

CONTROL OF POLLUTION IN POWER GENERATION

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Summary

Energy consumption is directly linked to the progress of society, because it substitutes for human and animal labor. This link can be followed to such achievements of civilization as the abolition of serfdom, slave and child labor, emancipation of women, social and physical mobility. Because of that, power generation is related not only to the physical definition of producing energy per unit time, but also to the power to improve life.

Emissions from power generation constitute a major contribution to the negative anthropogenic influence on the environment. In 1997, they were 99, 32, and 20 per cent of the carbon dioxide, methane, and nitrous oxide, respectively generated in the USA. Emissions of the rest of the nitrogen oxides from combustion in stationary and mobile sources represented 95 per cent of national emissions. Carbon monoxide, non-methane volatile organic compounds and sulfur oxides emissions contributed approximately 87,

46 and 93 per cent, respectively.

Forecasts indicate that by 2010 the energy use in the Organization for Economic Cooperation and Development (OECD) countries will be about 26 per cent above 1992 levels. The non-OECD countries will increase their energy use by almost 48 per cent. Given the depleting tendencies of crude oil resources, most of the countries intend to satisfy their future needs with natural gas and coal based energy.

The chapter describes modern pollution control technologies for power generation, which may provide adequate solutions to the problems the above outlined development will create.

Problems facing nuclear power generation and options to involve renewable and less polluting resources are also discussed.

Worldwide implementation of these technologies, together with new technologies for increased efficiency in energy consumption can face the challenges of the sustainable development of power generation.

1. Introduction

Energy consumption is directly linked to progress of human society, because it substitutes for human and animal labor. This link can be followed to such achievements of civilization as the abolition of serfdom, slave and child labor, emancipation of women, social and physical mobility. So, power generation is related not only to the physical definition of producing energy per unit time, but also to the power to improve life.

Energy consumption in the world increased more than a hundred times from the primitive era to the modern day. About one hundred and fifty years ago began the intensive use of fossil fuels, which provided the present high rates of energy consumption and environmental problems.

Fossil fuels bear chemical energy, which may be transformed into power. Usually, this is not done directly but through intensive, cleaner and easier to apply end-use energy products (energy carriers) like steam, gasoline, cleaned coal products, etc.

The most widely used process for releasing the chemical energy of fossil fuels is combustion. Every fossil fuel contains predominantly carbon and hydrogen bound in chemical structures. Small amounts of other elements can also be present in different proportions. The products of their combustion are the oxides of these elements. A considerable amount of the so-called “thermal” nitrogen oxides can be formed at high combustion temperatures by nitrogen and oxygen contained in the primary industrial oxidizer – air. Effluents contain also compounds from the original fuels and intermediate compounds, synthesized in the process (i. e., polycyclic hydrocarbons, particulate matter), since in industrial applications complete combustion is rarely realized.

Emissions from power generation constitute a major contribution to anthropogenic pollution. In 1997 they were 99, 32, and 20 per cent of the generated in the USA carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) greenhouse gases, respectively. Emissions of the rest of the nitrogen oxides (NO_x) from combustion in stationary and mobile sources represented 95 per cent of national NO_x emissions. Carbon monoxide (CO), non-methane volatile organic compounds and sulfur oxides emissions contributed approximately 87, 46 and 93 per cent, respectively.

The sources of fossil fuels are limited, not renewable and unevenly distributed in different places throughout the world. This motivates the need for greater participation of renewable less polluting resources like solar, hydroelectric, geothermal, nuclear, biomass, and tidal energy in power generation.

2. Environmental Pollution from Production and Pre-combustion Processing of Fossil Fuels.

The environmental problems arising from the production, transportation and processing of natural gas and crude oil are the object of the chapter on *Control of Pollution in the Petroleum Industry*. The present chapter concentrates on pollution in the production of electricity and thermal energy.

2.1. Composition of Fossil Fuels and Its Influence on Environmental Pollution.

Coal is a major source of energy. Coal-fired power stations generate almost 40 per cent of the world's electricity - more than twice the proportion from any other fuel. Currently around 55 per cent of the US electricity is also produced from coal. However, coal poses environmental problems that are not experienced in burning other fossil fuels.

There are different coals in Earth's crust. Coal was formed by accumulation in swamps, biological decomposition and geological transformation of plant debris around a hundred million year ago. It is classified by the degree to which organic matter has been transformed from cellulose.

Peat is unconsolidated and shows structures of vegetal matter. *Lignite* is of younger geological origin than high rank coal. Peat and lignite have high moisture content and volatile matter. *Anthracite* is the solid fossil fuel with the highest carbon content, only a few per cent volatile matter and hydrogen. It burns almost without smoke.

