COAL, OIL SHALE, NATURAL BITUMEN, HEAVY OIL, AND PEAT

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Keywords: fossil fuel, coal, oil shale, natural bitumen, tar sand, heavy oil, peat, lignite, anthracite, bituminous coal, resource, reserve, origin, formation, geochemistry, geology, mining, exploitation, processing, utilization, technology, preparation, mineral matter, maceral, clean coal technology, environmental pollution, sustainable development, desulfurization, combustion, power generation, carbonization, gasification, liquefaction, pyrolysis, non-fuel use, shale oil, tar, coke, gas, ecological system, acid rain, primary energy, industrial feedstock, crude oil, biomass, organic rock, coalification, coal rank, humic acid, plant debris, surface mining, underground mining, coal basin, seam, petrology, coking property, coking behavior, hard coal, vitrain, clarain, durain, fusain, vitrinite, exinite, inertinite, fusinite, ash, volatile matter, heating value, moisture content, metamorphism, fixed carbon, sulfur, nitrogen, trace element, heavy metal, pyrite, swamp, peatland, coal structure, crush, grind, washed coal, beneficiation, heavy medium, jig, fluidized bed, sorbent, wet scrubber, atmospheric pollutant, coal conversion, iron-making, regeneration, synthesis, catalyst, alternative, organic, inorganic, matter, kerogen, solvent extraction, retorting, chemicals. Deposit, recoverable, reservoir, enhanced oil recovery, mire, cut away, conservation, transportation, biodiversity, bog, humification, np-grading, refinery, retort, processing technology, char, asphalt

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Summary

Coal, oil shale, natural bitumen (tar sand), and heavy oil all belong to the group of fossil fuels. Peat is usually not classified as a coal, but can be seen as the precursor of coal. Coal is the end-product of a sequence of biological, geochemical, and geological processes—or a "coalification" process—originating from plant debris. Coal has been used as a major source of fuel by humankind for thousands of years. Known global reserves of coal are much greater than that of any other fossil fuels. Currently, coal is widely used for power generation, heat supply, coke making, and production of gaseous and liquid fuels etc.

Coal, as a complex, heterogeneous fuel, is composed of organic and inorganic matters, and contains a very large number of elements. It is difficult to burn or process without serious environmental implications and therefore substantial worldwide attention is being focused on the more efficient and clean use of coal. The future of coal is to a great extent dependent on the development and availability of new processes. Natural bitumen, found in tar sand and heavy oil from various reservoirs, belongs to a subclass of petroleum. Oil shale is also a sedimentary rock containing kerogen as its main organic constituent and, to a lesser extent, bitumen; both embedded in an inorganic matrix. Generally speaking, these latter are more closely similar to conventional crude

oil in their elemental composition of organic matter than they are to coal. Naturally, it is much easier to convert them into liquid fuels. Peat, as an important biomass resource, is an acidic mixture of dead and decomposed vegetable matter that forms in boggy areas. Although it is a low-quality fuel, it has a number of special applications and is important for the conservation of global ecological systems and environments.

1. Introduction

Coal, oil shale, natural bitumen (tar sand), and heavy oil are all fossil fuels. Strictly speaking, peat is not yet a real organic rock and can be regarded as the precursor of coal.

In global primary energy consumption, crude oil is still a major contender, supplying 40% of fuel, while coal supplies 30% and natural gas 20%. This means that fossil fuels currently supply 90% of our energy, which gives some idea of how much fossil fuel today's society consumes and how dependent upon those fuels the world has become. Fossil fuels are essentially the stored solar energy of several hundred million years. They are non-recyclable, exhaustible natural resources that will one day no longer be available.

Over the past 150 years, we have already used up one third of the proven amount of oil reserves, or about 700 billion barrels (1 barrel = 159 liters), which leaves only 1.5 trillion barrels remaining. The estimated remaining reserves of coal, calculated in terms of oil equivalent, are thought to be 9.1 trillion barrels; those of natural gas, 1.3 trillion barrels; and those of oil shale and natural bitumen together, 2.1 trillion barrels.

