



The environmental effects of coal and pollution control techniques for green coal mining

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ABSTRACT

The purpose of this study is to note the influence of coal on environmental pollution and introduce solutions for the removal of this pollution. Environmental problems caused by coal production and use can be improved or efficiently addressed during processing, recovery, conversion, or reclamation. Coal is a dominant primary source of chemical energy and the production of power, and the primary source of greenhouse gases and air pollutants. The demand for these coal products is increasing throughout the world. This demand in traditional markets is rising steadily. Coal is essential for developing countries; therefore, practical use is vital for energy-poor countries. If the adverse effects (or impacts) of coal on the environment are handled successfully, it can have a bright future. Clean coal technologies (CCT) are needed to utilize coal in an environmentally acceptable way and to improve coal utilization efficiency. Clean coal technology (CCT) is the main issue in maintaining a clean environment in an economically viable manner. Carbon sequestration and electrostatic and fabric filters are the other control techniques for coal mining pollution.

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1 . Introduction

In the process of industrial development, coal mining is the primary industry, which is contributing inadvertently to the pollution of the environment. But at the same time, it also assures the energy supply, which is indispensable for the development of a country [1]. Coal is a primary fuel used for generating electricity

worldwide. It provides around 27% of global primary energy needs and generates about 36% of the world's electricity [1]. From mining to coal cleaning, transportation to electricity generation to disposal, coal releases numerous toxic pollutants into the air, water, and land. These disrupt ecosystems and endanger human health [2]. Generating coke from coal causes dangerous effects on the environment, especially in its traditional methods. Releasing and disposal of clinker (The residual burned coke in the furnace) is one of the main problems in the environment, although it is beneficial for producing Portland cement.

Coal mining by both open mining and underground methods affects the area's environment, especially water resources, by discharging vast amounts of mine water [1]. When contaminated mine water discharges to environmentally sensitive receiving waters, it causes environmental problems. Most coal mines are located in the catchment area of the water authority and discharge their effluent to creeks and water sources under licensing conditions imposed by the environmental protection authority [3]. Mine water includes drainage from underground mines, water from the pit bottom of open-pit mines, and wastewater from surface constructions (waste rock dumps, roads, mechanical workshops, and sanitary facilities). Researchers present water intensity metrics for the coal lifecycles [4]. For example, [Table 1](#) shows the average water consumption for extraction, processing, combustion, and transport.

Table 1. Average water consumption for coal mining [4].

Average water consumption (l/MWh)	Coal
...for extraction	11–53
...for processing	0–109
...for combustion	1970–3940
...for transport	Negligible

Mining environment protection in the coal industry has been paid much attention in recent years, of which coal mine drainage treatment is the most critical issue. However, techniques of environmental rehabilitation, coal mine drainage treatments, and management are totally new [5]. Even though the technologies and techniques of coal mining treatment in developed countries have been accessed and researched, it is not possible to implement them for all coal mines due to differences in geography, climate, finance, and management experience.

Investigations in the southern section of the state of Santa Catarina in Brazil explained that the source of Acid Mine Drainage (AMD) in the river could be from four types of abandoned mine lands: surface mines, coal waste dumps, waste dumps in open pits, and acid dams. Researchers evaluated and analyzed watersheds impacted by mining and integrated other pollution sources, and they tried for water management and protection [6]. Also, they investigated mitigation procedures such as confinement, dry covers, and vegetation, which significantly reduce the number of pollutants released from such sites. In addition, discharges of contaminated drainage from abandoned underground mines are a major environmental problem in this area and influenced the surface and groundwater resources in and around the mines, and these effects propagate downstream. [Fig 1 'a'](#) and ['b'](#) show the river and its contribution, and [Fig .1 'c'](#) shows treatment sites and water quality improvement in the area's watersheds [6].



Fig. 1. a: Coal waste and an acidic pond, b: Surface mined area and spontaneous vegetation, c: Clay cover, spread soil, and vegetation [6].

This article introduces the specific difficulties of coal mine drainage management and treatment, solutions applied in this respect, and their results. These are the necessities of technology and management experiences and are needed to manage the resources of coal mine drainage effectively to contribute to the protection of the ecological environment and improve the living conditions of miners and the local community in the world.