Coal is primarily an organic substance with varying amounts of inorganic material. It contains clays, carbonates, silicates, chlorides, sulfides, sulfates, oxides and phosphates, or other mineral matter which is usually external to the organic material and not chemically combined with carbon or hydrogen. In some low-rank coals alkali and alkali-earth elements and some rare metals as Ge are often combined with carbon or hydrogen.

The total amount of sulfur in coal can be up to ten weight per cent but in most samples is in the range of one to four per cent. Three forms of sulfur occur in coal - organic sulfur, which is bound to the hydrocarbon structure of the coal, pyritic sulfur and

sulfates.

Pyritic and sulfatic sulfur is in the form of iron, calcium, and barium sulfates, generally of low concentration. Elemental sulfur has been found in some coals but is rare. Variations in coal sulfur content are usually due to the mineral matter. Sulfatic sulfur is usually water-soluble and easily removed by washing. Organic sulfur is distributed in the coal as sulfidic, disulfidic, mercaptanic and thiophenic groups. No organic sulfur compounds can be isolated from coal without changing its organic structure so organic sulfur is the most difficult to remove from coal.

The mineral matter in coal is distributed in various forms. Some occurs as mineral inclusions, dispersed in the carbonaceous coal matrix. Another portion is in cations with carboxylic acid side chains or in porphyrin-type structures. The behavior of mineral matter depends strongly on the chemical and physical state of the mineral inclusions.

Sulfur causes spontaneous combustion in stored coal. Sulfurous acid is formed when the flue gas is cooled below the “dew point”(the temperature at which water vapor condenses). This acid is corrosive to tubes, air heaters, economizer sections and stacks.

In the beginning of combustion, the coal moisture is desorbed. Later the organic matter is decomposed to yield “volatile matter” at temperatures over 300° C, depending on the structure of the coal. The mineral inclusions will decompose and fuse at temperatures between 600 and 900° C. The carbonates yield CO₂ and respective metal oxides that are partially converted to sulfates. Both volatile compounds, such as those of alkali metals, and less volatile compounds, such as the salts of Si, Mg, Ca and Fe are found to evolve during char combustion. After combustion, the inorganic material is found mainly in the ash, which is the noncombustible residue after complete combustion. Its quantity varies with the type of coal and the region in which it is mined. During burning, various chemical and physical changes take place. The basic oxides, as components of the ash, tend to lower its fusion temperature, while SiO₂, Al₂O₃ and TiO₂ raise the fusion temperature.

In combustion of solid fuels, an increase of ash content usually indicates an increase in carbon carried to waste or imperfect combustion. After the distillation of volatile matter, a solid is left. It consists mainly of carbon and mineral matter but contains also hydrogen, oxygen, nitrogen and sulfur that are not driven off with the gases.

Two major categories of *fuel oil* are burned for power generation: distillate oils and residual oils. Distillate oils are more volatile and less viscous than residual oils. They have negligible nitrogen and ash content with sulfur less than 0.3 percent (by weight). Distillate oils, used in domestic and small commercial applications include kerosene and diesel fuels. The heavier residual oils may need to be heated for ease of handling and proper atomization. Residual oils contain significant quantities of metals, nitrogen, and sulfur. They are used mainly in utility, industrial, and large commercial applications.

Waste oils include used crankcase oils from automobiles and trucks, industrial lubricating oils, heat transfer fluids, etc. Emissions from burning waste oils reflect their

composition. They include the typical combustion pollutants and increased amount of metals and toxic compounds from the additives incorporated in the original oils. The ash levels in waste oils are normally much higher than in distillate or residual oils. They have also substantially higher concentrations of most of the trace elements as compared to virgin fuel oils.

Without proper air pollution controls, the higher concentrations of ash and trace metals in the waste oils transform into higher emissions. Emissions of SO_x depend on the sulfur content, which in waste oils may be higher than in distillate oils but lower than in residual oils. High levels of halogenated solvents are also often found in waste oils.

2.2. Coal Mining and Technologies for its Pollution Control.

The environmental problems of power generation from coal combustion begin with its mining. There are two kinds of coal mining: - underground and surface. Coal lying deeper than 100 m is mined by underground techniques. A thin seam of coal that lies 2000 meters below the earth surface is not considered usable at present, because more energy would be required to extract it than can be gained.

The overburden ratio is very important for surface mining. It is defined as the ratio of the depth of overburden soil above the seam, to the thickness of the seam and ranges between 6:1 and 15:1. In order to avoid environmental problems the removal, storage and redistribution of topsoil must be strictly regulated by environmental laws. These should cover siting, and erosion control, drainage and restoration of coal haul roads, protection of water quality and hydraulic balance.

Coal mining operations are sources of air pollution in the form of methane, coal or rock dust. Methane originates from the underground formation. It is very well controlled in modern mines. The dust release is generally lower for underground mining than for the surface one.