The data suggests that coal is the most abundant fossil fuel yet discovered. If one adds to it the other low quality fossil fuels, such as oil shale, tar sand, and heavy oil, together they can certainly meet the global energy demand for at least several hundred years, thus acting as a bridge between oil and new energy resources in the future. In addition, these fuels are valuable resources of organic carbon and can be converted into a variety of industrial feedstock and materials.

By comparison with crude oil and natural gas, the above-mentioned fuels have some intrinsic drawbacks: (a) they are relatively deficient in hydrogen and rich in carbon, particularly in the case of coal; (b) they have a higher content of impurities, such as mineral matter and sulfur, leading to more environmental problems and more difficulties in processing; and (c) they are not convenient for transportation and handling etc.

The world requires sustainable development, involving clean energy and its reliable supply. Therefore, more attention should be focused on the development of more advanced technologies for the conversion of low-quality fossil fuels into synthetic crude oil and natural gas to compensate for the depletion of both. Coal has had a glorious history and we are convinced—with good reason—of its continued glorious future.

2. Coal Geology and Geochemistry

2.1 Origin of Coal and its Reserves of the World

Coal, an organic rock, was formed from partially decomposed and decomposing plant debris that collected in regions where waterlogged swampy conditions prevailed. These conditions prevented complete decay of the debris to carbon dioxide and water as it accumulated and the formation of peat gradually occurred. In general terms, the organic debris consisted of trees, ferns, rushes, lycopods, and several thousand plant species, the remnants of which have been identified in coal beds.

Firstly, most of the plant material making up the peat was biochemically broken down. Most of the cellulose was digested away by bacteria, and lignin was transformed into humic acid and humins. Some plant material was also thermally altered by partial combustion or biochemical charring. Still more plant material, such as spores and pollen, survived the diagenesis stage without much change. Strictly speaking, peat is not yet a real coal, and normally is not included in the coal series, but it is nevertheless believed to be the precursor of coal.

During the first stage of coalification, the various biological-bacterial processes might have predominated over any other potential processes. When peat was buried underneath sedimentary cover, the biochemical stage was terminated, and a variety of physicochemical and chemical processes (metamorphic), determined by temperature and pressure, subsequently occurred. Then peat was transformed through brown coal (lignite) and bituminous coal, finally into anthracite. (Shown in Fig. 1)

Although coal seams are found in rocks of all geologic ages since the Devonian, the age distribution is not even. Major coal deposits of Carboniferous age occur in eastern and central North America, in the British Isles, and on the European continent. Major deposits of Permian age occur in South Africa, India, South America, and Antarctica. In Jurassic times the major coal accumulation was in Australia, New England, and parts of Russia and China.

The last great period of coal deposition was at the end of the Cretaceous period and the beginning of the Tertiary period. Coals originating at this time are found in the Rocky Mountains of North America, Japan, Australia, and in parts of Europe and Africa. The distribution of coal seams throughout the world is also not uniform; most of the world's coal is located in only three countries: the United States, Russia, and China.

Although the figures vary from source to source, each of these countries has about 25% of the total coal resources, while the rest of the world shares the remaining 25%. The world's estimated reserves of coal are about 6.9 Tt of hard coal and 6.5 Tt of brown coal. With current technology only about 7–8% of the total coal reserves are economically recoverable.

However, this is a much higher amount than any other fossil fuel. The world coal production for 1991 was ca. 5.1 billion tons (short) and the major coal producing countries are China, United States, Russia, Germany, India, Australia, and Poland.

