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Part 3

ASH AND SLAG HANDLING

3.7. Analytics

3.7.10. Impact of new coal combustion technologies on types and character of ash and slag

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ABSTRACT

The necessity of cutting CO_2 emissions into the atmosphere is strongly impacting development and use of various energy sources, and is becoming a strategy for existence for practically all countries around the world. Coal, until now the cheapest source of thermal and electric energy, but also the most CO2 emitting, requires improvements to existing combustion technologies and development of new ones.

On the one hand combustion in pulverised and stoker furnaces is getting better and the fluidised bed combustion is becoming more common, and on the other the integration of gasification of fuels with electricity generation as well as mastering the combustion of fuels in oxygen is being vigorously pursued. All these actions aim at increasing the thermal efficiency of energy processes and eliminating negative environmental effects of combustion of coal, also when mixed with other alternative fuels.

This will bring new types of coal combustion by-products, having new composition and physical-chemical properties. The ongoing research and development efforts indicate the high utility value and utilisation potential of these new by-products as mineral materials and building products.

Research and development projects concerning economical utilisation of combustion by-products deposited in the past in landfills, run parallel to the direct utilisation of by-products resulting currently from newly developed combustion technologies. Marked increase in coal combustion products utilisation ratio, is brought about not only by economic considerations and careful management of natural raw materials, but also results from recently introduced legislation related to emissions of CO_2.

COAL IN FUEL AND ENERGY BALANCE

When we analyse the share of coal in the primary energy balance we see a systematic decrease, while the absolute volumes of extraction and use of coal increase. Most of the forecasts for the 21st century indicate, that the current share of coal in energy balance will remain unchanged, which in practical terms means a 2,5 % increase in coal consumption annually. Some forecasts, especially those going beyond 2030, are painting a significantly increased role of coal in energy provision, as illustrated by Fig. 1.

While in 2006 coal represented 25 % of the primary energy and 40 % of electric energy generation, in years 2006—30 the consumption of hard coal will grow from 5,370 to 10,560…12,000 m ton [1].

In 2000, the share of coal in the primary energy balance was only 5,4 % in France and 7,1 % in Italy, but 16,7 % in the UK, 17,1% in Spain and 25,1 % in Germany. The share of coal in electricity generation is much higher, and in 2006 was 93% in South Africa, 80 % in Australia, 78 % in China, 71 % in Israel, 70 % in Kazakhstan, 69% in India and Morocco, 59 % in the Czech, 58 % in Greece, 50 % in the USA and 47% in Germany. In Poland, the share of coal is one of the highest in the world, being respectively 64,9 % and 93 %.

The biggest increase in the use of coal in economic development is found in China (growth of coal-based electricity production from 30 EJ in 2000 to 70…85 EJ in 2050) [2], in India (increase in the consumption of coal for electricity generation from 310m ton in 2005/6 to 1.659m ton in 2031/32) [3,4] and the USA (increase by 20 % in the years 2006—30, but also -5 % and + 36 %) [5].

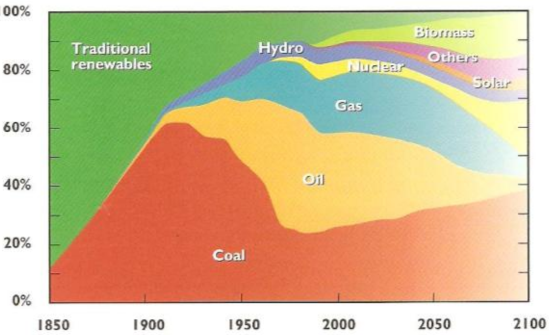

Fig. 1. The prospects for share of particular kinds of energy in the primary energy balance [1].

Most of the EU member states predominantly tend to eliminate coal as their primary energy source and limit its share in electricity production [6]. This makes the situation quite serious, as in 2000 coal represented 31% share in electricity production in EU-25 countries, with 50% of the installed capacity requiring retrofitting, and the electricity demand expected to rise by 40 % in 2030 [7].

Reconciling the increasing demand for electricity with the need for environmental protection, while providing conditions for societal growth, is becoming more and more difficult. Balance of resources is showing short term reserves of oil (41 years) and natural gas (64 years) with much longer horizon of coal seams availability (251 years) – Table 1.

One of the most important features of coal reserves is their practically universal availability across the world – Fig. 2, while 68 % of oil and 67 % of gas reserves in the world are concentrated in the Middle East and Russia.

