ARCHIWUM ENERGETYKI tom XLII(2012), nr 1, 3–22

Tadeusz Chmielniak
Sebastian Lepszy*

Silesian University of Technology
Institute of Power Engineering and Turbomachinery
Gliwice

Dual-fuel gas and coal-fired systems — concepts of new applications

The energy policy related to the reduction in CO_2 emissions creates interest in new concepts of multifuel systems. The paper presents an analysis of gas and coal fired power plants in which the flue gas waste heat of the gas-fired system is used to feed the CO_2 separation system of a plant fired with coal. The analysed structures are assessed in terms of savings in the fuel chemical energy and CO_2 avoided emissions.

1 Introduction

The energy policy of many countries assumes that fossil fuels, and coal in particular, will remain the main source of energy needed for electricity generation. This results from the high reserves of coal and their geographical distribution, which guarantees energy security [1]. The main downside of energy obtained from coal are the huge carbon dioxide (CO_2) emissions released into the atmosphere during its generation. This particular feature stimulates the search for new technologies in the use of coal. The most promising method of a significant reduction in coal-fired power plant CO_2 emissions seems to be the process of capture and storage (CCS technologies) [2–5]. Carbon dioxide capture involves additional energy expenditures which lower the electricity generation efficiency and the economic effectiveness. Moreover, the aim of the implemented market mechanisms concerning emissions trading is to enforce energy technologies that will limit the amount of CO_2 released into the atmosphere. These mechanisms, however, are burdened with a higher investment risk.

An interesting concept in the development of energy technologies is the use of diversified fuels in installations which are now being overhauled or designed.

*E-mail: sebastian.lepszy@polsl.pl

The use of such concepts is justified by the smaller risk related to changes in fuel prices, the high effectiveness of energy, the possibility of restoring power capacity of older units and the reduction in emissions in the case of fuels containing less coal per a unit of energy. So far, interest has been focused mainly on such multifuel solutions, e.g. combined cycles [6,7], that – if applied – make it possible to obtain an extra energy effect. This group comprises dual-fuel gas-steam cycles (gas, liquid fuel – solid fuel (coal, biomass)) and it generally includes the following:

- combined serial systems (with flue gas discharge into the boiler), Fig. 1a;
- parallel systems (installations coupled by means of a water-steam cycle), Fig. 1b;
- systems combining the characteristics of the two installations mentioned above.

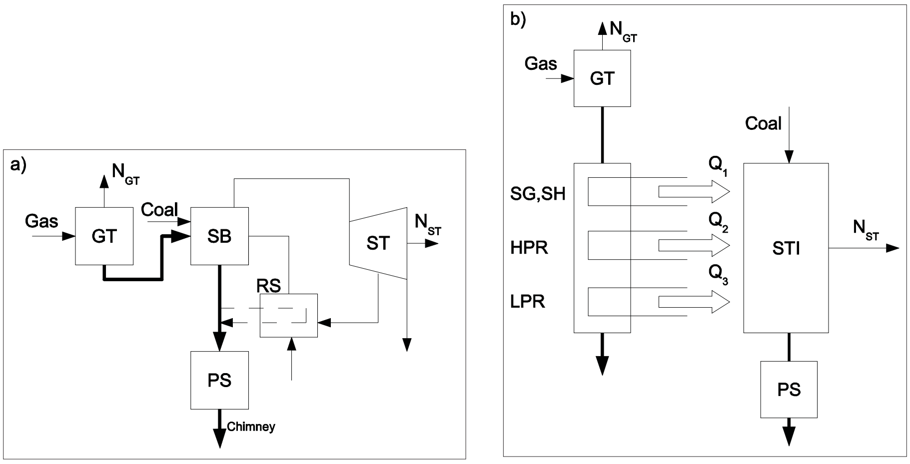


Figure 1. A dual-fuel system with a front gas turbine a), and combined dual-fuel parallel system b): GT – gas turbine installation, SB – steam boiler, ST – steam turbine, RS – regenerative system, PS - flue gas purification system, STI – steam turbine installation, SG – steam generation, SH – steam heater, LPR, HPR – low and high pressure regenerative systems, N_{GT}, N_{ST} – power capacity of the gas and steam turbine installations.

Efforts to reduce CO_2 emissions have resulted in new possibilities of application of multifuel systems. An example of this solution is the gas and coal fired system, where coal is the main fuel in the condensing power plant while the gas-fired power plant generates electricity and the heat for the CO_2 desorption process in the capture installation. The fuel for the gas installation is the natural gas, which features a smaller content of coal per a unit of chemical energy compared to hard coal. The most significant features of this system are: no interference with the cycle of the steam power plant, which guarantees the achievement of high values of efficiency, also in the case of operation with no CO_2 separation, and the need to provide big amounts of gas fuel, which may be difficult at the coal-fired power plant location.

Coal and gas fired power plants operating together feature a different efficiency compared to plants operating autonomously. Therefore, the assessment of the chemical energy consumption in comparison to facilities working separately is a vital issue from the point of view of the usefulness of such solutions for the economy. Assessing such solutions, it is also essential to determine the avoided emissions of CO_2. The results of these types of assessment may be important for the development of the power engineering strategy at the level of both national economy and the power sector plants.

