Review

Coal Research in Poland

— Current Activities and Future Needs —

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Coal has an exceptional position in the Polish economy both as a major indigenous source of energy and an important raw material for chemical and carbon industries. This review outlines the current situation and prospects in production and utilization of solid fossil fuels in Poland. Principal research centers dealing with science and technology of coal and related materials are presented. Some recent research activities in the field are summarized, particularly concerning fundamental studies on the structure and properties of coal, metallurgical coke manufacture, clean coal technologies, coal liquefaction, and the use of coal and its derivatives as precursors of carbon materials.

Key Words

Coal, Production, Utilization, Research prospects

1. Resources and Use of Coal in Poland

Coal has been considered as one of the main natural resource of Poland. Recent estimates concerning the structure of national energy resources (Table 1) clearly indicate that solid fossil fuels, in particular coal, have the dominant position.

The distribution of energy reserves justifies the exceptional position of solid fossil fuels in the national economy, both as a primary energy resource and a raw material for the chemical and carbon industries. Despite an increase in the consumption of natural gas and crude oil during the last five years, coal and lignite still account for about 75% of Poland's energy needs. Predictions (Table 2) are that the dominant position of these fuels will be maintained at least until 2010.

Table 1 Energy resources of Poland

<i>Fuel</i>	<i>Estimated resources</i>	<i>Relative Contribution</i>
Coal	63.5×10^9 tons	91.2%
Lignite	12.9×10^9 tons	6.4%
Peat	2.0×10^9 tons	1.8%
Natural gas*	164.0×10^9 m ³	0.3%
Water energy	12.0×10^3 Wh/a	0.2%
Wood	3.0 tons/a	0.1%

* excluding methane in coal seams

Current production of hard coal exceeds 130 million tons per year, including 100 million tons of steam coal and about 30 million tons of coking coal. Power generation together with heat gen-

Table 2 Expected structure of primary energy use in Poland

Energy source	Year					
	1995		2000		2010	
	<i>mln tons EF</i>	%	<i>mln tons EF</i>	%	<i>mln tons EF</i>	%
Hard coal	94.3	59.3	92.7	56.8	92.1	52.0
Brown coal	19.9	12.5	17.5	10.7	17.5	9.9
Natural gas	10.9	10.6	17.9	11.0	23.2	13.1
Liquid fuels	24.3	15.3	30.3	18.5	35.8	20.2
Others	3.6	2.3	4.9	3.0	8.6	4.8

mln tons EF-million tons of equivalent fuel

eration in municipal systems consume more than half of the total production. About 15 million tons is utilized for coke manufacture. Specific to Poland is an extensive direct use of coal as fuel in individual houses and local heating systems. This residential sector consumes every year about 18 million tons of raw coal. Traditionally, Poland is an important exporter of coal, exporting approximately 30 million tons of both steam and coking coals. Almost all lignite produced (68 million tons) is used for electricity generation.

2. Coal Research Centers

2.1 Fundamental and Applied Study of Coal and Related Materials

Coal research in Poland has a long history which began when the Coal Department of Chemical Research Institute in Warsaw was established in the early twenties. At present the fundamental and applied studies of coal and related materials are carried out in several universities and institutes associated with Polish Academy of Sciences. The laboratories most active in the area and major fields of activities are listed below.

- Institute of Chemistry and Technology of Petroleum and Coal, Technical University of Wrocław
 - constitution, structure and properties of coal
 - coal carbonization
 - carbons and graphites - production, structure/properties relationship
 - activated carbons - manufacture, characteriza-

tion by sorption methods

- organic geochemistry
- Department of Fuels and Energy, Mining and Metallurgy Academy in Cracow
 - metallurgical coke manufacture
 - physicochemistry and thermodynamics of sorption
 - activated carbons production and characterization
 - carbon and graphite artifacts - manufacture and performance
- Institute of Coal Chemistry, Polish Academy of Sciences, Gliwice
 - nature of coal as a two component polymeric system
 - fundamentals of coal liquefaction and pyrolysis
 - hydrolysis of coal and lignite
- Institute of Coal and Petroleum Technology, Silesian Technical University, Gliwice
 - theory and practice of coal blending and coke properties prognosis
 - co-pyrolysis of coal with petroleum residues to produce liquid fuels
 - coal tar processing
- Department of Geochemistry, Mineralogy and Petrography, Silesian University, Sosnowiec
 - constitution and properties of coals from different seams
- Chemistry Department, University of Poznan, and the Institute of Organic Chemistry, Polish Academy of Sciences, Warsaw
 - coal solubilization by alkylation, reductive alkylation and mild oxidation

- Chemistry Departments, University of Lublin and Nicolas Copernicus University, Torun, and The Military Technical Academy, Warsaw
- activated carbons and surface phenomena
- Institute of Applied Geology, Silesian Technical University, Gliwice
- geology of coal seams and coal petrography

2.2 Research and Development Study of Coal and Related Materials

Work on the development and implementation of new, more effective and environmentally safe technologies for solid fuels utilization is concentrated mostly in two large institutes situated in the Upper Silesia region.