1. Environmental pollution caused by coal mining

1.1. The environmental pollution caused by extraction

Numerous environmentally damaging impacts of coal occur through its mining, preparation, combustion, waste storage, and transport. The environmental effects of coal extraction include health, visibility, agricultural productivity, destruction of the existing ecology and groundwater, erosion, and disruption of public water supply, explosion, ground movement, surface deformation, spontaneous combustion, and aesthetics [7]. Coal mining environmental pollution can be caused by underground and surface extraction. Surface and underground mining methods seriously destroy the landscape, which reduces the natural environmental qualities in the surrounding land. Mining activity inception caused human populations to resettle in the mine site; therefore, activities of agriculture and hunting were interrupted. Surface extraction disadvantages included eliminates available vegetation, destroying the genetic soil, displacing or extirpating wildlife and habitat, altering current land uses, and to some extent, permanently changing the general topography of the area; indiscriminate mining occurs, adverse impacts on geological features in an opencast coal mine and maybe destroyed geomorphic and geophysical features and all aesthetic elements of the landscape such as vegetative cover [8]. Activities associated with the construction of haul roads, stockpiling of topsoil, and

hauling of soil lead to an increase in the quantity of dust which adverse impact on health and safety for mine workers and nearby residents [8].

1.2. The environmental pollution from coal washing

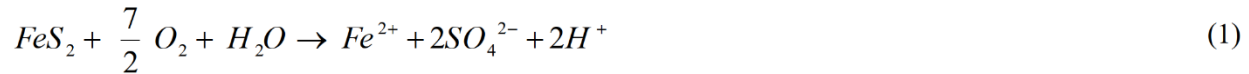
To remove impurities from coal and improve the quality of coal before combustion, coal-washing is applied [9]. Coal-washing not only causes two kinds of tailing: solid tailing and wastewater, but it also affects ecosystems and human health. The environmental effects of coal tailings depend on their origin and volume. The geochemical impact of processing and mineral wastes can be named: sulphide minerals oxidation and its capability of producing acid, sulphides oxidation and making soluble salts, washing the metals, penetrating to the local area, and the characteristics and toxicity of tailing effect on humans and ecosystems (plants and animals). Tailing or waste removal from coal can be achieved by an explosion. An explosion causes some parts of the waste to transfer inside the pit, but the remaining parts become weak enough to be removed easily [10].

Wastewater characteristics from coal mines vary at each zone (from one zone to another) and coal structure. Therefore, wastewater differs significantly in quality and quantity. Wastewater salt mainly consists of chlorides and sulphates. Salinity generally increases by increasing depth and distance from geologic outcrops and troughs [11-14]. Mostly, salty waters have a significant concentration of barium (Ba^{2+}), strontium (Sr^{+}), ammonium (NH_4^{+}), and manganese (Mn^{2+}) ions. The main problem of tailing dams is generating gas and polluted solutions, due to the biological decomposition of these collected wastes. The mentioned gases comprise carbon dioxide, hydrogen sulphide, and methane, which prevent plants from growing. Polluted solutions contain a significant concentration of biologically and chemically needed oxygen and ammonium, which are a severe hazard to groundwater. Raining in such areas leads to washing and releasing an enormous number of pollutants and causes harmful and dangerous effects by entering surface water and groundwater [15-17]. All mines in the world will eventually close, but if water is not controlled, it could acidify and re-enter the ecological system [15, 18]. To minimize the environmental impact of flooding water from old mines, a treatment plant or desalination plant can be constructed at the discharge point of the mine, which enables mine water to be treated to a potable, industrial, or agricultural standard.

1.3. Acid Mine Drainage (AMD) and mine water

Engineering projects, including road construction, airport development, and foundation excavation, are examples of civil projects that resulted in the generation of acidic drainage [19]. In mining, vast amounts of water are discharged to the surface to facilitate the mining operation. The discharged water often contains a high load of toxic shock syndrome (TSS), total dissolved solids (TDS), hardness, and heavy metals, which contaminate the surface and groundwater [1]. Wastewater caused by flotation can be contaminated by particulate matter, oil and grease, unburnt explosives, and other chemicals. If the coal contains a high number of pyrites, the mine water may be acidic and thus pollute the nearby stream after discharge. Runoff after rain can give rise to serious pollution problems, and a variety of other pollutants may also be transported into watercourses. Distinguishing characteristics of AMD are low pH and high concentrations of sulphate and heavy metals that are related to the mining industry [20-22]. Frequently, AMD is generated when the metallic or non-metallic (e.g., coal) sulphide mineral wastes, such as low-grade mine wastes and tailings are exposed to the atmosphere [23, 24]. The oxidative dissolution of sulphide minerals caused the majority of acid metalliferous drainage from mine sites, which represents a substantial environmental problem worldwide [25].