2 The idea and parameters of the gas-coal systems under analysis

The idea of the considered concept of gas-coal systems is presented in Fig. 2. The concept assumes that the coal-fired power plant is a high efficient system that features ultra-supercritical steam parameters with a cycle which is typical of the state-of-the-art power plants currently built. Generally, the cycle of such a plant does not differ from a plant without CO_2 capture. The only differences are in the path of the flue gases from the boiler into the surroundings. The coal-fired power plant flue gases flow into the CO_2 separation system, where the gas is separated. The main source of energy in the separation system is the heat (Q) for the desorption process. In each case, the gas system is composed of a gas turbine and a system designed to use the waste heat from the turbine flue gases. A part of this heat may be used to feed the CO_2 separation system and another part – to generate extra electricity (N_{el_g}). In the analysis it is assumed that CO_2 is not removed from the gas system flue gases due to lower emissions from the gas fuel.

The modelling of the gas, steam and gas-steam cycles is performed with the Gate Cycle program. The program makes it possible to determine the parameters of the gas and steam cycles. The parameters of the agents are determined based on the real gas model. The cycle parameters are determined for the nominal working point only and they ignore the impact of the change in the ambient temperature on the power plant operation. Despite this, it should be noted that

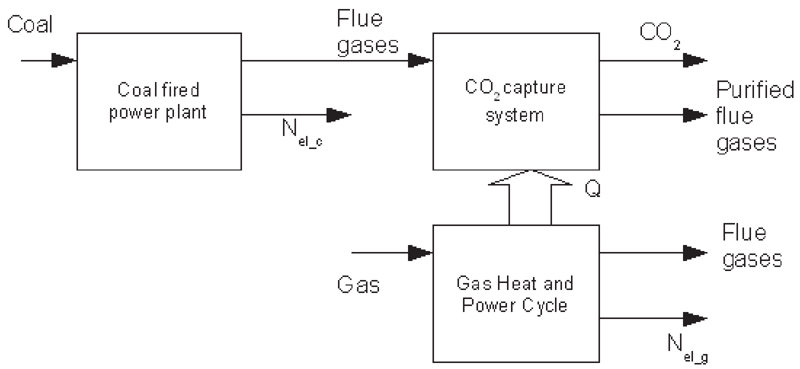


Figure 2. A block diagram of the concept of dual-fuel gas-coal systems (N_{el_c} – gross electric power of coal fired part, N_{el_g} – gross electric power of gas fired part).

most gas turbine characteristics are a linear function of the ambient temperature and for this reason the average value may be assumed for the calculations.

2.1 The coal-fired steam power plant

The coal-fired steam power plant under consideration features supercritical steam parameters (live steam t = 653 °C, p = 30 MPa, reheated steam t = 672 °C, p = 6 MPa). In this power plant cycle identical solutions and facilities are applied as those used in new coal-fired power plants (e.g., the steam attemperator as the final regenerative exchanger). The plant basic parameters are as follows:

- gross efficiency of electricity generation: $\eta_{el\_c} = 49.47\%$,
- gross electric power: $N_{el\_c} = 900$ MW,
- own needs: 10%.

The parameters of the power plant under analysis are dedicated for highly efficient and zero-emission power units and they do not reflect the present state of the art in the condensing power plant technologies. This is due to the paper is created within research programme "Development of technologies for highly efficient zero-emission coal-fired power units integrated with CO_2 capture from flue gases". The assumptions of this project are adopted in this paper.

2.2 The CO_2 capture system

One of the most often suggested methods for the systems of coal-fired condensing power plants is absorptive CO_2 separation. Absorptive methods allow CO_2 capture under low pressure (there is no need to compress flue gases), and it is possible to obtain a gas of high purity – 99%. They do not require a high CO_2 concentration in flue gases. The technology is well-known and it is successfully used in the chemical industry [8]. There are some drawbacks, of course, such as the need for sorbent regeneration, which requires high energy expenditures, and the need for deep gas purification (sulfur and nitrogen compounds, as well as dust, can result in sorbent degradation). Absorption is a phenomenon during which gas is taken in by a liquid in which it dissolves to a certain degree. Carbon dioxide separation is based here on one or several reversible reactions between CO_2 and other substances. The sorbing agents are aqueous solutions of compounds such as: amines – for example monoethanolamine (MEA) and diethanolamine (DEA)– ammonia, potassium or sodium hydroxide, and others which are still being examined and tested. The reactions that take place between the compounds and carbon dioxide are most often reversed with the use of external heat, and the product is a mixture of carbon dioxide and steam plus regenerated sorbent. The absorption process carried out in the absorber-stripper system is presented in Fig. 3 [9,10], where the subsequent stages of the chilled ammonia process are taken into account. It should be emphasised that only the heat needed for the sorbent regeneration is exclusively taken into consideration in the calculations as the amount of energy needed for the process of CO_2 separation. The demand for energy related to gas compression and to the needs of the flue gas attemperator is accounted for by increasing the own needs index.

The gas with CO_2 to be separated is fed into the absorber which contains a sorbent. CO_2 is separated from flue gases as a result of the reaction between the gases and the sorbent. After the absorption process is completed, the solution is heated in a heat exchanger and then brought to the top of the stripping column, where the gas undergoes the desorption process through heat feeding. After desorption, the sorbent flows into the exchanger and further to the absorber, and the separated CO_2 is directed to the compression process and transport [8]. For the variants under analysis, the sorbent before the stripping column is heated to the temperature from 115 °C to 155 °C.

The CO_2 separation by means of the absorption method with the use of ammonia is modelled with the Aspen Plus software code (the ELECNRTL model is selected for the calculations [4,5]). Carbon dioxide separation with the use of chilled ammonia (following the chilled ammonia process) is considered [10,11]. An analysis of CO_2 separation with the use of this method gives an amount of heat necessary to carry out the CO_2 separation process. The value is 2.02 MJ/kg of separated CO_2 [9]. However, studies are available where this value is lower, e.g. [12,13].