The activities of the Institute for Chemical Processing of Coal in Zabrze include:

- coal pyrolysis (metallurgical coke, clean coal technologies)
- environmental impact from coal utilization
- technologies of activated carbons manufacture
- coal derivatives utilization

The major fields of interest of the Central Mining Institute in Katowice are as follows:

- monitoring the properties of coals from different mines
- coal output technologies - mine safety
- coal beneficiation
- environmental impacts related to coal output and preparation
- coal liquefaction

In addition, the Oil and Gas Institute in Cracow has been involved for several years in the projects concerning coal gasification, and the Industrial Chemistry Research Institute in Warsaw has collaborated on coal tar utilization technology development.

3. Fundamental Study of Coal Structure and Properties

Polish classification of coals by rank, based on volatiles content, calorific value, coking properties (Roga index, swelling index, dilatation), gives a preliminary evaluation of coal properties. Further characterizations including petrographic com-

position, elemental composition (C,H,N,O,S), vitrinite reflectance are routinely performed.

However, a better understanding of the nature of coal is necessary to gain considerable progress in the proper and effective utilization of coal. The contribution of Polish scientists to basic knowledge has been particularly relevant in the following areas:

- development of molecular/macromolecular model of coal¹⁾²⁾
- study of hydrogen transfer mechanisms from hydrogen - donor solvents to coal using kinetic isotope effects³⁾⁴⁾
- chemical pretreatment of coal (mild oxidation, reduction, reductive alkylation with different agents) to increase solubility⁵⁾⁻⁸⁾
- colloidal nature of different rank coals and their lithotypes⁹⁾¹⁰⁾
- nature of coal thermoplasticity¹¹⁾¹²⁾
- determination of sulphur forms and their inter-conversion during coal processing¹³⁾¹⁴⁾
- application of biological marker techniques for fossil fuels¹⁵⁾¹⁶⁾

4. Metallurgical Coke Manufacture

Poland with coke production of about 11.4 million tons per year (1994) is the sixth largest coke producer in the world. Most characteristic of the coke consumption structure is the relatively low consumption of iron metallurgy (40%) and the high contributions of domestic heating (25%) and exports (25%).

Resources of coals suitable for coke manufacture in conventional coke ovens constitute mostly caking coals and coking coals of relatively high volatiles content. The contribution of prime-coking coal and low volatile bituminous coals amounts to only about 10% of the current production of coking coals. Similar supply structure is expected until 2010. In addition, high inertinite content is characteristic of coking coals from some mines.

Hence the preparation of blends for metallurgical coke manufacture, particularly the influence of bituminous additives (coal tar pitch, petroleum re-

sidue, coal extract) and leaning components (coke breeze, anthracite, petroleum coke) on the structural and mechanical properties of coke has been extensively studied for many years. Combined use of plasticizing and leaning components has been recommended for improving the coking behavior of blends from poorer coking coals, such as those with high volatile matter or inertinite contents¹⁷⁾

Characterization of plastic properties such as Gieseler plasticity and permeability of the plastic layer, and correlation of the parameters with the optical texture and microstrength of coke is proposed for evaluation of coal blends for metallurgical coke manufacture¹²⁾. A new idea being studied is recycling of waste plastics by thermal treatment with coal tar pitch, and adding the resultant "reactive" pitch into the coal blend¹⁸⁾.

5. Clean Coal Technologies

It has been considered that the maximum efficiency of coal conversion into energy, approaching 90%, can be achieved by pyrolysis combined with electricity and heat generation. The projects being developed in this area include:

- pyrolysis with ash or another coke heat carrier, followed by char combustion in a fluidized bed reactor or an existing pulverized fuel boiler. This process has been tested in the Institute for Chemical Processing of Coal in Zabrze at a scale of 6 tons/day.
- pyrolysis of coal in gas streams of temperature 1500–2000°C obtained from partial combustion coal powder in the presence of steam. The process was tested at semi-industrial scale.
- pyrolysis of coal in a fluidized bed reactor using indirect heating and recirculation of resulting gas. The pyrolysis is combined with air gasification of char to produce low-calorific value gas for gas turbines. The process was tested in a 50 kg/h pilot plant at the Institute of Fuel Energetics at the Silesian Technical University in Gliwice.