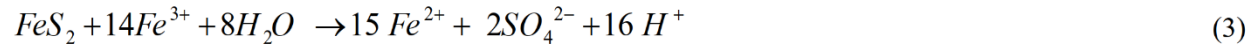
Reaction mechanisms are less well-known, and predicting and controlling the environmental aspects of pyrite oxidation require a better understanding of the chemical reactions. The overall stoichiometric reaction describing pyrite oxidation and AMD generation is given by Eq. (1) [26]:



As Eq. (1) shows, 1 mol of pyrite reacts with 3.5 mol of oxygen to produce 1 mol Fe²⁺, 2 mol SO₄²⁻ and H⁺.



As Eq. (2) shows, the Fe²⁺ may be further oxidized by O₂ converted to Fe³⁺ [27].



As Eq. (3) shows, Fe³⁺ can further oxidize the pyrite to produce additional Fe²⁺ and SO₄²⁻ and H⁺ or hydrolyses into amorphous iron hydroxide, accompanied by the release of additional H⁺ ions into the environment at pH values greater than 3.5, Eq. (4). It should be noted that reaction 2 is slow at low pH values [28].

Indeed, the pyrite oxidation rate highly depends on the temperature, pH, acidophilic Fe microorganisms, moisture, and the availability of oxygen within the tailings, which is mainly governed by the gaseous diffusion process [29]. AMD with high concentrations of iron, SO₄²⁻, and low pH can carry potentially toxic metals such as Cd, Zn, Co, Mo, Ni, Pb, and Cu, and other dissolved materials away from the tailings site [30, 31]. As the acidic water is low-pH and generally contains a high level of heavy metals, it will affect the ecosystem and people in the surrounding area. Therefore, it is essential in mining operations to avoid such problems. Passive treatment is low-cost and easy to maintain, dealing with AMD problems [19, 32]. For many years, several mathematical models have been developed for estimating the prediction of pyrite oxidation and AMD generation and the behavior of the heavy metals in AMD [33-46]. Researchers explained in detail the process of pyrite decomposition [48]. Mine process water treatment is done with various methods, including methods of adsorbent modification [48-52] or treatment plant [18, 53] at the discharge point of the mine.

1.4. Pollution from coal combustion

One of the critical challenges in the world is the danger of global warming under the influence of greenhouse gases. The greenhouse gases cause the Earth's surface, which includes chlorofluorocarbons (CFCs), water vapor, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (NO₂), and ozone. Coal is undoubtedly part of the greenhouse problem, as many coals contain intrinsic contaminants such as sulfur, arsenic, silica, fluorine, lead, and mercury. A notable point is that during combustion, these contaminants are not destroyed but released (or spread) into the air in their original or oxidized form. The primary emissions from coal combustion are Sulphur dioxide (SO₂), nitrogen oxides (NO_x), particulates, carbon dioxide (CO₂), and mercury (Hg). For the coal industry, the negative impacts of greenhouse gas (GHG) emissions, especially NO_x and SO₂, are of the most concern. Increasing combustion temperature and decreasing atmospheric temperature assist in the release of trace elements [54]. The largest source of anthropogenic GHG emissions is CO₂ generated from the combustion of fossil fuels, and nowadays, coal is responsible for 30–40% of world CO emissions from fossil fuels [54, 55].