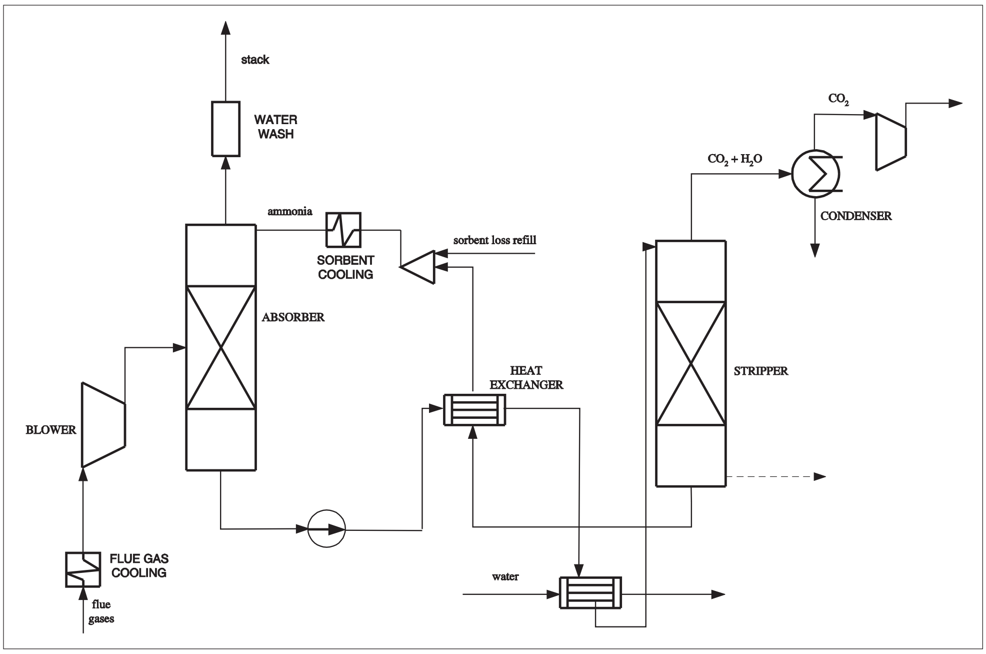


Figure 3. A block diagram of the installation for the CO_2 capture from flue gases.

2.3 The gas-fired part

A gas turbine model composed of separate components is used. In the modelling process, the air mass flow at the gas turbine inlet is selected in order to match the size of the steam and gas cycles to the demand for heat needed for desorption. For this reason, the gas turbine power capacity does not have to correspond to the power capacity of gas turbines which are commercially available at present. It should also be noted that the biggest state-of-the-art gas turbines feature a power capacity that allows the construction of such systems.

The gas turbine model is defined considering the parameters featured by the most advanced gas turbines. In particular, this concerns the pressure ratio of 20 and the turbine inlet temperature (TIT) of 1265 °C. Within the model, the cooling of the expander components is modelled in a simplified way. The obtained efficiency value is comparable to that of current-generation gas turbines, especially while considering gas turbines fed with air with a temperature lower than nominal.

Three variants of a gas turbine plant are considered. One of them (variant A) is composed of a gas turbine and a water heater. The next variant is composed of a simple gas turbine, a single pressure heat recovery steam generator and a backpressure steam turbine (variant B) and the last – of a simple gas turbine with the air bottoming cycle (variant C). In variant B, the steam from the backpressure turbine outlet and the hot water from last heat exchanger in the heat recovery steam generator (HRSG) is the source of heat for the desorption process in the system of CO_2 capture of the coal-fired plant. The thermodynamic analyses are conducted assuming that the heat needed for desorption in systems A, B and C is supplied in a form no other than hot water. All exchangers are modelled assuming minimal temperature differences between the agents of 5 °C. Additionally, it is assumed that the water heat capacity flux is equal to the sorbent heat capacity flux, which guarantees that the difference between the sorbent and the heating water temperatures is constant.

The parameters of the gas-fired part of the system with a water boiler are as follows:

- net efficiency of electricity generation: $\eta_{el\_g\_A} = 40.0\%$,
- net generated power: $N_{el\_g\_A} = 268$ MW,
- flue gas temperature at the water boiler outlet: $t = 125$ °C.

An essential feature of this gas system is that the use of waste heat from the gas turbine flue gases does not entail any significant changes in the electricity generation efficiency values, which affects the ecological indices (e.g. CO_2 avoided emissions).

The parameters of the gas-fired part of the system with a backpressure turbine are as follows:

- net efficiency of electricity generation: $\eta_{el\_g\_B} = 47.47\%$,
- net generated power: $N_{el\_g\_B} = 375$ MW,
- flue gas temperature at the steam boiler outlet: $t = 125$ °C.

The gas-steam system under analysis features a relatively low electricity generation efficiency compared to current-generation systems of gas-steam electrical power plants, but this efficiency basically depends on the parameters of the heat supplied to the CO_2 capture installation.

The electricity generation efficiency can further be raised by using a multipressure waste heat boiler. Although this will increase investment expenditures significantly, a system like this, after a detailed analysis and optimisation, may be more effective economically. Multipressure boiler systems are not considered in this paper due to their more complex structure and the need to carry out a multivariant optimisation. Another step which could improve the efficiency of the system is to use a steam cycle with a condensing turbine. However, this solution results in a decrease in the total efficiency and a rise in the gas- to coal cycle power ratio, which may have an adverse effect on avoided emissions and on the economic effectiveness.

