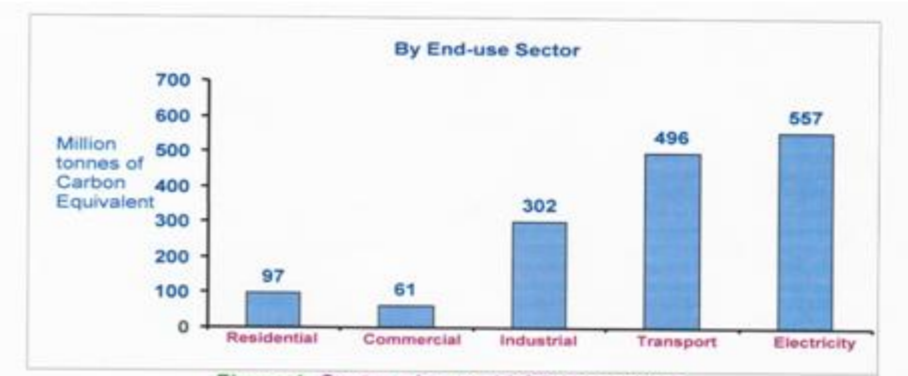

Figure-1: Sector wise world CO_2 emissions

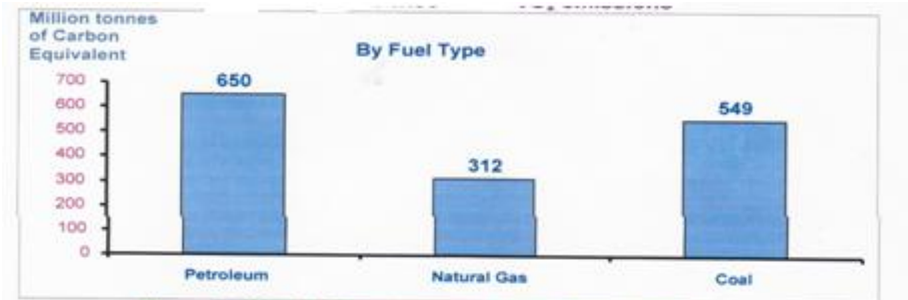

Figure-2: World CO_2 emissions by fuel type in 1999

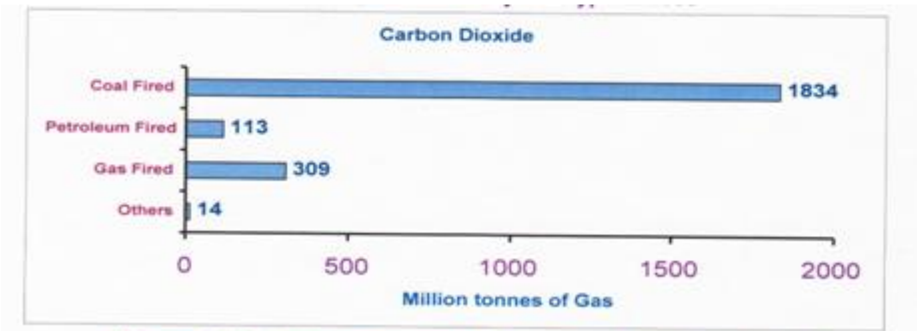

Figure-3: World CO_2 emissions from electricity generation in 1999

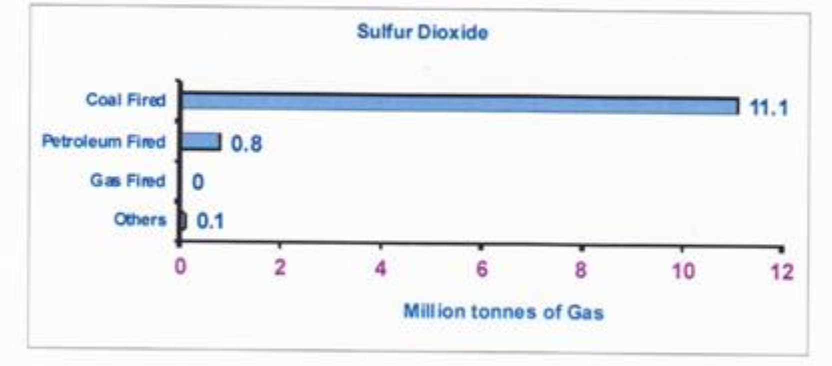

Fig 4: World SOx emissions from electricity generation in 1999

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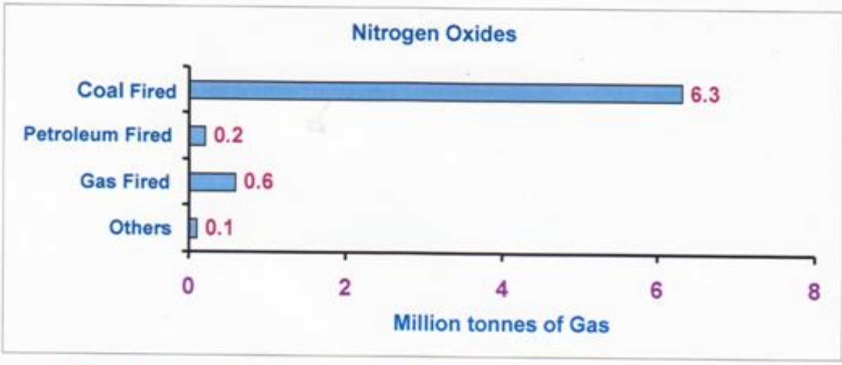

Figure-5: World NO_x emissions from electricity generation in 1999

IV. CLEAN COAL TECHNOLOGIES

Clean Coal Technologies (CCTs) are defined as 'technologies designed to enhance both the efficiency and the environmental acceptability of coal extraction, preparation and use'. These technologies reduce emission, and waste, and increase the amount of useful energy gained from each tonne of coal. CCTs can be applied at any stage of the coal chain from its mining to utilization. CCT programmes are being vigorously pursued by many countries (USA, Japan, Australia and Europe etc.) for developing utilization technologies that will enable coal use to be increasingly efficient and environmentally acceptable. Most CCTs concentrate on power generation from coal, as more than 60% of coal produced globally, is used to generate electricity.

4.1 Emission Control Devices / Technologies

To control / reduce emission of SO2, NOX and particulates from the coal-fired thermal power plants, an impressive array of technologies already commercially viable/ being practiced is available and includes Physical cleaning of coal, Advanced coal cleaning, Low-NOx burners, Sorbent injection / Duct injection, Pre-ESP, Post-ESP, wet FGD, Dry FGD, SNCR, SCR, deSOx/ deNOx Bag filters, Advanced ESP, Hot Cyclones, etc.

4.2 Advanced Power Generation Systems