All projects have been intended to gain experience necessary for creating integrated systems, combining the existing power stations with the

pyrolysis units being developed.

In Poland, extensive direct use of coal in the domestic sector (about 18 million tons per year) is characterized by very low efficiency and high emissions of pollutants including dust, CO, SO₂, NO_x tarry substances and benz[a]pyrene. Severe damage to the environment and human health is caused by the concentration of highly polluting, inefficient, often dilapidated coal-burning facilities in the big population centers. Measurements done in Cracow and the Upper Silesia region showed that about 60% of average annual air pollution emissions comes from residential heating and rises to 90% during the winter season¹⁹⁾.

Table 3 compares pollutant emissions from coal combustion in a power station and in a typical residential heating oven.

To improve combustion efficiency and environmental protection, low-emissions large-scale production of fuels is of great importance. There is an urgent demand for 2 million tons per year production of a fuel of this type for the residential sector.

Applied research relating to formed fuels has been a subject of intense study for many years at the Institute for Chemical Processing of Coal in Zabrze. Currently, two processes for the production of formed fuel for general use in the residential sector are being developed.

1. Cheap production of low emission (ecological) fuels by briquetting coal/char fines.

Volatile matter content below 18% is a primary requirement for this type of fuel. Raw materials considered for the process are coke breeze, anthracite, low rank coal char, and wastes from

Table 3 Estimates of pollutant emissions from coal combustion (g/ton of coal)

	Dust	CO	SO ₂	C _n H _m	Benz [a] pyrene
Power station	3400	1000	19000	27	0.01
Domestic sector	7500	45000	21000	5000	20

coal preparation plants. The main problems associated with this project are related mostly to the selection of a suitable nonpolluting binder.

2. Production of smokeless fuels according to the original technology of the Institute. This process consists of pyrolysis of low rank coal and hot briquetting of resultant char with a caking coal in a 3 : 1 ratio. Autothermic pyrolysis occurs in a circulating fluidized bed reactor (CFBR) at 800 - 850°C with partial gasification in the air. Hot char is mixed with a caking coal acting as a binder and briquetted at about 450°C. The final step is conditioning of the briquettes at the pressing temperature. This process has been tested in a demonstration unit producing 200 tons of briquettes per day. The resultant fuel contains from 6 to 12% volatiles and shows suitable burning characteristics in firing units commonly in domestic use.

The circulating fluidized bed reactor combined with a gas turbine and a circulating fluidized bed boiler for char combustion has been proposed as an integrated energy generation system.

Table 4 shows the properties of coal and briquetted fuels, and the emissions resulting from their combustion²⁰⁾.

6. Coal Liquefaction

The coal liquefaction project was intended to

produce motor fuel completely competitive to crude oil processed fuel, using high sulphur coals located in the reach seams of the Upper Vistula coal district. This research, widely conducted since 1957 with the Central Mining Institute as the leading unit, was terminated in 1990.

Initially, a two stage process including coal extraction with hydrogenated anthracene oil and catalytic hydrogenation of coal extract was studied. Finally, a new concept based on direct hydrogenation of coal/anthracene oil (1 : 2) slurry was developed. The process was tested at a scale of 2 tons of coal/day, and the light fraction of the product was successfully used as a component in motor fuel. Hydrogenation of a selected high volatile matter coal from the "Janina" mine at 450°C, under hydrogen pressure 20 MPa and coal/oil slurry mass velocity 1 kg/dm³h gave about 50% conversion of the coal to liquid products. A demonstration unit for the hydrogenation of 200 tons coal/day was designed.

The proposed integrated process of coal conversion based on direct hydrogenation included the production of motor fuels, electrode coke and smokeless fuel.