An interesting example of a gas turbine development aiming at an improvement in the electricity generation efficiency is the use of an gas-air cycle.

The features that make gas-air cycles interesting are as follows [14–17]:

- the chance to raise the efficiency of power installations with gas turbines,
- the potential to meet the peak demand for power,
- mobility,
- no demand for water,
- no toxic substances in the cycle.

Figure 4 presents the diagram of the simple gas turbine system coupled to an air turbine system through a heat exchanger HTHE treated as an air waste heat boiler with heat exchange efficiency of 96%. The gas part exhaust gases and the air from the air turbine contain enough heat to use in the CO_2 separation system.

The following internal efficiencies of the machines are assumed:

- internal efficiency of the compressor C_2 – η_{C2}= 88%,
- internal efficiency of the air turbine E_2 – η_{E2}=90%,
- efficiency of the electricity generator G_2 – η_{G2}=98%.

In the simple gas-air cycle a compressor with no inter-stage cooling, a heat exchanger coupling the gas and air cycles, and an air turbine are used. The heat from flue gases and air is recovered in two heat exchangers, where heated water is used in the CO_2 capture system of the coal-fired power unit. The mass flow of the water cooling exchangers HE_1 and HE_2 is selected so that the temperature of flue gases and air at the exchanger outlet is at the level of 90 °C. The pinch between the cold inflow and hot outflow at exchangers HE_1 and HE_2 is maintained at approx. 10 °C, as the temperature of the re-circulating water is approx. 80 °C. Water is heated to the temperature of 135 °C. In the case of the flue gas exchanger, it is also important that the temperature does not drop below the dew point. Due to the possibility of corrosion, the direct flue gas – amine exchangers are not used here.

An important parameter affecting the efficiency of the gas-air cycle is the pressure ratio in the S2 compressor. The impact is illustrated in Fig. 5. The curves are plotted for three mass flows which correspond to 75, 100 and 125% of the mass of the flue gases from the gas turbine set, respectively. The optimum

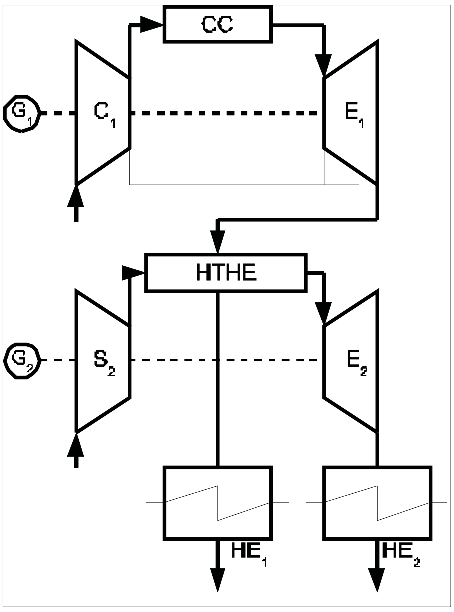


Figure 4. The simple gas-air cycle (G – electric generator, C – compressor, E – expander, HE – heat exchanger).

parameters are obtained for the compression rate π_2= 5.1 and the air mass equal to 112.7% of the flue gas mass m_{sp}. The electricity generation efficiency is then η_{el} = 47.35%.

Figure 6 presents the amount of heat that can be absorbed by water in exchangers HE_1 and WC_2 for the needs of the coal-fired power unit CO_2 capture installation (simple system). For the air mass flow for which the electricity generation efficiency is the highest, the value of the heat absorbed by the water is not the highest. The heat that may be absorbed in the exchanger is given in relative units and defined by the dependence:

$$Q = \frac{Q_{HE1} + Q_{HE2}}{m_g LHV} \ , \tag{1}$$

where $Q_{HE1,2}$ are the heat duty of heat exchangers 1 and 2, respectively, m_g is the gaseous fuel mass flow, and LHV denotes low calorific value. Using the presented curves, it is possible to determine the power capacity of the gas turbine and of the air cycle that would be able to provide a sufficient amount of heat for the CO_2 desorption process.

Based on the presented analyses of the simple air cycle, it is possible to achieve

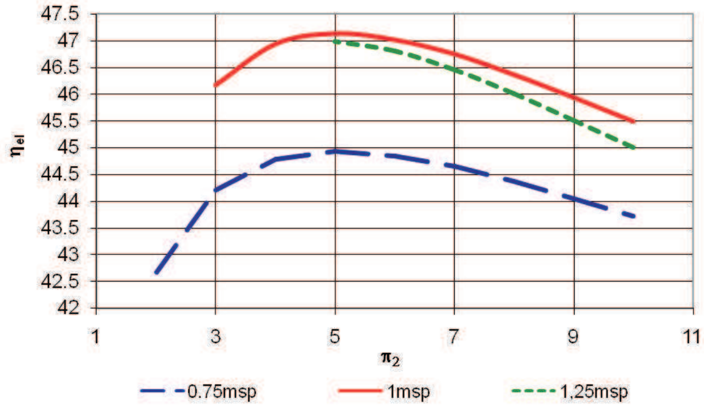


Figure 5. Electricity generation efficiency depending on the compression ratio in the simple system.

the following parameters of the gas-air cycle co-operating with a coal-fired power plant:

- net power capacity of the gas turbine: 360.7 MW,
- net power capacity of the air turbine: 59.8 MW,
- net efficiency of the gas-air cycle: 0.45.