When compared with the conventional technologies such as, natural gas based combined cycle (NGCC) and pulverized coal fired plant (PC), it is evident that the Clean Coal Technologies, namely, the Integrated gasification combined cycle (IGCC) and Pressurized fluidized bed combustion (PFBC) have higher efficiencies, are environmentally superior and economically comparable.

4.2.1 Pressurized Fluidized Bed Combustion (PFBC)

PFBC technology has been adequately demonstrated and has also progressed towards full commercial acceptance and is projected to improve further as shown in Table-3.

TABLE-3: Progression of Pfbc Cost And Performance

Parameter	1990 Tidd Plant	1999 Karita Plant	DOE Goal by 2010
Net Output,MW	70	360	320
Efficiency,%	35	42	45-50
Cost,$/KW	1943	1263	-
SO2 emission	95% removal	0.16	97% removal
NOx emission, lb/106 btu	0.30	0.10	0.10
Particulate, lb/106 btu	0.02	0.01	0.002

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Improvement in efficiency, cost optimization and environmental performance of PFBC is taking place through technology development.

4.2.2 Integrated Gasification Combine Cycle (IGCC)

Coal based power generation is slated to increase substantially in the next two V-year plan periods. With growing awareness of the harmful effects of the atmospheric pollution caused by the low efficiency combustion of coal, the gasification route is expected to be the preferred choice for its utilization. The attractiveness of IGCC as a power generation technology has progressed towards full commercial acceptance and is projected to improve further as shown in Table-4.lGCC can also economically meet emission levels to far below the norms. Sulfur in coal feed is recovered as saleable sulfur economically, controlling SO2 emission without the need of expensive FGD unit.

TABLE-4: progression of IGCC Cost and Performance.