It can be controlled by water sprays or wetting in the case of surface mining. Ground or surface water is consumed for coal mining in sluicing, cleaning and transfer as well as for dust suppression and coal preparation.

Gaseous air pollutants may also be generated by the transport operations within the mine area. In order to minimize air pollution, electrically powered rail transport and coal slurry pipelines are used. In a coal slurry pipeline, the coal must be ground to a uniform size of particular dimension by crushing and pulverization in the liquid phase.

Slurry pipelines have the advantages of being able to move large amounts of coal over long distances. Water consumption is about one m³ per ton of coal for a one-way pipeline and less, if a two-way re-circulating slurry pipeline is employed. Water consumption requirements can be significantly reduced if methanol or crude oil is used as the transport medium.

Underground mines release also coal dust particles from blasting or loading operations. Gases like hydrogen sulfide, sulfur dioxide, methane, etc. are in relatively low

concentrations. Particulate emissions are up to 0.3 g per ton of coal. They are greater in surface mining because of the open exposure to the atmosphere. Major variables affecting fugitive emissions of particulate matter from surface operations are the vegetation cover present, the rainfall amount, the terrain and the moisture content of the soil.

Total gaseous emissions from coal mining are less significant than particulate emissions. Diesel oil combustion for in-mine transport is usually also a major source of gaseous air pollutants.

Water pollutants are suspended and solved solids, sulfates, acidity and alkalinity. Acidity derives from oxidation of coal pyrites by the oxygen dissolved in water or contained in the air pumped in. Acidification is accelerated by microorganisms. The overall effect is the conversion of sulfur compounds into sulfuric acid.

Other chemicals are present in mine-effluents as well. Their composition varies considerably from one location to another. Against the formation of acid, mine-water landscaping and sealing of coal mines, is used.

Sometimes the mines are flooded with water in order to keep oxygen out. Another method uses lagoons to impound acid mine-water, which can be used for washing coal. Acid mine drainage is controlled by neutralization and softening with limestone, lime or alkaline ash.

When coal is mined, the land surface is disrupted. Back filling, grading, restoration, re-vegetation and post mining land uses are needed after surface mining. The storage and disposal of mine wastes must be on well designed, constructed and maintained sites in order to prevent combustion, adverse water quality impact and corrosion. Soil overburden from surface mining and dirt from shaft mining can be kept in embankments and backfields after mining is completed.

The impurities removed during preparation are also included in the solid wastes. They can be concentrated and placed temporarily in refuse piles to be followed by landfill or mine-fill disposal. The coal fines from the coal preparation can be concentrated, dried, reclaimed and sold for use.

2.3. Pre-combustion Cleaning.

Pre-combustion cleaning (sometimes called coal “beneficiation”) is used to reduce the mineral and ash content in the coal. Coal preparation involves storage, handling, sizing and mechanical cleaning. Physical cleaning separates undesirable matter from coal by relying on differences in densities or other physical characteristics. Pyrite for example is three times denser than the organic fraction of coal.

Crushers used in coal preparation are rotary breakers, roll crushers, hammer mills and impactors. When the coal is crushed and then washed, the heavier impurities are separated. Low-rank coal is generally not beneficiated with water because it is hydrophilic. The equipment of physical beneficiation methods includes jigs,

concentrating tables, dense-medium or pneumatic separators, hydrocyclones, etc.

Froth flotation is used for cleaning the fine (less than 0.5 mm) classes of hydrophobic bituminous coal. The process performance depends on rank and state of oxidation of coal, differences in surface characteristics between the coal and mineral particles, pH, conditioning time and temperature.

Physical cleaning can remove only matter that is physically distinct from coal. Pyrites are hydrophobic and tend to float with the coal during the process of flotation. Physical cleaning can not remove organic sulfur and nitrogen. Thirty to fifty per cent of the pyritic sulfur and about 60 per cent of the ash-forming minerals can be removed. Modern physical cleaning techniques achieve increased effectiveness by grinding coal into smaller sizes.

Biological cleaning capable to remove about 90 per cent of the total sulfur (both pyritic and organic) and 99 per cent of the ash in coal is being tested. Suitable bacteria utilize these impurities in a coal-water slurry.

Water used for transportation of coal or the various cleaning processes must be clarified. The water clarification is based on gravity settling to reduce solids content to less than 0.5 per cent. Different types of flocculants are used to enhance the settling process, and gather the solids into large flocs.

Coal needs to be de-watered in order to avoid freezing during transportation, to reduce heat loss in the processes of combustion or conversion and to decrease transportation cost. Different types of centrifuges or filters are used for de-watering.