3 Savings in the fuel chemical energy

The savings in the fuel chemical energy after the application of dual-fuel gas and coal fired systems may be assessed assuming the same effects of the operation of the power systems. The indices that may be used for this purpose are the electricity generation efficiency, η_{el}, or the heat rate, defined as:

$$HR = \frac{m_f LHV}{N_{el}} , \tag{2}$$

where $m_f LHV$ is the fuel chemical energy flux and N_{el} is the net power capacity of the power plant.

A significant feature of multifuel power systems is the change in the electricity generation efficiency in the subsystems, compared to single fuel systems. In the case of the systems under analysis, where the gas cycle provides heat, a drop in efficiency related to the heat generation has to be taken into account. An example

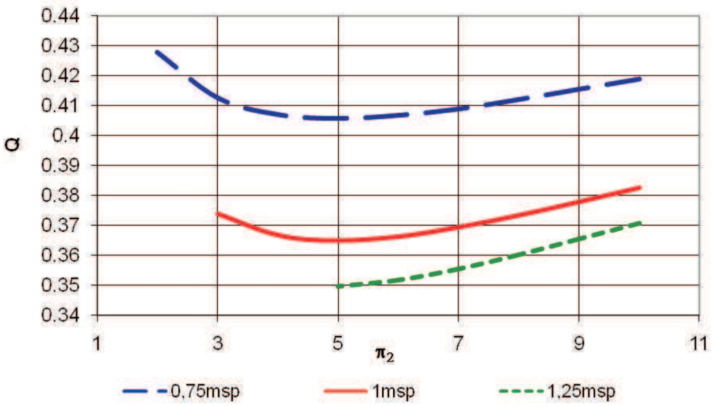


Figure 6. Heat absorbed by the agent in relation to the fuel chemical energy depending on the compression ratio (exchangers HE_1 and HE_2).

of a value which allows the determination of the savings in the chemical energy of fuels may be the index defined as follows:

$$HR_s = HR_{sep} - HR_{mf} \ . \tag{3}$$

The essence of this index is to determine the difference between the fuel chemical energy consumption in separate single fuel systems (HR_{sep}) and in a multifuel system (HR_{mf}).

While considering hybrid gas and coal fired plants, two methodologies may be distinguished. In one, it is assumed that the system of the coal-fired plant is replaced with a gas and coal fired system. The HRs index determined in this case conforms to the effect of the application of this technology if there are no gas cycles in the plant under consideration. In this case, each new system that features a positive HRs index is also characterised by savings in the fuel chemical energy. In the other method, it is assumed that the effects of a coal-fired system operation in a hybrid plant replace the reference coal-fired system, and the effects of a gas-fired system replace the gas technology. The positive value of the HRs index in this case reduces the consumption of energy of primary fuels in a system composed of both coal-fired and gas-fired power units.

The values of the HR index for the systems under analysis are shown in Fig. 7. The presented values ignore the consumption of the energy of fuels related to their production and transport. The savings in the chemical energy of fuels may be determined by deducting the consumption of this energy in the assessed power plant from the consumption in the reference plant. The first bar in the chart illustrates the fuel chemical energy consumption in a power plant without a CO_2 capture installation. Due to a higher efficiency of this plant compared to the efficiency presented in Section 2 (resulting from lower own needs), the system features a lower consumption of the fuel energy. The next analysed system is a power plant with a CO_2 capture installation where bleed steam from the steam turbine is used for the desorption process. Because of a substantial drop in efficiency, the system features the highest chemical energy consumption. In the case of the considered gas and coal fired systems, the system with a gas turbine and a steam cycle with a backpressure turbine features the lowest, and the system with a gas turbine and a water boiler – the highest chemical energy consumption. It should be noted that all systems under analysis feature a lower consumption of chemical energy compared to a coal-fired system with CO_2 capture. In order to compare the chemical energy consumption when gas and coal fired systems are used, the appropriate values of the three systems under consideration are presented in the chart. It is assumed in the calculations that the coal-fired system replaces the reference coal-fired power plant with CO_2 capture and with an efficiency of 40.7%, and the gas-fired system – a gas-fired plant with no CO_2 capture installation and with an efficiency of 52.5%. The presented results indicate that in the case of a system with a gas turbine and a water boiler the energy consumption is the same as in the reference systems, whereas for the remaining gas and coal fired systems the chemical energy consumption is lower than for the reference ones.

4 Avoided emissions

The impact of a given power technology on the environment in the form of CO_2 emissions may be compared after assuming identical effects of the operation of power plants. As the main effect of a power plant operation is electricity, it is convenient to relate the amount of emitted CO_2 to the amount of electric power. The power plant CO_2 emissions factor may therefore be defined as follows:

$$e = \frac{E}{N_{el}} \,, \tag{4}$$

where E is the mass flow of emitted carbon dioxide, N_{el} is the net power capacity of the power plant.