Parameter	1985 Cool Water	1995 CCT	DOE Goal by 2000	DOE Goal by 2010
Net Output,MW	100	>250	>250	>250
Efficiency,%	32	40	42	>50
Cost,$/KW	2500	1500	1250	1000
SO2 emission	0.14	0.10	0.12	1.12
NOx emission, lb/106 btu	0.07	0.16	0.06	0.06

IGCC is aimed at improving efficiency, environmental performance and achieve cost optimization through the following areas of technology development: Advanced gasifier and gas separation, Hot gas desulfurization and hot particulates removal, Advanced turbine systems etc. IGCC operating costs can be lower than those of a PC plant due to reduced fuel use from its low heat rate, by-product sulfur credits and low volume of solid waste. Other potential economic advantages of IGCC can be achieved through phased construction, co-production/co-generation and fuel flexibility. Coal gasification route is the cleanest and efficient means of coal utilization since ash and sulfur present in the coal are removed in the gasification system itself efficiently and economically. The fuel gas / synthesis gas from coal gasification is as clean as natural gas. High ash and high sulfur coals can also be gasified to produce clean gas. Coal gasification offers multiple choices of coal utilization since coal gas can be used as fuel gas for power generation and as syngas for production of chemicals, fertilizers and liquid fuels and as town gas and as reducing gas for making iron and steel etc. Thus coal gasification is a good choice for high ash coals of India.

PFBC & IGCC have higher efficiencies leading to reduced emissions of CO2 per MWh of power. The technologies are cost-effective due to their higher efficiency levels. It can be seen that, both these technologies are incomplete without the Hot Gas Clean up system and R&D work on the development of processes for high temperature clean up of the gases has been in progress world over.

V. INDIAN EXPERIENCE ON COAL GASIFICATION

In India two commercial K-T gasification plants were in operation in the 900-tpd fertilizer plants at Ramagundam and Talcher. Hailed as the "World's Largest Gasifiers". They were the first-two Four headed K-T gasifiers set up in the world. A unit based on the Winkler fluid bed gasification system was in operation in Neyveli, processing lignite for the production of urea. Bharat Heavy Electricals Limited (BHEL) has a 150 tpd IGCC demonstration plant at Trichy based on air blown moving bed gasifier. This plant can produce a total of 6.2 MW and was commissioned in

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1988. Later, a 150 tpd PFBG unit was erected to feed fuel gas to the Combined Cycle at the same site, based on the technology developed in their 18-tpd Process Development Unit (PDU) at Hyderabad for fluidized bed gasification. CSIR laboratories have been engaged in developmental work on gasification for four decades. Central Fuel Research Institute (CFRI), Jealgora, installed a down-draft gasifier, a cross draft producer, and a powdered coal gasification unit (about 25 kg/h) and a 110 kg/h K-T entrained bed gasifier. In 1962, a 0.8 m diameter moving bed pressure gasifier (19 tpd) was set up and gasification characteristics of eight coals were studied. A moving bed pressure gasifier of 1.3m dia. (24 tpd) was in operation at the Indian Institute of Chemical Technology, (IICT) Hyderabad during the period 1983-92 and high pressure gasification trials on seven different Indian coals and lignite were conducted, generating valuable process data on the gasification characteristics of these coals. IICT studied extensively in its 1 tph pilot plant, the gasification characteristics of the coals from different coal-fields in India, which were identified to be used for power generation in the future. Coals from Godavari Valley (Godavarikhani and Manuguru), Wardha Valley (Hindustan-Lalpeth), Ranigunj (Samla), Singrauli (Jayant), and North Karanpura (Dakra) and lignite briquette chips from NLC, Neyveli were used in the gasification pilot plant to test their amenability to moving bed gasification and to collect operating data required for the design of bigger plants.