Emissions of NO_x cause acid rain and ground-level ozone photochemical smog [56]. Solid fuels are very difficult to burn in simple combustion devices such as household cooking and heating stoves without substantial emissions of pollutants, basically because of the difficulty of completely premixing the fuel and air during burning, which is done quickly with liquid and gaseous fuels [57, 58]. Consequently, a substantial fraction of the fuel carbon is converted to air pollutants such as carbon monoxide (CO), nitrogen dioxide (NO₂), and particulate matter (PM). In households that use coal, the pollution issue affects not only indoor air

quality (IAQ) but also outdoor air quality at a local or regional scale [58]. For example, household coal and biomass cook stoves in China divert more than 10% and up to 38% of their fuel carbon into CO, NO₂, and PM [59]. Therefore, seventy percent of NO_x emissions in China are primarily from coal combustion [60]. SO₂ emissions have been linked to acid rain, and many industrialized countries, even developing countries, have instituted policies or regulations to limit them. SO₂ and similar gases are one of the most harmful air pollutants, evolving mainly from the combustion of fossil fuels in transport vehicles, industrial furnaces, and thermal power plants [60]. SO₂ emissions in the air combine with rainwater and form sulfuric acid. Acid rain resulting from SO₂ harms agriculture and causes air pollution, and, on the other hand, destroys the ecological balance [55].

Determining size distribution is significant in assessing health impacts because it specifies how the particles can travel within and beyond the respiratory tract. So that the smoke resulting from large solid fuel particles against PM generated from the fuel combustion have ultrafine [58].

2. Effect of pollution on humans

Although some of the coals contain toxic contaminants with unique health consequences, few studies of their health effects have been conducted. Regardless of how the pollutants are absorbed in the human body, through breathing, drinking water, or the food chain, each leads to severe impacts. Some of the contaminants, along with their effects and their allowable concentration in drinking water in Iran, are mentioned in [Table 2](#).

Researchers have investigated the various occurrences of mineral matter in coal and their association with organic matter/ constituents [61]. Pyrite is a significant source of many trace and heavy metals, particularly in Tertiary coals and lignite [62]. In addition, pyrite exists in clausthalite (PbSe), and ferroelite (FeSO) absorbed in galena (PbS), in clays of coal, and also has an organic association [62]. Lead is attached to sulfides, such as (PbS) and pyrite [63]. Copper (Cu) in coal occurs as a primary phase CuFeS₂, while associations of Cu with organic matter and carbonate are less common. In addition, most of the mobile elements are associated with oxides (Ge, Mn, Mo, Se, V, W, and Zn) and salts like borates, sulphate, and arsenates. When trace elements and heavy metals like Cd, Co, Cu, Ni, Pb, and Zn-bearing coal ash are ponded or landfilled, they influence the environment depending on their mobility[64]. Querol et al. 1996 have discussed finer particulates (<2.5 μm), known as respirable particles, and Allsopp et al. 2001 have investigated that ultrafine particles (<0.1 μm) cause adverse effects on humans[65, 66]. El-Mogazi et al. 1988 have expressed that toxic elements may mix with soil and get absorbed in the plants, and eventually enter the body through the food chain and cause serious health problems[67].

There are several methods available, including the physicochemical processes involved in chemical oxidation, reduction, chemical precipitation, complexation, and ion exchange. These methods are not popular because they are costly and create secondary sludge problems[62].

Explosions, fire, asphyxiation, and mine falls are the most common hazards for miners and environmental problems. Hundreds of miners around the world die due to such events each year. Lung disease is another significant environmental problem of coal mines. Black lung is a common disease in miners due to breathing polluted coal dust, as about 5 to 10 percent of miners suffer from this disease [68, 69]. Abundant sources of coal exist in China. Hence, more than 100 papers report the health effects of solid fuel combustion in Chinese households; most of them have focused on coal usage both in urban and rural populations [58]. Nowadays, some countries like America have rigid regulations towards using special ventilation equipment to reduce dust in mines[70]. Generally, about 1 to 7 mg/m³ of coal dust in the air would cause diseases such as black lung, lung cancer, prostate cancer, and cyclosis. Therefore, rigid laws are necessary to protect miners' health.

Table 2. Environmental impacts of elements in coal and the maximum allowable concentration of toxic minerals chemicals (these measurements were retrieved from experiments and a recent study).