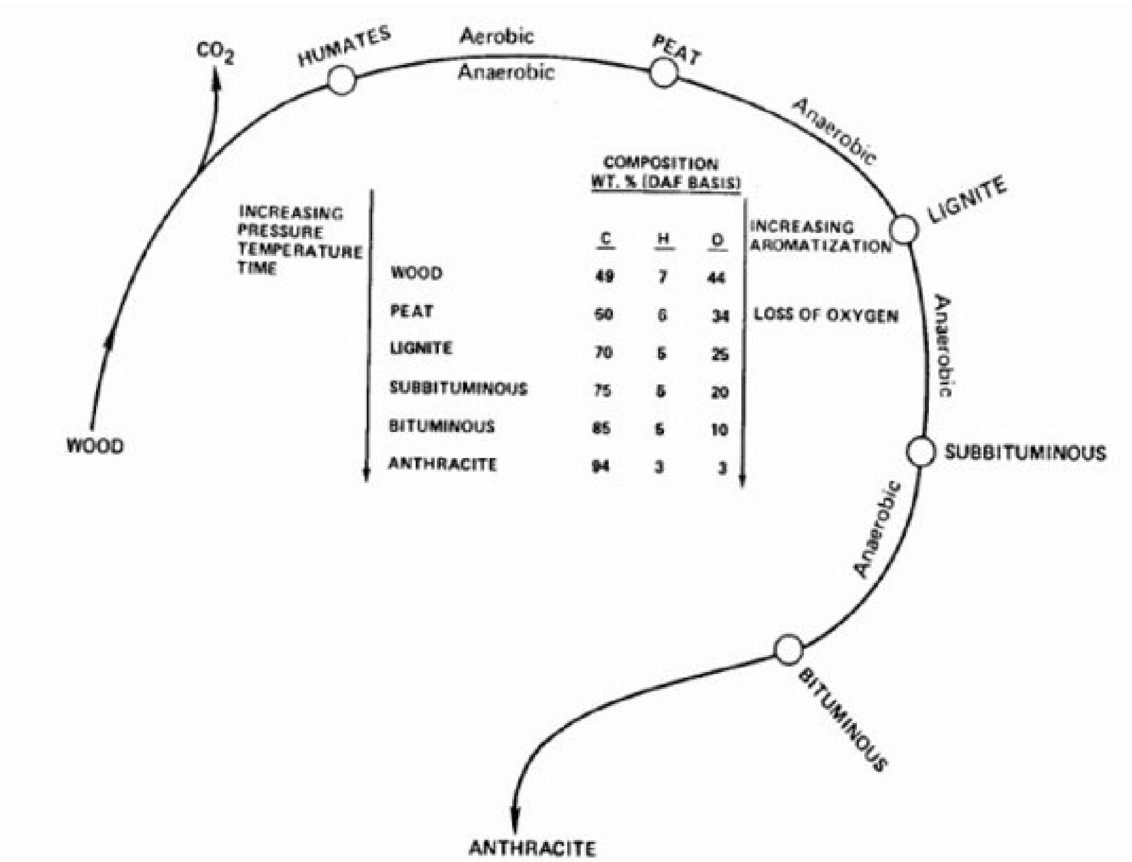

Figure 1. Schematic representation of the coalification process

2.2 Coal Exploration and Mining

The purpose of coal exploration is to determine the nature, location, and extent of the resources available in a particular situation, and delineate the features that may affect their economic extraction. A program of geological exploration for coal usually has one of two possible objectives: (a) to find an area from which a given amount of coal of a specific quality may be successfully recovered, or (b) to determine the amount and quality of coal that can be economically extracted from a given area. Like other exploration activities, the evaluation of coal deposits involves the following operations: one must (a) obtain legal title to explore the area; (b) evaluate the geological information already available; (c) carry out surface exploration; (d) carry out subsurface exploration; (e) collect and analyze samples; (f) estimate the coal resources and the significance; (g) communicate the results with other members of the project team. Geophysical methods now play a critical role in many coalfield investigations. The techniques used at an early stage in the exploration program are normally those that give broad-scale information on a large area at relatively little cost. These include air-borne magnetometer investigation, regional gravity surveys, and broad-scale seismic studies, used to delineate the sedimentary and structural framework of the area involved. They may be followed by ground magnetic, electrical resistivity and more detailed seismic investigations that give a higher resolution of individual features, but at a significantly greater expense. Further information on the depth, thickness, and quality of coal at any point across the area, and of the strata with which the coal is associated, requires the effective use of exploratory drilling techniques such as core drilling and non-core drilling. Because of the wide range of information that the both drillings can yield, core samples of coal seam and the adjacent non-core strata should be examined in as much detail as possible. Especially with coal seams, but also overburden or mine roof and floor rocks, the collection of a complete core, with as little disturbance as possible, is vital to the success of this stage.