Emissions from waste oils can be controlled by pretreatment to remove the pollutant precursors or with emission controls to remove the air pollutants. Reduction of emission levels is not the only purpose of the pretreatment. Improvement in combustion efficiency and reduction of erosion and corrosion of the combustor are also important considerations.

The most common pretreatment scheme uses sedimentation followed by filtration. Water and large particles are removed without much effect on sulfur, nitrogen, or chlorine contents. Other methods of pretreatment involve contacting with clay; demetallization by acid, solvent, or other chemicals; thermal processing to remove residual water and light ends and solvent extraction.

The latter processes are attractive as waste reduction schemes or for regeneration of waste oil. The added costs hinder their use as part of a combustion process. Blending of waste oil with a virgin fuel oil is practiced frequently and has the same effect as some of the other pretreatment processes.

3. Power Generation from Fossil Fuels.

Figure 1 provides a simplified scheme of a fossil fuel electric power generating facility and outlines the typical pollution sources.

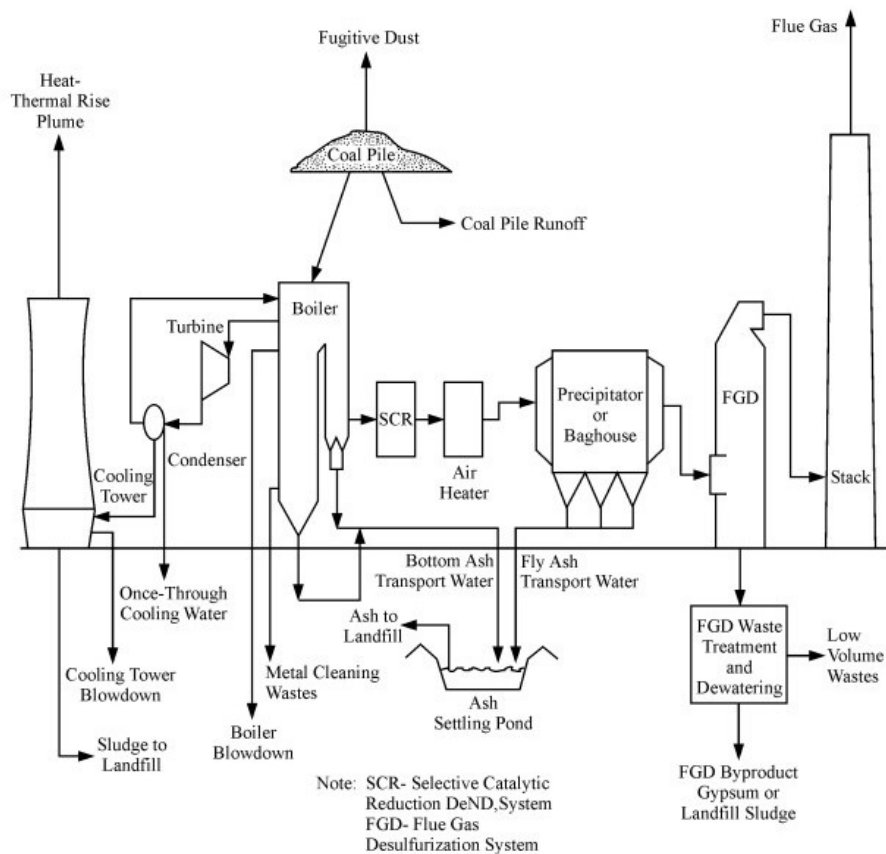


Figure 1. Waste Streams Generated at a Typical Fossil Fuel Electric Power Generation Plant.

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Biographical Sketches

Georgi St. Cholakov is Associate Professor at the University of Chemical Technology and Metallurgy in Sofia. He received his first hands-on experience of ecological problems during his compulsory military service as the Head of the Fuels and Lubricants Unit of an airbase. His PhD dissertation was on development of replacements for lubricant additives synthesized from the sperm oil, obtained from blue whales. He did a post doc specialization in tribology at the University of Birmingham, U.K. Later he specialized in effective and ecological processing and use of petroleum derivatives at Imperial College, London, the French Institute of Petroleum, and other leading universities. The scientific and research interests of G. St. Cholakov are centered around petroleum processing and petroleum derivatives – environmentally compatible processes and products, process and product design for the petroleum industry, chemistry of combustion and ecology, etc. He is teaching advanced courses in related academic disciplines – alternative fuels and lubricants, air pollution management, chemistry of combustion and ecology, additives for fuels and lubricants, technological computation in petroleum processing, etc. He has contributed more than 50 papers in refereed international journals and co-edited the Bulgarian edition of Miall's Dictionary of Chemistry. G. St. Cholakov is member and has served in elective positions in different Bulgarian and Balkan professional organizations. He has been member of the editorial boards of two journals, published in Bulgaria in the English language.

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