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CCS TECHNOLOGY ISSUES IN CONDITIONS IN THE CZECH REPUBLIC

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In recent time, carbon dioxide capture from fossil fuel fired power plants is a highly actual topic for research and development. The paper is focused on issue of CCS technology implementation into a production unit of a lignite coal fire power plant as well as into a combined cycle gas fired plant in the Czech Republic. There are various methods of CO_2 capture. In this paper post-combustion scrubbing as the reference technology is used. In the paper several interactions and the most important impacts on the studied power plants are shown. The most discussed impact is overall decrease of net efficiency of the production unit. For the case of coal combustion, the efficiency is decreases by 10.7 % points by application of the post-combustion capture technology. In the case of combined gas cycle, the decrease is by 8.5 % points. The main reason of this decrease is high electricity consumption for compression and pumping work in the scrubbing system. In addition, increased consumption of water is not negligible.
Key words: CCS–carbon, capture and storage, lignite coal, fossil fuel, carbon dioxide, combustion.

Problematika CCS tehnologije u uvjetima Češke Republike. U novije vrijeme, praćenje ugljičnog dioksida u elektranama na fosilna goriva aktualna je tema za istraživanje i razvoj. Rad je usredotočen na problematiku provedbe CCS tehnologije u elektrani na lignit kao i u kombiniranoj plinsko-parnoj elektrani u Republici Češkoj. Postoje različite metode praćenja CO_2. U ovom radu je korišteno pročišćavanje ispiranjem nakon izgaranja kao referentna tehnologija. U radu je prikazano nekoliko interakcija i najvažnijih utjecaja na istraživanim elektranama. Utjecaj o kojem se najviše raspravljalo je ukupni pad neto učinkovitosti proizvodne jedinice. U slučaju izgaranja ugljena, učinkovitost se smanjuje za 10,7 % bodova pri primjeni tehnologije praćenja nakon izgaranja. U slučaju kombiniranog plinsko-parnog ciklusa, pad je za 8,5 % bodova. Glavni razlog ovog smanjenja je visoka potrošnja električne energije za rad kompresora i pumpe sustava pročišćavanja ispiranjem. Pored toga, povećani utrošak vode nije zanemariv.
Ključne riječi: CCS–ugljik, skupljanje i skladištenje, lignit, fosilna goriva, ugljični dioksid, izgaranje.

INTRODUCTION

The topic of CO_2 emission reduction from fossil fuel combustion is currently a highly discussed topic. It is also an important topic for research in almost all developed countries. Within the Czech Republic, the CO_2 emission lowering is also included in the Air protection law 201/2012 Sb. There are many ways how to reduce CO emission. This paper presents main connections and impacts of CCS technology application to a model case of a 250 MWe power plant running on lignite coal and a model 880 MWe combined cycle gas fired power plant.

In this presented study was used an absorption post-combustion method in order to minimize impact into the studied power plant.

METHODS OF CO_2 CAPTURE FROM FLUE GAS

The methods of CO_2 removal from flue gas can be classified according to their chemical and physical principles as follows

- Absorption – scrubbing by an absorbing liquid
- Adsorption – absorption at the surface of a solid matter or extraction by ion liquids
- Physical separation – membrane process, cryogenic separation
- Hybrid approach
- Biologic capture

The methods are currently at different level of their development, from laboratory scale to pilot units. For the case of the power plants in the Czech Republic are considered only the absorption techniques, because these are currently the most technically developed. In this case the CO_2 is captured either by physical dissolving in a solvent or by absorption by a chemical reaction. The operation principle of these technologies is similar, however. The flue gas enters an absorption tower where it is counter-current scrubbed by an absorption liquid (solvent).

The saturated solvent is transferred to another tower where the solvent is regenerated and the dissolved CO_2 is removed at high concentration. During the operation, there are however certain losses of the solvent, e.g. by unwanted reactions and products or escape along with the flue gas. Therefore, the solvent is a consumable. At present, the mostly applied solvents are water solutions of:

- amines – various kinds (primary, secondary, tertiary, heterocyclic)
- ammonia
- carbonates of alkali metals (sodium or potassium carbonate)
- blended solution

LIGNITE COAL FIRED POWER PLANT

The model case for CCS for a coal fired power plant was considered at 250 MWe gross electric power output. Detailed parameters of the model plant are summarized in table 1.