5.1. The Indian IGCC Demonstration Project & The Tefr

Integrated Gasification Combined Cycle (IGCC) power generation technology, being developed elsewhere in the world, offers a superior alternative with better performance indicators, both in technical and environmental aspects. However, the technology as of now is, as good as being 'half-baked', as long as it is not demonstrated to be amenable to the kind of low-grade coals that are locally available. It was also seen in an earlier Techno-Economic Assessment (1992) that, IGCC appears to be a slightly costlier option. This may not be true once, the technology is fully absorbed and in fact, the unit capital costs for commercial-scale plants are supposedly lower, compared to that for a much smaller demonstration plant. Government of India, from time to time in the past, had initiated specific action plans to study the R&D efforts world over, for developing suitable clean energy technologies such as the Integrated Gasification Combined Cycle for power generation. Large-scale R&D programmes on gasification of the low grade, non-caking Indian coals were carried-out at various research institutions like IICT, Hyderabad, CFRI, Dhanbad and BHEL(R&D), Trichy.

At IICT, the development of suitable technologies for the rational utilization of the low-grade coals that included studies on various aspects of utilization of Indian non-caking coals including briquetting of coal fines (and bio-mass), hydrogenation of coal tar products, low temperature carbonization (LTC) of coal etc., was done. IICT under a UNDP programme during the 80's erected and operated a 24-tpd moving bed gasification plant and collected extensive operating data on Moving bed gasification of various Indian coals. Extensive trials with different coals for generation of operating data were concluded. The proposed demonstration project should therefore, try to utilize the indigenous capabilities/expertise developed through the aforesaid local R&D programs and thus, get perfectly linked to the national priorities and objectives in the Energy sector. The Government had set up an expert group in 1987 with CSIR as the nodal agency to look into various available gasification technologies and to select the most suitable gasification technology for an IGCC demonstration plant, keeping in view the high ash content of coals that will be available for power generation. The group had studied various first and second-generation gasification

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technologies available by visiting these facilities abroad. Based on the status of their development, the operating performance projected by the process-licensors and other factors, the following four processes were short-listed for testing the candidate coal:

a) Dry ash moving bed process indigenized by IICT

b) Kellogg-Rust-Westinghouse ash-agglomerating fluidized bed process

c) Shell dry entrained bed process, and

d) Texaco slurry-fed entrained bed process

The candidate coal from North Karanpura (NKP) identified by the group as the feed coal for the demonstration plant was to be tested in the moving bed process at pilot and demonstration level facilities of IICT and BHEL (T) respectively and at lab- scale by other process-licensors in their respective facilities in USA.

Accordingly IICT had procured about 2000 tons of NKP coal. Extensive experimental programmes with varying parameters like Steam/Oxidant ratio in the gasifying medium, Operating Pressure, etc., with a choice of oxidant between Air and pure Oxygen were executed and the data collected during the best operating conditions were evaluated for scale up. Based on the above data from the 24-tpd pilot gasifier of IICT, Hyderabad and also the data from the 150 tpd BHEL unit at Trichy, the dynamic similarity between the two units could be established. llCT's data was scaled up to suit the production of fuel gas required to generate 600MWe of power through IGCC, in collaboration with PDIL (Sindri) for assessing the performance of Moving bed gasification process when using high ash North Karanpura coal from Bihar. The above study became a part of the Techno-Economic Feasibility Report (TEFR) for a 600 MWe conceptual IGCC plant prepared by M/S. Bechtel Corporation, USA for the U.S. processes (Shell, Texaco and KRW) and was compared with that for a conventional PC plant (NTPC) with and without FGD. The Techno-economic Assessment concluded as under:

"The study showed IGCC is a viable power generation option for the high ash Indian coal. In comparison with PC plant, it has superior heat rate at comparable cost of generation. In addition to the better heat rate, IGCC also offers lower emissions, less water consumption, higher plant availability, and flexibilities for modular construction and phased construction. Therefore, IGCC can be an attractive power generation alternative in the future for India. Among the four IGCC technologies considered, the KRW gasifier or similar fluidized bed gasification processes, such as U-Gas, is most attractive to use for the high ash Indian coal. The KRW gasifier, however, has several technical uncertainties. This gasifier has been proven only on a pilot scale. The in-bed sulphur capture and hot particulates removal for gas cleanup have been tested but only with limited experience. The ability to achieve a high Cas conversion in the ash sulphation unit has not been demonstrated. The moving bed gasifier, on the other hand, is commercially proven and has been tested for Indian coal. Even though it is less efficient and more costly than the fluidized bed technology, it is considered equally attractive to use for the high ash Indian coal.