Table 1. **Reserves and resources of different primary energy sources as of 2004 [8]**

Energy sources	Reserves		Resources	
	Gtoe	Years	Years	Years (R/P)
Fossil fuel	787	-	-	
Oil	143	41	~ 200	125
Natural gas	138	64	~ 400	210
Coal	506	251	~ 700	360
Nuclear	55	82	~ 300	> 10000

DIRECTIONS OF DEVELOPMENT OF CLEAN ENERGY TECHNOLOGIES

The necessity of reducing CO_2 emissions into the atmosphere is seriously impacting the development of the primary energy sources. In this context hard coal and lignite rank amongst those emitting the highest amount of pollution into the atmosphere. On the other hand, the most environment-friendly are processes of energy capture from renewable sources (sun, water, wind, geo- etc.) and nuclear energy – Fig. 3.

Development of various sources of renewable energy and low-emission technologies is conditioned by the costs of electricity generation. Analyses of actual and forecast costs in the EU states and the USA. show that the most expensive

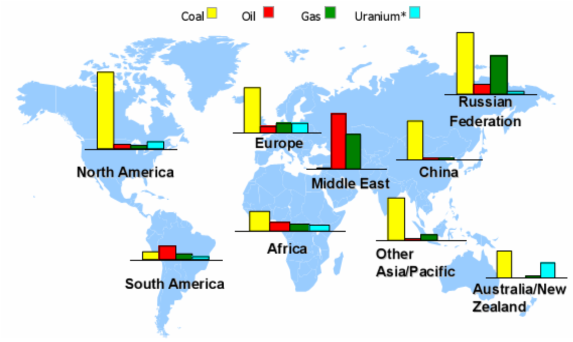

Fig. 2. World energy reserves 2005 [1]

electricity comes from photovoltaic and wind farms, while the cheapest is provided from coal and nuclear plants – Table 2.

Given this situation, it seems highly unlikely that coal should disappear as a source of electric and thermal energy, and as chemical raw material, amongst others because of:

- - the highest reserves among fossil fuels and relatively universal availability of coal;
- - economic competitiveness of „coal calories";
- - lower sensitivity to economic and political changes (crisis situations);
- - progress in technologies of using coal for power generation;
- - significant share in the existing energy sources;
- - tradition.

Table 2. **Comparison of electric energy production costs in the EU and in the USA [10, 11]**

Energy sources	EU - 27 €/MWh 2005	EU - 27 €/MWh 2030	USA c/$/kWh 2004
Biomass electricity	25...85	25...75	5...15
Wind electricity	35...175	28...170	5...-13
Solar photovoltaic electricity	140...430	55...260	25...125
Solar thermal	-	-	
Hydroelectricity large	25...95	25...90	3...20
Hydroelectricity small (< 10 MW)	45...90	40...80	2...8
Hydroelectricity micro	-	-	4...10
Geothermal electricity	-	-	4,2
Marine energy	-	-	2...10
Coal power plant PF with FGD	30...40	45...60	8...20
Coal power plant CFBC	35...45	50...65	3,2...3,9
Coal power plant IGCC	40...50	55...70	3,6...3,9
Natural gas combined cycle	45...70	55...85	3,1...3,4
Natural gas comb. cycle co-generat.	35...45	40...55	2
Spark-ignition engine - generators	70...80	80...95	6,9
Nuclear	40...45	40...45	

< 50 €/MWh; 51-100 €/MWh; > 100 €/MWh

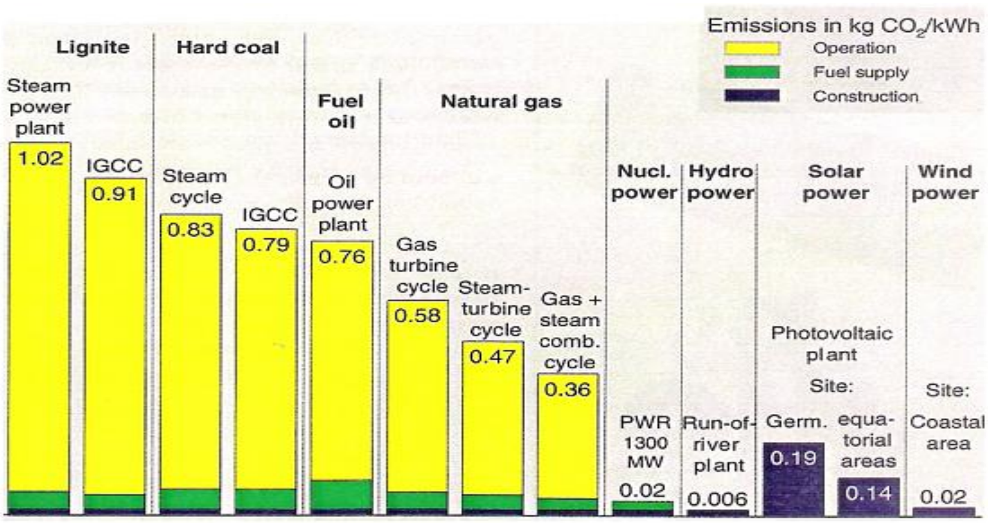

Fig. 3. The volume of CO_2 emission in the processes of electric energy production depending on the fuel and technology of generation [9]