The model power plant consists of a pulverized lignite coal fired boiler equipped with primary NOx removal measures, steam turbine and electrostatic precipitators. Wet limestone scrubbing method is used for desulphurization of flue gas below 150 mg/Nm^3 SO_2 (dry gas, 6 % reference O_2). The emission limit for NOx is 200 mg/Nm^3.

Table 1. Key parameters of the studied model plant
Tablica 1. Ključni parametri proučavanog modela postrojenja

Parameter	Unit	Value
Gross electric output	MWe	250
Coal consumption	t/h	214
Energy in fuel input	MWt	588
Internal consumption	MWe	24
Production of CO_2	t/h	211
Emission of CO_2 into atmosphere	t/h	211
Net electric output	MWe	226
Overall efficiency	%	38,4

Based on available literature, it was decided to consider the ammonia scrubbing CO_2 removal method for this model case. The ammonia scrubbing technology consists of following key components:

- heat exchanger between raw and decarbonized flue gas
- flue gas cooler
- flue gas fan
- CO_2 absorber
- final cleaning of scrubbed flue gas
- CO_2 desorber
- final cleaning and cooling of desorbed CO_2
- CO_2 compressor
- cooling water circuit
- auxiliary cooling source
- ammonia management

Impact on the model technology

The proposed CCS technology will significantly influence whole model power plant system, mostly in a negative way. The main impacts are defined as follows:

- increase of water consumption – the ammonia scrubbing requires cooling down of the flue gas to approx. 0°C which is provided by a cooling water
- increase of electricity consumption – additional devices are relatively high energy demanding. The highest consumption has compressor cooling and then CO_2 compressor, flue gas fan, feeding pumps for absorber, fans of cooling towers and cooling water pumps. For the model case, overall additional electricity consumption is 51 MWe.
- steam consumption – a heat is required for the regeneration process, which consists of decomposition of ammonia carbonate and further heating up to approx. 120°C. For the model case the steam consumption for the heating is approx. 20,73 kg/s, which is equivalent to decrease of electric power output by 12 MWe.
- waste water – the waste water from ammonia scrubbing contains ammonia salts produced by reactions of ammonia with acidic compounds in the flue gas (mostly SO_2, SO_3, NO, NO_2, HCl and HF). Total amount of

waste water therefore increases and puts higher demand on waste water treatment system. It is also necessary to solve ammonia removal.

- area demands – based on further calculations and references to similar systems were estimated dimensions of the ammonia scrubbing technology. The required area is approx. 140 x 200 m, i.e. 28 000 m^2.

In table 2 are summarized operation parameters of the model case with and without post-combustion ammonia CCS technology.

Table 2. Lignite coal fired model plant parameters with and without ammonia CCS technology
Tablica 2. Parametri elektrana na lignit s ili bez amonijaka CCS tehnologije

Parameter	Unit	Current state	With CCS
Gross electric power output	MWe	250	238
Coal consumption	t/h	214	214
Energy in fuel input	MWt	588	588
Internal consumption	MWe	24	24
Production of CO_2	t/h	211	211
Captured CO_2	t/h	0	190
Emission of CO_2 into atmosphere	t/h	211	21
Internal consumption of CCS	MWe	0	51
Net electric power output	MWe	226	163
Overall efficiency	**%**	**38,4**	**27,7**
Efficiency decrease	**%**	**0**	**10,7**

COMBINED CYCLE GAS FIRED PLANT

As a model case for ammonia CCS implementation was taken a combined cycle of 880 MW$_e$. The system consists of two gas fired turbines, two heat recovery steam generators and one steam turbine. Based on literature research, for the combined cycles is mostly considered and tested an amine scrubbing technology. However, the amine scrubbing technology is mostly similar to the ammonia methods regarding the main technological components.