The Shell technology has an attractive heat rate and is very close to commercialization. But as it has a very high capital requirement, it probably does not warrant further consideration. Because of the severe penalties imposed by its slurry feed system on the heat rate and capital cost, the Texaco technology is not recommended.' Keeping these in view, IICT had been actively engaged in the programmes to propagate the need for clean coal technologies and build up awareness regarding the efficient, economical and eco-friendly use of this fossil fuel resource. IICT continued to participate in the pre-feasibility studies conducted by the steering committee for various power plant

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locations such as Desu, Dadri, Badarpur, Maithon, Sabarmati etc., for retro-fitting the existing inefficient thermal power stations with a Gas Turbine and a Gasifier to convert them into combined cycle plants economically. Subsequently, IICT was associated with a Project Advisory Group, Ministry of Power, Govt. of India, which worked out the modalities for the implementation of a 100 MW green-field IGCC project at Dadri (1998).

VI. NEED FOR FUEL GAS CLEANUP

The subject area is relevant to gasification of coal, which has been widely accepted as an efficient method of utilization of coal. Integrated Gasification Combined Cycle (IGCC) system has been recognized as an attractive method for clean power generation. Since the overall performance of the process in technical, environmental and economic terms depends on the characteristics of the fuel gas used in the combined cycle, the cleanup of the fuel gas prior to its use in gas turbine becomes essential in order to effectively protect the environment and the equipment. For example, combustion of fuel gases in a gas turbine to produce power requires that the gas must be devoid of particulates and sulfur compounds so that the turbine blades and other internals are not subjected to erosion or corrosion. This also results in avoiding the formation of the pollutant gases such as oxides of sulfur that cause the acid rain problems in the environment. Thus, the gas clean up system must achieve contaminant levels that satisfy the combustion turbine requirements as well as the emission levels that can meet the stringent environmental demands of the future.

Desulfurizing the fuel gas before its combustion in gas turbine not only prevents the formation of the sulfur dioxide but also could make it possible to recover a saleable, elemental sulfur by-product that could be a credit on the process financially. Instead, if the flue gases after combustion were to be desulfurized, it would mean handling of large volumes of exhaust gases, requiring larger equipment and higher operating costs. Conventionally, water-washing the hot crude gases from the gasifier had been practiced for cleaning the gases off its dust content and to remove the acid-gases by absorption in aqueous alkali solutions. However, this method results in cooling the crude gases to near-ambient temperatures and the associated loss of sensible heat results in lower overall efficiency of the system. On the contrary, the hot gas cleanup methods that are under various stages of development, aim at cleaning the crude gases at high temperatures so that the overall efficiency is not penalized. While Hot cyclones, ESPs, Ceramic candle filters, Cross flow filters and Granular bed filters serve the purpose of removing the dust and fine particulates from the crude gases, chemical adsorption on regenerable sorbents such as oxides of iron, zinc, copper, manganese etc., is being developed for hot gas desulfurization. Other sorbents such as zinc ferrite, cobalt aluminate, iron chromite, iron orthosilicate and cobalt titanate were reported to have exhibited good absorption abilities towards sulfur content of the crude gas.

As a part of continuing efforts towards realizing the goal of setting up of an IGCC demonstration plant for high-ash Indian coals, it was proposed to find synergistic means to utilize the available expertise, in order that a meaningful solution could be found to the pollution problems that the power industry is faced with today. Accordingly, the dust and sulfur emission problems were identified to be addressed at very high temperatures of 850°C in the first phase of this work, while the development of dry methods for removal of the trace contaminants such as Ammonia and Alkali metal vapor along with the sulfur components at medium temperatures of around 500°C to suit to the actual gas stream temperatures as available in a real plant situation in a fluidized bed gasification plant, were taken up in the second phase, in order that the gap areas in the indigenous development of environmentally benign power

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generation technologies could be abridged. Thus to start with, IICT had taken up a R&D project involving experimental trials on "Production of Clean fuel gas from coal-derived gases using Reactive, regenerable sorbents for Sulphur removal, and Candle Filters for Particulates control" for enabling the country to adopt indigenous technology for 'Hot Gas Cleanup', whenever such a need arises in future. Apart from the advantage of having the technology developed indigenously, the project would also result in building capability in terms of operating expertise that could be gainfully utilized in the implementation of the Indian IGCC project.

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