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Some technical issues of zero-emission coal technology

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Abstract

A concept of zero-emission coal technology, proposed by ZECA Corporation, is presented and discussed. The process can produce electricity at 60–70% efficiency with zero emission to the atmosphere. The carbon dioxide is produced as concentrated, clean stream, which is easy to sequestrate. The process uses $CaO/CaCO_3$ reaction to enhance hydrogen production and to separate carbon dioxide. Hydrogen feeds a stack of solid oxide fuel cells (SOFCs), which produce electricity. High-temperature byproduct heat from the SOFC drives the calcination reaction, which restores CaO. Unfortunately, the possible realization of the process may encounter various technical difficulties mainly connected with requirements for the SOFC (very high operating temperature, high sulfur tolerance, integrated heat exchanger) and $CaO/CaCO_3$ process (the decrease of the performance with increasing number of cycles and problematic heat transport into calcination vessel).

Keywords: ZECA; SOFC; Coal; Power generation; CaO; CO_2 sequestration; H_2S removal

1. Introduction

Energy demands of human civilization are growing fast. Energy consumption is still growing in the developed countries (despite the improvements in the efficiency of energy utilization), but there are also plenty of developing countries, where this growth is much faster. Such countries are trying to follow developed countries and reach a similar standard of living. This cannot be done without rising energy consumption. Table 1, based on [1], provides some data about energy consumption and resources. Total world energy consumption in the year 2001 was 10 029 Mtoe (4.2×10^{20} J). The majority of today's energy comes from fossil fuels ($\sim$ 80%); nuclear energy counts only for 7% and renewables (including fuel wood) for 13%. One should not expect that renewable or nuclear energy will meet the world energy demands in the near future (this is partially caused by the fact that fossil energy is cheaper, but there are also some technical barriers for introducing wide renewables). Nevertheless, fossil fuel reserves are finite and will not last forever. At the present consumption rate, oil will last for about 40 years, natural gas for about 70 years and coal for about 200 years. (Obviously, new deposits can be discovered, so the proved reserves can grow to some extent.) Coal reserves are larger than oil and gas reserves together and coal can give some time for our civilization to accommodate to the post-fossil fuel world and to fully develop renewable sources or nuclear power (especially nuclear fusion).

Unfortunately, lack of energy sources is not the only problem. The Earth's biosphere cannot successfully accommodate today's scale of byproducts of energy production like CO_2, SO_x, NO_x and others. Coal is considered the dirtiest fossil fuel. It contains quite a large amount of sulfur and also produces the largest amount of carbon dioxide per unit of energy released. In addition, the efficiency of the present coal plant is lower than oil or natural gas plants.

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Table 1
Energy consumption, reserves and reserves to consumption ratios, data from 2001 [1]

Source	Consumption (Mtoe)	Share of total (%)	Proved reserves (Mtoe)	Reserves to consumption ratio (years)	Reserves to all fossils consumption ratio (years)
Crude oil, natural gas liquids and petroluem products	3507	35.0	151 984	43	19
Natural gas	2122	21.2	156 706	74	20
Coal and coal products	2342	23.4	501 172[a]	214	63
Total fossil fuels	7971	79.5	809 862		102
Nuclear	692	6.9			
Renewables (incl. fuel wood)	1284	12.8			
Total from all sources	10 029	100.0			
Balance difference	82	0.8			

[a]Data from 2003.

There is a need for new energy technology based on coal, which would supply energy for human civilization before renewables or nuclear power can meet humankind's power demands. Such coal technology must be highly efficient and environment friendly. Moreover, all CO_2, the main product of coal oxidation, should be discarded or sequestered and not emitted into the atmosphere. Various proposals of how to realize this idea can be found in the literature [2].

One project using such a technology was proposed a few years ago by Hans Joachim Ziock and other members of ZECA Corporation [3].

The idea itself was very attractive. It is claimed that electricity can be produced with efficiency around 70% without any emission into the atmosphere (also, CO_2 is not emitted) [4]. Nevertheless, there are some difficult technical problems that must be addressed. This concept is briefly described below and the technical difficulties are discussed. All thermodynamic data, if not specified differently, are calculated on the basis of [5–7].

2. Description of the zero-emission coal technology

The zero-emission coal (ZEC) process converts chemical energy of coal into electricity with claimed efficiency of up to $\sim 70\%$ and produces a clean stream of carbon dioxide, which can be sequestered or stored in various ways. Such a concentrated stream of CO_2 is much easier for sequestration than CO_2 diluted by another gas, for example nitrogen. ZECA often proposes CO_2 mineralization as $MgCO_3$ as a favorite, geologically stable form of CO_2 sequestration. Nevertheless, power production and CO_2 sequestration in this project are not tied together and can be realized separately.

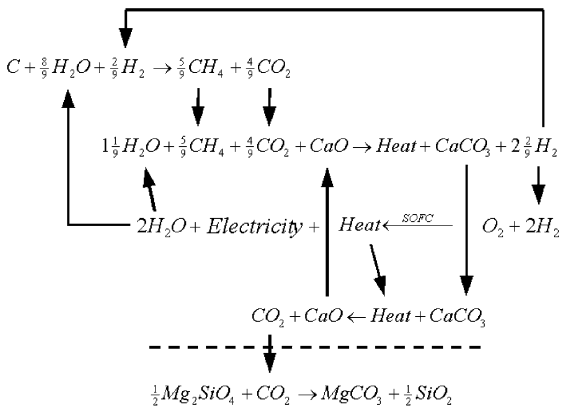

Fig. 1. Reactions in the ZEC process. Coal (carbon), oxygen and magnesium silicate are process substrates. Electricity, magnesium carbonate and silica are process products. The lowest reaction, CO_2 mineralization, is one variant of CO_2 sequestration.

The main characteristics of the process are as follows:

- Recycling of matter, energy and contaminants inside the process.
- Separation of hydrogen from carbon dioxide during coal gasification and hydrogen production, which is obtained thanks to $CaO/CaCO_3$ reaction. (The use of lime to aid coal gasification was first proposed by DuMotay and Marechal in 1867 [8].)
- Utilization of the solid oxide fuel cell (SOFC) instead of gas or steam turbine, which frees the process from Carnot limitation and allows obtaining the byproduct heat at a high, useful temperature.

Figs. 1and 2 outline the ZEC process. The process comprises (1) coal gasification, (2) hydrogen production +