Row	Compound	Maximum limit(mg/L)	Impacts
1	As	0.01	Adsorbed through the skin, it ought up globin and hemoglobin in the erythrocyte, Arsenic in its trivalent form is more toxic than its pentavalent form, associated with vomiting, and diarrhea severe throat and nasal irritation and eventually dead.
2	Pb	0.01	Cause similar impacts as, but leads to a more severe impact on human health
3	Cr	0.05	Carcinogenicity possibility, dyspraxia, and neurological disorders
4	Se	0.01	An excess of it in animals, causes abnormalities and diseases.
5	Cd	0.003	It causes vomiting, diarrhea, pain, and alertness, delay in bone growth, increase in blood pressure, and carcinogenicity possibility. Breathing would cause cough, bronchitis, and muscle complications.
6	Sb	0.02	Cause similar impacts as arsenic, but leads to more severe effects on human health
7	Hg	0.006	Cause neurological disorders
8	Ni	0.07	Cause lung cancer and nasal cancer
9	Ba	0.7	In different tissues of the body, the spleen and blood vessels leave insoluble sediment. When it reaches the maximum allowed limit, it leads to salivation, vomiting, diarrhea, and, in some cases, causes cancer and trembling in the nervous system.

3. Clean Coal Technology (CCT)

Clean coal technologies are needed to utilize coal in an environmentally acceptable way and to improve coal utilization efficiency[71]. The importance of coal will continue in the future because it is a primary source of energy and carbon. Coal demand is expected to increase by 50% by 2030 [72]. If the adverse effects of coal on the environment are handled successfully, it can have a bright future. The development of energy supply and utilization technologies has made considerable progress in increasing coal efficiency and decreasing environmental impacts.

The development of clean coal technology (CCT) is an essential issue to remain environmentally clean. The environmental impacts of coal can be reduced by increasing the efficiency of the combustion process through many technological options [73]. As mentioned before, sulphur oxides, nitrogen oxides, and particulate matter (PM) emissions from coal are the primary pollution sources in the world. These came from the direct combustion of coal or went through all kinds of coal utilization (including direct combustion emission and emission from coke stoves and other industrial furnaces) [74]. Therefore, the development and deployment of clean coal technologies are crucial to promoting sustainable development in the world.

As mentioned, coal combustion leads to the emission of particulate matter (PM) into the atmosphere [75]. The formation of particulate matter (PM) can be decreased with ESPs (electrostatic precipitators), wet scrubbers, inertial collectors (cyclonic separators), and baghouses with FFs. The most valid among these technologies is ESP [76]. ESP (electrostatic precipitator) is a particulate control device used in modern pulverized-coal-fired power plants and in the cement industry. FFs or baghouses are widely used in the general industry [9]. Fig. 2 shows some control methods for PM [77, 78].

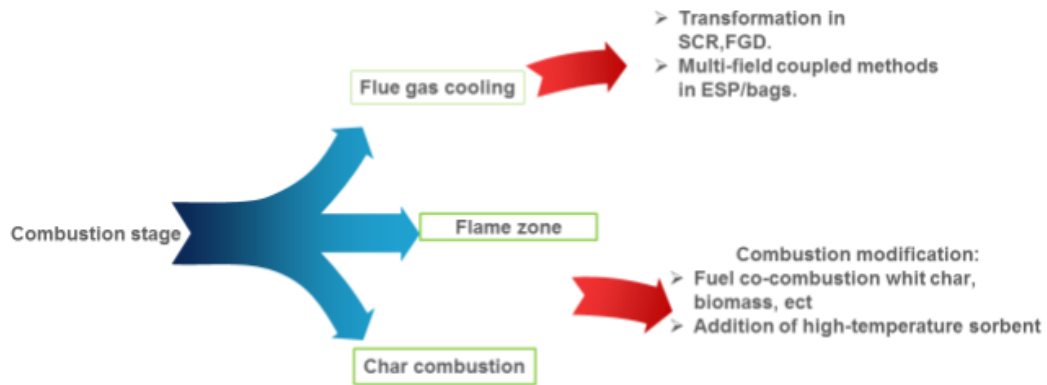


Fig. 2. Control methods of fine particles during coal combustion [77, 78].

Researchers declare that developed coal combustion technologies, such as fluidized bed combustion (FBC) and integrated gasification combined cycle (IGCC), are used as ultraclean coal techniques [79]. Researchers introduced and discussed the developing CCTs in Japan, including high efficiency combustion technologies, advanced gasification technologies, (CO) recovery and utilization technologies, and flue gas cleaning technologies[80]. Clean coal technologies included Integrated gasification combined cycle (IGCC) with carbon capture, the Rankine cycle, the Brayton cycle, combined cycle, advanced pulverized coal-fired plants, advanced ultra-supercritical coal-fired plants, oxy-fuel firing in pulverized coal-fired boilers, supercritical fluidized-bed boilers, oxy-coal firing in fluidized-bed boilers, and combined cycle power plant. Fig. 3 shows three approaches for capturing carbon dioxide from Coal Power Plants [74, 81-84]. Integrated gasification combined cycle (IGCC) technology generates gas from coal for use in a gas turbine, rather than direct coal combustion. It can use the broadband of different solid fuels with high efficiency.