A significant feature of power plants with CO_2 capture is the lower value of the electricity generation efficiency compared to those without a CO_2 capture installation. In the case of methods based on chemical absorption of CO_2, the

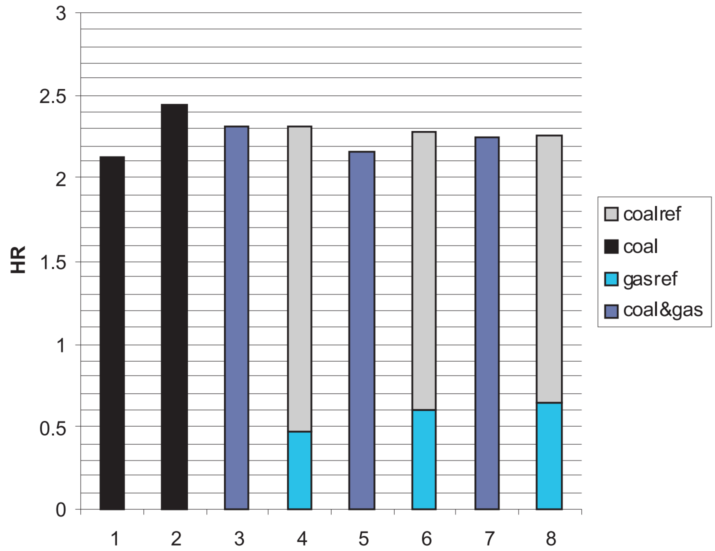


Figure 7. Comparison of the heat rate in coal fired and gas and coal fired systems: 1 – coal fired without CCS, 2 – coal fiered with CCS, 3 – coal and gas system (variant A), 4 – coal and gas (reference power plants for variant A), 5 – coal and gas system (variant B), 6 – coal and gas (reference power plants for variant B), 7 – coal and gas system (variant C), 8 – coal and gas (reference power plants for variant C).

reduction in efficiency is related to the need to provide great amounts of heat for the absorption process. Consequently, a comparison of different power plants in terms of CO_2 emissions requires a determination of a value that accounts for the effects related to the reduction in the efficiency of plants with CO_2 capture. An example of such a value may be the avoided emissions factor (e_{av}). The essence of the factor is to define the difference between the direct effects of the impact of the reference and the assessed technologies:

$$e_{av} = e_{ref} - e_a \ , \tag{5}$$

where e_{ref} and e_a are the factors of reference system and assessed system respectively. A beneficial effect on the environment may be obtained if emissions determined for the technology with CO_2 capture are lower than those for a technology without it ($e_{av} > 0$).

While considering hybrid gas and coal fired plants, two methodologies may be distinguished. In one, it is assumed that the system of the coal-fired plant is replaced with a gas and coal fired system. The avoided emissions determined in this case conform to the effect of the application of this technology if there are no gas cycles in the plant under consideration. Therefore, each new plant with positive avoided emissions has an advantageous impact on the environment by reducing the amounts of CO_2 released into the atmosphere. In the other method, it is assumed that the effects of the coal-fired system operation in a hybrid plant replace the reference coal-fired system, and the effects of the gas-fired system replace the gas technology. A positive value of avoided emissions in this case results in a beneficial effect on the environment in a power generation system composed of both coal-fired and gas-fired power plants.

The described methodology to determine the avoided emissions factor is presented in Figs. 8 and 9, using the emissions factors for the replaced reference system (e_{c,g_ref}), the assessed system (e_{c,g_a}), and the power capacity ratio (β):

$$e_{c,g\_ref} = \frac{E_{c,g\_ref}}{N_{el\_c,g}} , \qquad (6)$$

$$e_{c,g\_a} = \frac{E_{c,g\_a}}{N_{el\_c,g}} , \qquad (7)$$

$$\beta = \frac{N_{el\_c}}{N_{el\_c} + N_{el\_g}} . \qquad (8)$$

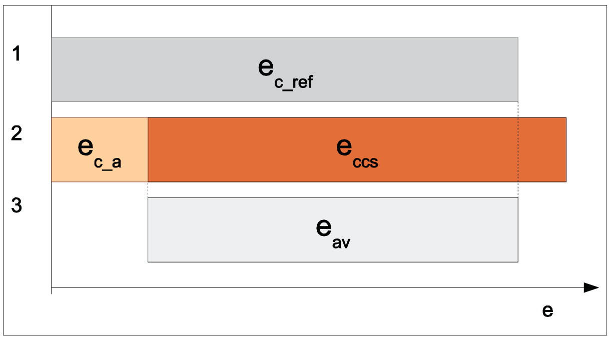
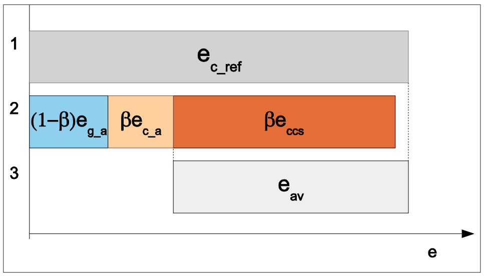
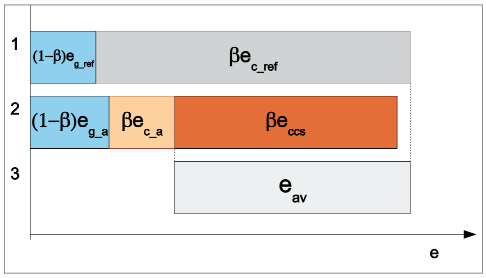


Figure 8. The diagram of the determination of avoided emissions for a coal-fired power plant with a CO_2 capture installation: 1 – emission of reference coal fired power plant, 2 – emission of coal fired power plant with carbon capture system (e_{ccs} – captured emission), 3 – avoided emission.