Coal mining techniques can be divided into two categories: surface mining (open cast or open cut mining) and underground mining. Surface mining has a number of advantages over underground mining, including greater recovery, greater safety for personnel, and, in most cases, a greater level of overall productivity. The chief disadvantage, however, lies in the often unfavorable impact, at least in the short term, on the surrounding environment. Surface mining involves two main methods. These are: (a) strip mining, where the material above the seam known as overburden is emplaced directly from the digging equipment used to remove it from the ground into an area immediately adjacent to the working place; and (b) open-pit mining, where the overburden is moved from the face to an emplacement site some distance away by an intermediate haulage or transposition process. However, most coal deposits so far have been extracted by underground mining due to thick overburden and the depth of coal seams. Underground mining involves room and pillar mining, short-wall mining, and long-wall mining etc.

In conventional mining the operations are performed in a cyclical pattern as follows: (a) a slot is cut in the coal face to make controlled blasting possible; (b) a pattern of holes is drilled into the face around this slot; (c) the holes are charged with an approved explosive and fired; (d) the broken coal is picked up from the floor of the opening and transferred to the haulage system; and (e) the roof of the extended opening is supported as required. In continuous mining, a single machine using a cutting head equipped with hardened metal pick breaks up the solid coal at the face without the need for any blasting opening. The continuous miner provides a greater rate of output than a cyclical conventional unit and requires fewer operating personnel. In order to meet the need of the modern coal industry, more advanced techniques for exploration and mining are in development.

2.3 Coal Geology

Coal is the end-product of a sequence of biological, geochemical, and geological processes. Coal geology, as an important field in coal science, deals with the formation, distribution, composition, and character of coals, as well as with the exploration, extraction, and utilization of coal resources. Paleobotanical, paleogeographic, and paleotectonic factors affected the evolution of coal formation; therefore, the various characteristics of coal from different basins are closely related to the different periods of geological history. Coal geologists both study this and attend to the relationship between the utility of coal and the development of human society. With industrial development and scientific progress, coal requirements have greatly increased and the study of coal geology has thus made great progress. Achievements in the fields of coal petrology, coal-bearing formations, coal basins, coal accumulating environments, coal metamorphism, the distribution of trace elements in coal, and the utilities of coal have been made, and this has greatly extended the content of the study of coal geology.

Generally speaking, the formation of a coal seam represents the evolutionary process of a peat swamp. The formation of a thick or a thin coal seam often depends on crustal movement, which not only influences the thickness of coal seams, but also controls the split and thin away of coal seams. Studies on global and regional coal-accumulating laws show that there were several important coal-forming periods in geohistory, and the distribution of chief coal fields in each coal-forming period are all regularly zonal. The migrations of coal-accumulating zones and coal-accumulating centers are closely related to paleostructure and paleoclimate. Coal basin analyses play an important role in the understanding of regional coal-accumulating laws and thus offer a capacity for seeking both areas abundant in coals and areas within which are distributed excellent coals. For example, low-sulfur and low-ash coals were separated from high-sulfur and high-ash coals using the analysis of Carboniferous coal basins in Appalachia, in the east of the USA.

Coal metamorphism—one of the important factors influencing coal ranks and qualities—can be divided into the following types according to its genesis and characteristics:

- Geothermal or deep burial metamorphism—the degree of metamorphism of this kind increases markedly with increasing depth of burial.
- Telemagmatic metamorphism, resulting from the geothermal abnormality produced by magma actions.
- Contact metamorphism, caused by direct contact with magma intrusion.
- Hydrothermal metamorphism, resulting from the gas and liquid thermals generated by the actions of magma and groundwater.
- Tectonic metamorphism, caused by the intensive compression and shear of strata due to crustal movement.