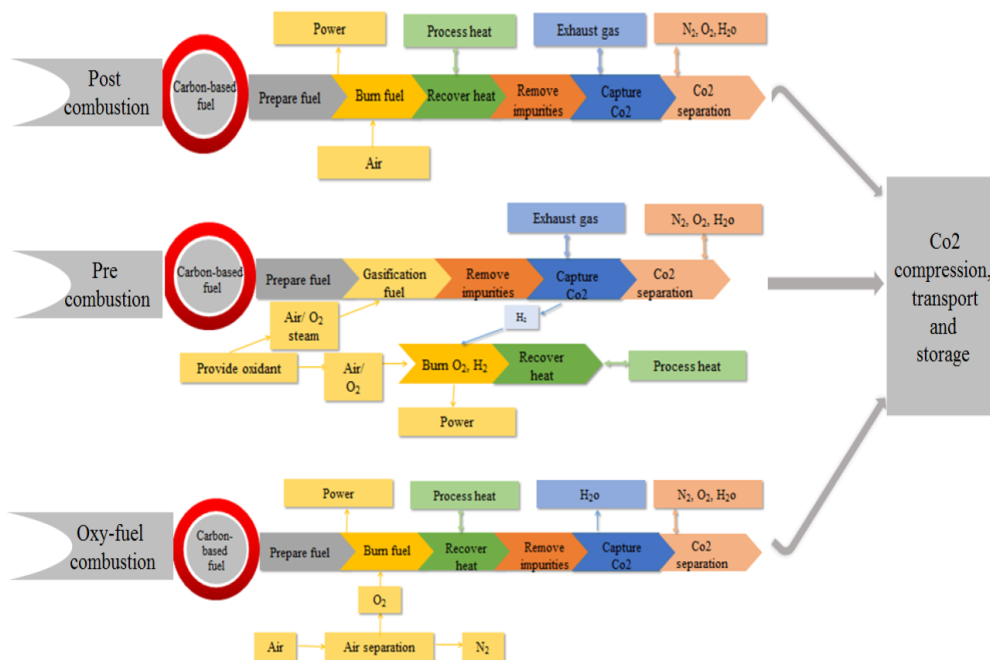


Fig. 3. Schematic diagram of CO2 Capture technologies.

Since the 1970s, in Japan, most pulverized coal-fired power generation plans have been equipped with wet limestone and gypsum-based desulfurization systems, selective catalytic reduction (SCR) de NO_x process, and an electrostatic precipitator for particulate treatment [80]. Table 3 summarizes the main SO_x and NO_x reduction technologies in parts of the world. Coal transformation technologies, IGCC (integrated gasification combined cycle), and carbon capture and storage (CCS) were developed in China [71]. Researchers explain pollution control in coal-fired power plants. Electrostatic precipitators (ESPs) and flue gas desulfurization (FGD) units were installed in most coal-fired power plants, and selective catalytic reduction (SCR) units were installed in 80% of coal-fired power plants by 2014 [74]. The control technology for SO emissions is pre-combustion desulfurization of coal. This process uses microbial entities in controlled conditions [9, 85].

Another technique to reduce SO_x emissions includes flue gas desulfurization with different classifications of FGD, including wet and dry methods, expressing the production of waste in the form of a wet slurry or dry material, respectively. Most coal-burning power plants now contain NO controls in the form of Low NO Burner Technology (LNBT), the over-fire air (OFA) technique, or a combination of both. Two secondary NO_x control technologies are usually used to create combustion conditions that reduce the amount of N₂x (from the air) oxidized to NO and generally have an efficiency up to 40–60 % (relative to uncontrolled emissions). A new technology, selective catalytic reduction (SCR), has more recently been added, often in combination with LNBT or over-fire air, to many plants to increase removal efficiencies (>90 % NO reductions). SCR involves a catalyst and the addition of a reagent, ammonia (NH₃), that promotes the reduction of NO_x to nitrogen and water [86]. Fig. 4 shows the Selective contact reduction (SCR) method for NO_x removal.