For a gas and coal-fired plant, it is possible to define the dependences between their power capacities, that guarantee that a positive value of avoided emissions



(a)



(b)

Figure 9. The diagram of the determination of avoided emissions for a hybrid coal and gas fired power plant for different replaced systems: methodology 1 (a), and methodology 2 with a CO_2 capture installation (b) (1 – emissions of reference power plants, 2 – emission of coal fired power plant with carbon capture system (e_{ccs} – captured emission), 3 – avoided emission).

is obtained: for first methodology

$$\frac{N_{el\_g}}{N_{el\_g}+N_{el\_c}} > \frac{e_{c\_ref}-e_{g\_a}}{e_{c\_a}-e_{g\_a}} \tag{9}$$

and for second methodology

$$\frac{N_{el\_c}}{N_{el\_g}} > \frac{e_{g\_ref}-e_{g\_a}}{e_{c\_ref}-e_{g\_a}} . \tag{10}$$

Figure 8 presents the methodology to determine avoided emissions for a plant with CO_2 capture, in which the heat source is steam from the steam turbine bleeds of a coal-fired plant. The plant with the capture installation has a higher emissions factor due to lower efficiency. This causes that the avoided emissions are smaller than the captured emissions. Figure 9a shows the emissions factor values for the hybrid coal and gas fired plant and the coal-fired plant (the replaced one). Because the emissions factor for a gas-fired plant is low, a situation may arise in which captured emissions are smaller than avoided emissions. The chart 9b presents emissions factors for hybrid plants and for the coal-fired and gas-fired systems as the ones to be replaced.

In order to determine the effect of the proportion of the gas to steam cycles on the emissions and energy efficiency of the whole system, three variants of the system are considered:

- system with a gas turbine with a water boiler (GT+WB);

- system with a gas-steam cycle characterised by the net electricity generation efficiency equal to 47% and overall efficiency equal to 74% (CC);

- system with a gas-steam cycle characterised by the net electricity generation efficiency equal to 53% and overall efficiency equal to 62% (HECC).

The dependence of the emissions factor calculated using formula (1) and of the net electricity generation efficiency on the β parameter is illustrated in Fig. 10. In addition, the figure presents the real achievable values of β for the respective systems in the form of arrows. Analysing the dependence of emissions on β, it can be concluded that the high-efficiency clean combustion (HECC) system features lower emissions than the other variants. However, the β values which may be achieved in a real system are low, which can in consequence lead to higher CO_2 emissions. As for the dependence of the electricity generation efficiency on β, it can be seen that an increase in the share of electricity produced from coal raises the efficiency of the system for the low efficiency gas cycle, and lowers it for the high efficiency gas-steam cycle.

The value of avoided emissions for each system using the first methodology can be read from the chart as the difference of ordinates of the system without a CO_2 capture installation, and analysed. In order to determine avoided emissions, and taking account of both methodologies, CO_2 emissions for the same systems as those analysed in Section 3 are presented in Fig. 11. The coal-fired system with no CO_2 capture features the highest CO_2 emissions, which is related to the high content of carbon in the fuel. The system with CO_2 capture features the lowest emissions which result from the fact that CO_2 is not separated entirely and from the system reduced efficiency. All the gas and coal fired systems feature much lower emissions than the coal-fired system without the CO_2 capture installation, and by 83–102% higher compared to the coal-fired system with CO_2 capture.

In order to find the CO_2 emissions in the replaced coal-fired systems, it is assumed that the gas-fired power plant with an efficiency of 52.5% is characterised by emissions at the level of 377 kg/MW and that this is a system without CO_2 separation. Two systems are analysed in the case of the reference coal-fired power plant:

- coal-fired system with CO_2 capture, with an efficiency of 40.7% and CO_2 emissions of 105 kg/MWh;

- coal-fired system without CO_2 capture, with an efficiency of 47.2% and CO_2 emissions of 726 kg/MWh.