Many researchers in the world have studied the potentials and the geochemical characteristics of coal and coal measures with regard to producing other fuels. The discovery and exploitation of some industrial oil-gas fields confirmed the potentials of coal and coal measures in the USA, Australia, Indonesia, and Canada. Statistics suggest that about 70–80% of the large gas fields and their natural gas reserves are from coal measures. In the mid-1980s, it was found that the oil-generating ability of humic coal is related to the desmocollinite content of vitrinite. Recent studies of the repressed desmocollinite thus give us a new way to research coal-formed oil.

2.4 Classification of Coal

The nature of a classification system will depend upon the particular application for which the system is to be employed. Classification of coal may be subdivided into scientific or genetic categories, and technical or commercial ones. In order to classify coals by means of numerical parameters, different kinds of tests are necessary, such as: (a) chemical analysis, including proximate and ultimate etc; (b) technological assay, simulating coals in their behavior on heating; or (c) petrographic analysis. In addition, a number of supplementary tests have been developed, which in some special cases may be extremely useful, for example: the friability (grindability) test for combustion coals; the fusibility test of coal ash for combustion and gasification of coals; and the plasticity test for coking coals. Some of the newer analytical techniques that have been used to characterize coal are also being tested, e.g. FTIR, NMR, DTG, Py-MS, and GPC etc. These techniques may provide parameters that are more reproducible than some of the conventional empirical tests.

Coal rank is an important concept in all classification of coal. The rank of coal is the degree or stage that the coal has reached during its coalification process; that is, its degree of metamorphism or geochemical maturity. The parameters conventionally used to characterize coal rank are (a) fixed carbon, carbon content, reflectance, and heating value (only for low rank coal), and (b) volatile matter, and hydrogen content (only for anthracite). The other parameters used to characterize the technological properties or grade are caking and coking parameters, ash content, and sulfur content etc.

Every country with a coal industry has tended to develop its own criteria in order to classify its domestic coals, often for a particular application. The international system of coal classification came into being just after the Second World War as a result of the greatly increased volume of trade between the various coal-producing and coal-consuming nations and still finds limited use in Europe. It divides coals into two major types: hard coal, which is defined as any coal with a calorific value greater than 23.9 MJ/kg (5700 kcal/kg) on a moist but ash-free basis, and brown coal, defined as coal with a calorific value less than 23.9 MJ/Kg. In this system, the hard coals are firstly divided into classes according to their volatile matter, then coals of the same class are subdivided into groups and subgroups according to their caking and coking properties, respectively. A three-digit code number is then employed to identify the coal. The first figure indicates coal class, the second figure indicates the group into which the coal falls, and the third figure is the subgroup. In 1998 the International Classification of Medium and High Rank Coals was published to assist in characterizing coals involved in the international coal trade. The new system published involved eight parameters and a 14-digit code. The international system (ISO 2950, 1974) categorized brown coal on the basis of the total moisture content (ash-free) and the yield of tar produced from a dry ash-free sample. The moisture content is indicated by the class number (10–15); the tar yield is described by the group number (00–40). A four-digit code number is finally derived from the combination of the class and group number categories.

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Biographical Sketch

Dr. Jinsheng Gao was born on January 8, 1939. Graduation in Fuel Chemical Technology in 1961 at the East China University of Chemical Technology (since 1993 renamed as East China University of Science and Technology (ECUST)), Dr. Ing. In 1981 at the Technical University Clausthal, Germany. He was appointed professor of ECUST in 1990. He has worked from 1961 to now teaching and researching at ECUST. For over 30 years he was in charge of research projects in the field of coal chemistry and processing. He has published 160 scientific papers and 9 books, mostly in Chinese, and obtained 4 (Scientific and Technological Process) awards from ministries in China. The author has been actively involved in national and international cooperation projects and acts as member or chairman in several Scientific and Technical Societies and Editorial Boards of Journals.