Many undertakings will be necessary in order to reconcile the environmental protection requirements with the sustained and expanded use of coal, including:

- - more common co-combustion of coal with alternative fuels, including biomass;
- - increased efficiency of coal combustion and processing of chemical energy into thermal, mechanical and electric;
- - maintaining flue-gas cleaning by capture of SO_2, NOx, particulate matter and Hg;
- - implementation of the technologies of capture and sequestration of CO_2;

- - implementation of the new technologies of high-efficiency coal combustion, combining energy generation with other process technologies, and use of nuclear energy for coal gasification, yielding syn-gas and hydrogen;
- - production of „clean” coal from available fuels.

It is for these reasons that we may observe a considerable growth in efficiency and capacity of the retrofitted and newly built power units, amongst others based on:

- higher thermodynamic parameters of steam;
- technology of fluidised combustion of fuels;
- combustion of fuels in oxygen-enriched atmosphere and in oxygen (oxyfuel);
- gasification of coal in integration with gas-steam system (IGCC).

The choice of a solution for electricity generation based on combustion of hard coal and lignite, with consideration to environmental protection, to large degree will depend on the costs of constituent technologies and availability of investment finance – Fig. 4. The lowest investment and generation cost from coal combustion are offered by units working at super- and ultra-supercritical parameters. When capture and sequestration of CO_2 is needed, then the best economic effects are provided by gas-steam systems integrated with coal gasification.

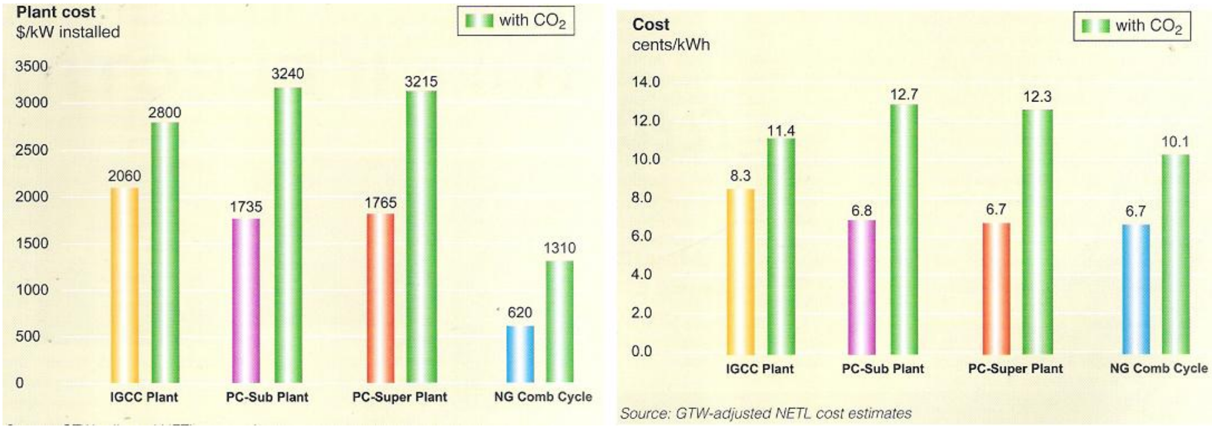

Fig. 4. A comparison of investment costs of building power units fueled with hard coal and natural gas vs. electric energy production costs (for coal price of 1,80 and gas price 6,75 USD/MMBtu - according to January 2009 USD exchange rate) [12]

Particularly substantial growth is forecast in the construction of super- and ultra-supercritical blocks and coal gasification installations.

While before 2002, approx. 500 gasification installations were in operation (including 22 IGCC), till 2015 some 70 new power units of this type are planned to be put into operation. In the years 2004—2010 the chemicals and fuel industry saw capacity of gas-generators rise from 45 to 73 thousand MW_t. Chinese forecasts for 2050 indicate a 85 % share of gasification processes in the balance of coal use.

IMPACT OF NEW COAL COMBUSTION TECHNOLOGIES ON QUALITY AND VOLUMES OF COAL COMBUSTION PRODUCTS

The first half of the 21st century will witness an increase in the volumes and kinds of combustion by-products, resulting not only from general growth of coal use, but also from combustion of lower grades of coal, as well as development of new technologies of co-combustion of coal and mixed fuels. At the same time combustion technologies will be developed and improved in terms of limiting the emissions into the atmosphere, producing new kinds of combustion by-products.

Forecasts indicating the increase in the consumption of hard coal in the years 2006—2030, with 60 % used for power generation and average ash content of 15 %, mean that the **output of flyash and slag from power plants is going to grow from approx. 480 to approx. 950…1080m ton.** The biggest growth in coal consumption will take place in Asia, where the volumes of flyash and slag will proportionally increase.