Impact on the model technology

Similarly to the previous situation, also here the post-combustion CO_2 scrubbing negatively influenced the model case, mostly in terms of increased energy consumption a feedstock. The most important impacts are following:

- amount of NO_x in the flue gas – all available studies suppose that demands for the CCS technology are directly integrated into the gas combined cycle. This is mostly about NO_x concentration in the flue gas. In the model case is considered a SCR $DeNO_x$ technology that will decrease NO_x concentration below 2 ppm.
- water consumption – similarly to the previous case, water is needed for cooling. Even if the water consumption is decreased on the side of the steam turbine (a part of steam is extracted for CCS), the water consumption is still higher with the CCS. For caption of approx. 258 t/h CO_2 is estimated water consumption at 528 m^3/h (assuming temperature difference 10°C). It represents water evaporation approx. 375 m^3/h and production 153 m^3/h.
- increase of electricity consumption – in the combined cycle is the electricity consumption slightly decreased due to lower pumping work of cooling water. However, large increase is represented by the scrubbing technology that is energy demanding in multiples compared to the combined cycle itself. Similarly to the previous case, the highest consumption is for cooling and compression. Total increase of electricity consumption for this model case is 49,2 MWe.
- steam extraction – steam is required for desorption of CO_2 from its saturated absorption solution. Required temperature is approx. 130 -140°C. At nominal capacity load is expected the steam consumption 122 kg/s. Due to this high consumption is decreased the gross electric power output of the steam turbine by 73 MWe (at 100 % load of both gas turbines and ambient temperature 10°C).
- waste water – the situation is similar to the previous model case. The waste water contains additional ammonia salts (or sodium salts when using NaOH) that must be treated.
- area demands – preliminarily the area demand is around 20 000 m^2 for all required parts of the CCS technology. This is estimation since a real technology has not been taken into operation yet.

Table 3 summarizes key parameters for the model 880 MWe gas combined cycle with and without amine CO_2 scrubbing technology.

Table 3. Combined cycle model plant parameters with and without amine CCS technology
Tablica 3. Parametri elektrana s kombiniranim plinsko-parnim ciklusom s ili bez amina CCS tehnologije

Parameter	Unit	Current state	with amine CCS
Gross electric power output-gas turbines	MWe	567,9	567,9
Gross electric power output-steam turbine	MWe	276,4	203,5
Gross electric power output-total	MWe	844,3	771,4
Natural gas consumption	t/h	104,9	104,9
Energy in fuel	MWt	1434,4	1434,4
Internal consumption	MWe	14,1	63,3
Production of CO_2	t/h	287,5	287,5
Captured CO_2	t/h	0	258,7
Emission of CO_2 into atmosphere	t/h	287,5	28,8
Net electricity production	MWe	830,2	708,1
Overall efficiency	**%**	**57,9**	**49,4**
Efficiency difference	**% points**	**-**	**8,5**

CONCLUSION

Results of the calculations and proposed assumptions concerning implementation of ammonia (or amine) CCS technology into two model cases show that it is possible to add the CCS technology to the studied plants, however with significant negative impacts. The first problem is already the fact that the CCS should be added to and existing plant. In such a case are always very limited possibilities of any modification of the plant. Therefore it is not possible to satisfy needs of the CCS technology with the current plant. This includes mainly possibilities of changes in flue gas compositions, i. e. decrease of concentrations of unwanted components (NO_x , SO_2) and also possibilities of steam extraction and condensate return into current steam cycle. These reasons make impacts of the CCS addition more serious compared to a full integration into a newly designed plant with CCS.

However, even the ideal situation cannot the impact on net electric production (and efficiency) is still significant. The most important issues are heat extraction that decreases gross electricity production and internal electricity consumption of the CCS technology. For the lignite coal fired power plant is the electricity production decrease by 63 MWe and efficiency decrease by 10,7 % points and for the gas combined cycle 122 MWe decrease which means 8,5 % points efficiency decrease.

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