7. Coal and Coal Derivatives as Precursors to Carbon Materials

Possibilities for the utilization of coals and coal

Table 4 Properties of briquetted fuels in comparison to raw coal

		<i>Type of fuel</i>			
		<i>Coal</i>	<i>Ecological fuel</i>	<i>Smokeless fuel</i>	
Content					
moisture	W ^a	%	3.0 - 18.0	0.8 - 10.1	0.6 - 4.7
ash	A ^a	%	2.2 - 15.0	9.2 - 14.8	10.1 - 12.4
volatile matter	V ^{daf}	%	32.3 - 40.4	19.6 - 21.4	7.3 - 11.5
sulphur	S _t	%	0.27- 1.30	0.60- 0.70	0.48- 0.56
Emission					
C _n H _m		mg/MJ	700 - 3000	470 - 700	135 - 330
CO		mg/MJ	2000 - 5500	2000 - 4500	2000 - 4000
SO ₂		mg/MJ	350 - 700	130 - 270	125 - 185
NO _x		mg/MJ	110 - 180	30 - 100	20 - 70
Tar		mg/MJ	480 - 700	170 - 330	50 - 200
Benz[a]pyrene		mg/MJ	400 - 600	100 - 275	20 - 80

derivatives in the carbon and graphite industries have been extensively studied from different aspects.

One of the central aims of the research was the implementation of electrode coke production from coke oven tars and heavy products from coal liquefaction. The project covered several topics relevant to the technology, from selection and pretreatment of raw materials up to the testing of baked and graphitized model electrodes²¹⁾⁻²³⁾.

At present, the research in the area of coal-derived raw materials for constructive carbons manufacture is concerned mostly with:

- evaluation of pitches using advanced characterization methods
- upgrading of available coal tar pitches for use as a binder and impregnating agent in conventional electrode manufacturing processes, C - C composite matrix, sealing and insulation material, precursor for the mesophase (mild oxidation, hydrogenation, and blending with polymers)
- preparation of the mesophase (microbeads and bulk) suitable for the manufacture of high density binderless artifacts
- upgrading of domestic anthracite to replace imported anthracite in the manufacture of carbon linings for blast furnaces and alumina electrolysis cells.

Unquestionably, preparation and characterization of active carbons to be utilized as carbonaceous adsorbents and catalyst supports have been owing the most extensively studied areas concerning coals and carbons. Surface properties, pore structure and reactivity, with respect to the nature of the material, and fossil fuels representing the whole range of coalification from low rank coals to anthracites, active carbons, charcoal cloths, synthetic polymer carbons, are being studied²⁴⁾⁻²⁶⁾. The basic aim of this research is to establish the rules governing the development of porosity during carbonization and gas activation as well as the effects of preoxidation and metal addition. Various approaches to the evaluation of adsorption data are being

attempted to obtain consistent results referring to micropore volume, pore size distribution and surface area of the materials.

Currently, the fields of special interest are:

- coke breeze as a cheap (unrecoverable) adsorbent for water treatment
- use of domestic anthracite as a precursor to microporous adsorbents (molecular sieves)
- activation of synthetic fabrics and felts
- special adsorbents from carbonaceous materials with the addition of graphite intercalation compounds and carbonaceous mesophase

Based on the experimental results, two new technologies for activated carbons production have been developed recently in the Institute for Chemical Processing of Coal. CROSSACTIV produces formed activated carbons for domestic water purification and removing organic vapours from the gas phase. The process consists in carbonization of coal dust granulated with a binder at 550°C in a fluidized bed reactor, followed by activation with a steam/flue gases mixture. TANDDEM technology starts with drying and oxidation at 200°C of a grained hard coal or anthracite. The oxidized coal then goes to two-stage fluidized bed reactor where carbonization at 500°C followed by autothermal activation at 1020°C with air/steam mixture occurs.

8. Concluding Remarks

Coal has an exceptional position in the Polish economy as a major indigenous source of energy and an important raw material for chemical and carbon/graphite industries. Expert opinions indicate this position will be maintained for the foreseeable future.

Several research groups associated with universities, the Polish Academy of Sciences, and industrial institutes have been involved for many years in the science of coal and related materials, as well as the fundamental technologies for their application. The Polish contribution to the knowledge in the areas of coal structure and properties as affected by rank, fundamentals of coal pyrolysis, and metallurgical coke and activated

carbons manufacture have been recognized worldwide.

Clean and efficient use of coal continues to be the greatest challenge to all those dealing with the science and technology of coal. It seems that particular interest in the research of coal and related materials should be focused in the near future on the following topics:

- better understanding of the relationship between coal constitution and properties as a basis for proper utilization of various coals
- development and possibly wide implementation of clean coal technologies, such as a combined system of coal pyrolysis/gasification for power generation and the production of low emission and/or smokeless fuel for common use in the residential sector
- new materials from coal and coal derivatives; in particular, utilization of coal tar pitch as a precursor to advanced carbon materials
- science and technology of activated carbons

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