In the largest group of combustion by-products, arising in **pulverised fuel atmospheric furnace boilers**, we may expect that the content of char (unburnt coal) is going to fall due to the introduction of higher-efficiency new systems and modernisation of older plants. We should remember however, that often diversifying the origins of burnt coal (economic reasons) may limit the possibility of full utilisation of resulting flyashes, due to a changeability of their parameters. Also co-combustion of coal with biomass is impacting the quality of selected flyashes and slags.

After 2015, the problem with ammonia slip in fly ash used in concrete production may become more pronounced, because of more and more common use of Denox installations for limiting the emissions of NO_x. Often it will be necessary to start processing ashes in order to remove or neutralise ammonia. In many cases these processes may be combined with other methods, such as grain size classification, densymetric or magnetic classification, etc.

More widespread use of **oxyfuel combustion** is affecting not only operating parameters of boilers, but also impacts coal combustion by-products. High concentration of oxygen and high combustion temperatures, result in the full burn-out of organic mass and full oxidation of organic and inorganic compounds. Resulting flyashes will specifically lack char and will have the highest content of type-III iron. We may also expect increased production of cenospheres to accompany the combustion of hard coals.

The growing share of **fluidised bed boilers** brings increased amounts of calcareous coal combustion by-products [14]. Depending on sulphur content and percentage of co-combusted bio-fuels, the properties of particular flyash and bottom ash vary significantly. Majority of fluidised bed ash have good binding properties, constituting good base for many building and road-making binders [15].

Decisive change in quantity and quality of combustion by-products will be brought by mass-scale implementation of **fuel gasification** processes **[**16]. Majority of such installations employ gas-generators providing for removal of mineral residues of gasified fuel in liquid state, with melted slag constituting a gasification by-product [13]. Only small number of these installations yield granulated slag (bottom ash) and fly ash, as by-products containing considerable amounts of char.

Amongst the new combustion by-products, especially interesting is melted slag from gasification process, which is not only neutral to the environment but also applicable in the production of rock wool, active aggregate for concrete, cement-less binders, etc. Its high hydraulic activity has roots in the accumulated inner energy (quenched liquid).

Known **technologies of beneficiation and utilisation of combustion by-products** will become more widely applied and supported by new industrial-scale solutions. Increase in degree of utilisation of combustion by-products will result amongst others from their value as raw-materials, their mass- and geographical availability, and from the need to save natural resources, accompanied by the increase in the costs of landfilling and reduced availability of locations for new landfills. Recent years proved that increased utilisation may also be stimulated by possibilities for reducing CO_2 emissions and bringing cost savings, which for many technologies presents a major limiting factor for their use [17].

Depending on practicalities of economic and environmental policy of a given country, this large volume of combustion by-products may be treated as a valuable source of materials or a problematic waste. Very often the forecasts for coal-based power generation are limited only to the issues of combustion technology, process efficiency, flue-gas treatment, transmission of energy, etc., leaving out the issues of optimal management of combustion by-products. It needs to be emphasized, that forecasts adopted by the Government of India in this respect are quite exceptional [3], seeing the utilisation of growing volumes of combustion by-products (2000 = 125 m ton; 2017 = 225 m ton) as one of important tasks for the Indian economy.

In order to tackle the utilisation of coal combustion by-products in optimal way, it is necessary that this issue is dealt with at the design stage of the new and retrofitted plants. It is important, that the possibilities of releasing and producing ready products complying with REACH requirements, from mixtures and selected fractions of flyashes, slags, cenospheres, magnetite dust etc., are taken there into account.

In those countries, where raw-material potential of combustion by-products is not only well recognised, but also brings significant economic effects, as well as in those countries, which limit coal combustion as fuel, more and more historic deposits of ashes at landfills are being opened up and taken for segregation and drying, thus becoming a source of high-quality materials. Coming years may bring more international trade in ashes.

Utilisation of coal combustion by-products varies greatly in different countries. These differences result from many factors. Effective exchange of information and sharing of experience between countries and companies is greatly supported by organising conferences, seminars and workshops.

CONCLUSIONS

1. Analyses of fuel-energy balances indicate, that coal consumption will double in the period 2006—2030, which means that the production of combustion by-products will increase from the level of 480 to nearly 1000 m ton.
2. New technologies of fuel combustion and flue gas treatment are implemented in order to reduce and eliminate the negative environmental impacts, which is influencing the quantity and quality of arising combustion by-products.
3. New by-products of co-combustion of coal and biomass in pulverised and fluidised bed furnaces, as well as from fuel gasification, require intense research for defining optimal conditions for their beneficial utilisation.
4. Because of big differences in the degree and practice of utilisation of combustion by-products in different countries, of particular value are international conferences etc., providing opportunities of effective exchange of experience and establishing contacts.

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