Table 3. SO_x and NO_x reduction technologies.

	Technology		Features	
SO _x			Soot-separation process:	A dust tower is installed upstream for dust collection and HCl/HF removal High-purity gypsum can be obtained High cost
	Wet limestone gypsum process	Water-mixed limestone slurry as SO absorption material	Soot-mixed process Without a dust tower installed	Low cost
	Coal-ash-based dry desulfurization process	The absorbent is from coal ash, limestone, calcium hydroxide and spent absorbent		SO removal efficiency: 90% NO _x removal efficiency: 20% Dust collection efficiency: 96%
	Spray dryer process	Water is added to burned lime to make Ca (OH) slurry for SO chemical absorption		Desulfurization reaction and limestone drying occur simultaneously High-quality gypsum can be obtained
	Furnace desulfurization process	Limestone mixed with coal for desulfurization		
NO _x	Selective catalytic reduction process	Ammonia (NH ₃) is blown into the exhaust gas, and reacts with NO _x over the catalyst.		NO _x is decomposed to H ₂ O and N ₂ Grid- or plate-like catalyst is used. The catalyst is mainly comprising of TiO ₂ , doped with active ingredients such as vanadium and tungsten. Catalytic reaction temperature: 350 °C NO _x removal efficiency: 80%–90% NO _x removal efficiency is not so high.
	Selective non-catalytic reduction process	NH ₃ is blown into the exhaust gas at 850–950 °C		
	Radical injection method	Argon plasma is injected into NH ₃ , generating NH ₃ plasma and other plasmas, which can decompose NO _x into N ₂ and H ₂ O effectively (NO _x concentration < 10 × 10 ⁻⁶)		High cost

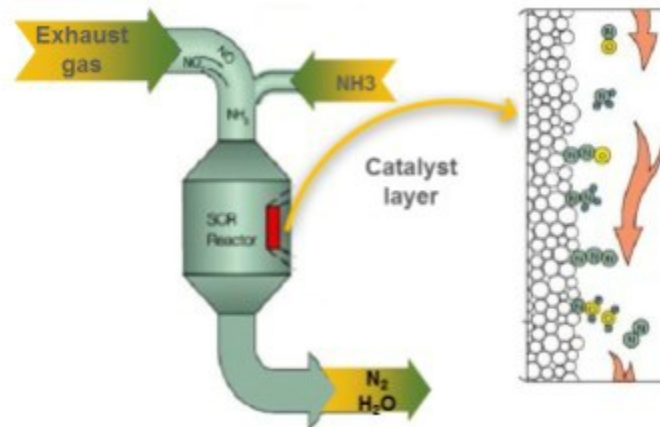


Fig. 4. Selective contact reduction (SCR) method for NO_x removal.

Clean coal technologies included Integrated gasification combined cycle (IGCC) with carbon capture, the Rankine cycle, the Brayton cycle, the combined cycle, advanced pulverized coal-fired plants, advanced ultra-supercritical coal-fired plants, oxy-fuel firing in pulverized coal-fired boilers, supercritical fluidized-bed boilers, oxy-coal firing in fluidized-bed boilers, combined cycle power plant. Researchers explain early all power plants in the US and Canada use baghouse filters or electrostatic precipitators (ESP) with removal efficiencies up to 99.9 % [86].

4. Conclusions

Nowadays, coal energy is a significant phenomenon in the research and development of new technologies. Despite its profound impact on health and the environment compared to other fuels, it is still expected that coal will account for a significant portion of world energy consumption in the future. Population growth and industrial development lead to an increase in coal consumption and, therefore, remain the primary energy resource. Due to the increasing demand for coal products and to eliminate the mentioned worries, coal quality improves through the use of modern technologies for clean coal production. This research provides an overview of the environmental impact of coal. The efficient and clean use of coal is the main subject of this study. For this purpose, the potential environmental impact should be identified in scientific studies before extraction and processing; scientific methods should be used to prevent or minimize environmental impacts, using technologies that increase fuel efficiency and decrease emissions of harmful gases and particulate matter from power plants.

Ethical Considerations

The authors avoided data fabrication, falsification, and plagiarism, and any form of misconduct.

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Conflict of Interest

The authors declare no conflict of interest.

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