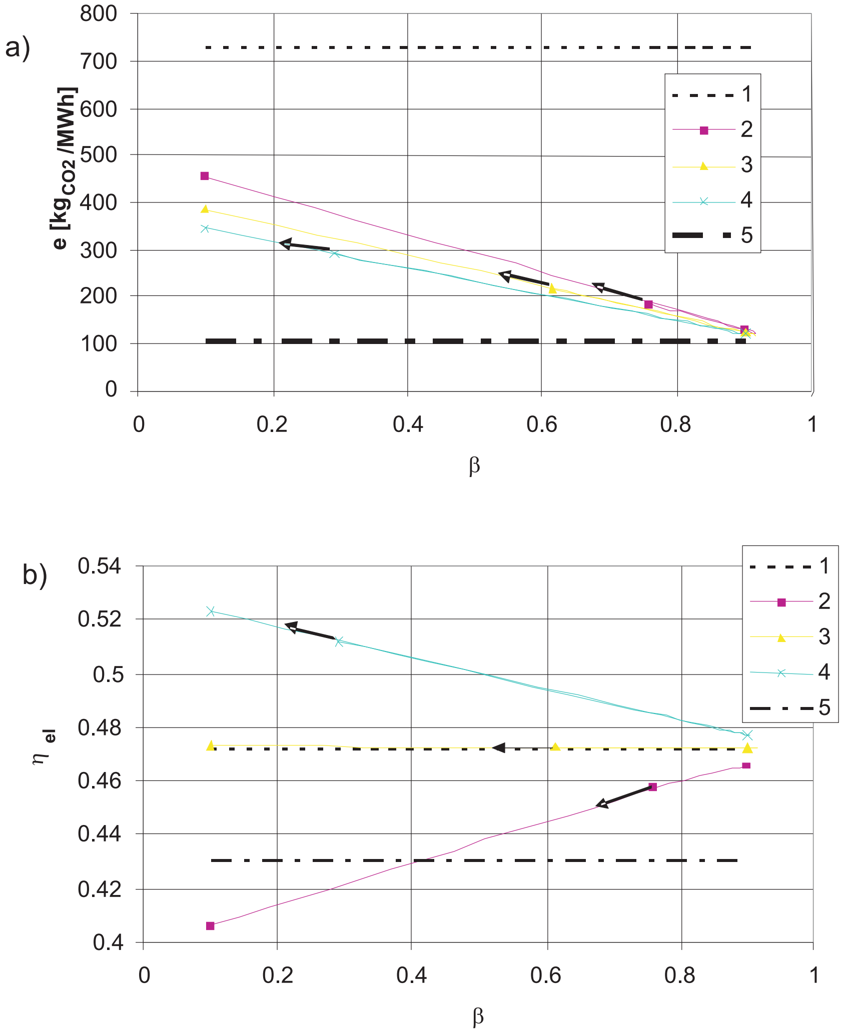


Figure 10. Emissions of the analysed systems a) and electric efficiency b) as a function of the β parameter (1 – coal-fired power plant without carbon capture and storage (CSS), 2 – GT+WB, 3 – CC, 4 – HECC 5 – coal-fired power plant with CCS).

All the analysed coal and gas fired systems feature a much lower emissivity compared to the replaced power plants without CO_2 capture. The system with a gas turbine and a water boiler features the highest avoided emissions.

When gas and coal fired systems are compared to the reference power plants where the coal-fired power unit is equipped with the capture installation, the gas

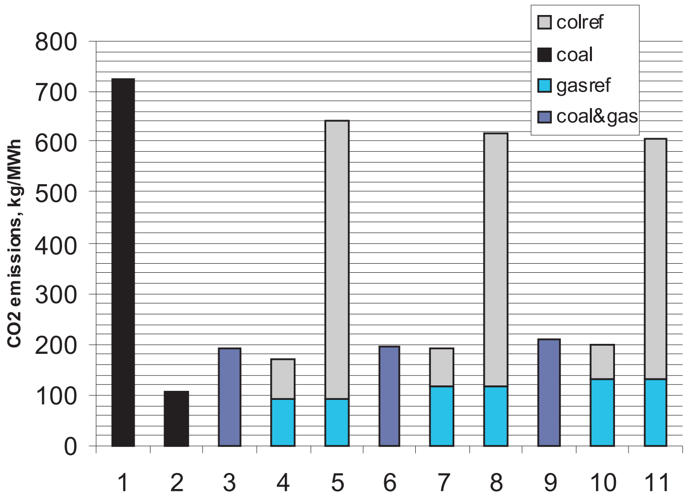


Figure 11. Comparison of CO_2 emissions in coal fired and gas and coal fired systems: 1 – coal fired without CCS; 2 – coal fiered with CCS; 3 – coal and gas system (variant A); 4 – coal and gas (reference power plants for variant A), coal power plant with CCS; 5 – coal and gas (reference power plants for variant A), coal power plant without CCS; 6 – coal and gas system (variant B); 7 – coal and gas (reference power plants for variant B), coal power plant with CCS; 8 – coal and gas (reference power plants for variant B), coal power plant without CCS; 9 – coal and gas system variant C; 10 – coal and gas (reference power plants for variant C), coal power plant with CCS; 11 – coal and gas (reference power plants for variant C), coal power plant without CCS).

and coal fired systems are characterised by higher emissions, and the smallest difference is for the system with a gas turbine and a steam cycle ($e_{av} = -5$ kg/MW).

5 Conclusions

Efforts to reduce CO_2 emissions in power engineering have made it possible to use new concepts of gas and coal fired systems. The performed analyses of the examples of gas and coal fired systems are characterised by the fact that the heat obtained from gas-fired systems is used for the desorption process of CO_2 produced in the coal-fired systems. The essential features of these systems, which were identified at the beginning and which became the stimulus for deeper studies, are: a possibility of fuel source diversification in the process of electricity generation and a construction of a system featuring a high electricity generation efficiency – even if there is no need for CO_2 capture, which involves a lower investment risk.

The analyses of the three gas and coal fired systems make it possible to draw the following conclusions:

- Combined gas and coal fired systems allow the achievement of savings in the chemical energy of fuels compared to separate systems where the coal-fired plant is equipped with the CO_2 capture installation.
- The system with a gas turbine and a steam cycle with a backpressure turbine features the lowest energy consumption.
- The analysed systems are characterised by much lower CO_2 emissions than those in separate systems with no CO_2 capture.
- The analysed systems are characterised by similar CO_2 emissions compared to those in separate systems with a CO_2 capture installation in the coal-fired plant.

The presented results together with the results of economic analyses [18] suggest that these systems are interesting from the point of view of energy generation, ecology and economy. However, due to the fact that the results often differ only slightly, the decision concerning the commercial application of any of the systems has to be preceded by more detailed studies.

Acknowledgments The results presented in this paper were obtained from research work co-financed by the National Centre of Research and Development in the framework of Contract SP/E/1/67484/10 – Strategic Research Programme – Advanced technologies for obtaining energy: Development of a technology for highly efficient zero-emission coal-fired power units integrated with CO_2 capture.

Received in June 2012

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Układy dwupaliwowe gazowo-węglowe — koncepcje nowych zastosowań

S t r e s z c z e n i e

Polityka energetyczna związana z ograniczeniem emisji CO_2 powoduje, że interesujące jest rozważanie nowych koncepcji układów wielopaliwowych. W pracy poddano analizie układy węglowo-gazowe, w których ciepło spalin z układu gazowego wykorzystywane jest do zasilania układu separacji CO_2 z siłowni opalanych węglem. Analizowane struktury oceniono pod względem oszczędności energii chemicznej paliwa oraz emisji unikniętej CO_2.