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Analysis of energy indices of a power plant adapted for the production of heat integrated with the amine Carbon dioxide processing unit

A. Ziębik*, M. Budnik, M. Liszka

Silesian University of Technology, Institute of Thermal Technology, Konarskiego 22, 44-100 Gliwice, Poland

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ABSTRACT

The adaptation of a power plant for heat production is an effective way of realizing high-efficiency cogeneration, and although the consumption of chemical energy of fuel decreases in comparison with the separate production of electricity and heat leading to a certain reduction of CO_2 emission, the installation of CO_2 capture ought to be applied. The paper concerns an amine installation of CO_2 processing unit. The application such an installation (capture and compression of CO_2) requires the supplementing of the calculation algorithms of energy indices of an integrated power plant adapted for the production of heat. The paper presents characteristic indices of a power plant adapted for heat production, viz. power loss coefficient (PLC) and overall energy efficiency as well as coefficient of heat cogeneration (COHC). The internal electro-mechanical power and heat consumption have been analyzed concerning various values of the unit consumption of heat for the purpose of regenerating the sorbent. Formulae expressing the overall net energy efficiency of an adapted power plant concerning the analyzed variants of integrated power plants have been derived. The influence of the unit consumption of heat for the regeneration of the sorbent on overall net energy efficiency of the adapted power plant and the coefficient of heat cogeneration have been analyzed.

1. Introduction and state of the art

One of the ways of high-efficiency cogeneration (Directive, 2004/08/of t, February 2004) is the adaptation of an already existing condensing power plant for the production of heat in order to feed a district or industrial heating systems situated within an economical distance of heat supply. Besides primary energy savings, cogeneration leads to a reduction of emissions, particularly of CO_2, if compared with the separate production of heat and electricity. After the adaptation of a power plant for heat production, cogeneration leads to losses in the production of electricity due to the lack of reserves in the capacity of the boilers. They are the lower, the lower is the pressure level at which steam is supplied to the heat exchangers of the district heating systems (Ziębik, November 2010). These losses can be compensated by the production in other power plants within the domestic electro-energy system.

In spite of decreased CO_2 emissions due to the cogeneration, a power plant is after its adaptation for heat production still a source of considerable CO_2 emissions, particularly in the case of a coal-fired power plant. A post-combustion CO_2 processing unit (CPU), absorbing CO_2 chemically in an ethanolamine solution, is actually the most realizable way of CO_2 capture as confirmed in several publications, but investigations concerning other solvents are still underway. For instance in (Bryngelsson and Westermark, 2009) a pilot test of CO_2 capture at a pressurized coal fired CHP plant using potassium carbonate absorption has been described in which 98% CO_2 capture efficiency was achieved. In (Harkin et al., 2010a) where optimizing investigations concerning power stations integrated with carbon capture plants based on monoethanoloamine with a mass fraction of 30% it was stressed that this is a chemical agent which is widely considered as a benchmark solvent for post-combustion capture. The same authors have proposed a combined the pinch point method and linear programming optimization in order to reduce the cost of implementing commercial available amine-based post-combustion CO_2 capture unit from which waste heat is utilized (Harkin et al., 2010b). The authors of (Mangalapally and Hasse, 2011) have been stressed that post-combustion CO_2 capture is a more mature process than pre-combustion capture and oxy-fuel combustion technology, but the reducing of heat demand for regenerating the solvent is all the time a challenge for this CO_2 capture technology. Also the authors of

* Corresponding author. Tel.: +48 32 237 10 49; fax: +48 32 237 28 72.
E-mail addresses: andrzej.ziebik@polsl.pl (A. Ziębik), michal.budnik@polsl.pl (M. Budnik), marcin.liszka@polsl.pl (M. Liszka).
URL: http://www.itc.polsl.pl/aziebik

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Nomenclature

$\dot{B}$	exergy flux
b	unit consumption of fuel
E	energy
e	unit consumption of driving energy
h	specific enthalpy
N	power
$\|\Delta Nel\|$	absolute value of power loss
n	amount of gas in mol
P	fuel flux
p	pressure
T	temperature (Kelvin scale)
t	temperature (Celsius scale)
$\dot{Q}$	heat flux
q	specific heat

Greek symbols

η	efficiency
ε	relative internal consumption

Subscripts

a	ambient
ad	adapted
b	bleed
c	compressors
ch	chemical
E	energy
el	electric
em	electro-mechanical
fg	flue gas
FP	fans and pumps
G	gross
h	hot, heat
hr	heat recovery
int	integrated
N	net
PE	peak exchanger
ph	peak heat
q	heat
r	replaced, removal, returned
rec	recovery
ref	reference
reg	regeneration
s	supplementing
th	thermal
w	feeding water
wr	without recovery of waste heat

Abbreviations

CHP	combined heat and power
COHC	coefficient of heat cogeneration
CPU	CO_2 processing unit
DHS	district heating system
LHV	lower heating value
PLC	power loss coefficient
SCR	selective catalytic reduction

(Ogawa et al., 2009) confirmed that the amine-based post-combustion CO_2 capture technique can be applied for an effective reduction of CO_2 emissions from power plants. In (Shaw, 2009) the integrated amine based regenerable post-combustion CO_2 and SO_2 capture technology has been proposed in which SO_2 as sulphuric acid and CO_2 as dried agent can be removed. The authors of (Kuramochi et al., February 2009) also stressed that the post-combustion CO_2 capture technology is most mature among other CO_2 capture technologies. After experiments with aqueous ammonia solution the authors of (Rivera-Tinoco and Bouallou, 2010) compared the results of absorption kinetic rates and its capacity with data concerning alkanoloamine solvents commonly used to absorb CO_2 qualifying NH_3 aqueous solution as a suitable solvent of CO_2 capture. It has also been stressed in this paper that ammonia has a negative environmental impact. In studies concerning (Kuramochi et al., 2010) the application of post-combustion CO_2 capture based on chemical absorption technology applying aqueous alkaline solvent has been considered because at a low concentration of CO_2 the chemical absorption is the preferred method of CO_2 removal.

A CPU unit comprises also CO_2 compressors. The integration of a power plant adapted for heat production with the amine CO_2 processing unit is connected with an increased consumption of heat and electricity for internal consumption, but on the other hand the CPU installation is a source of waste heat which can be recovered. In the CPU unit the sources of waste heat are the condensation of H_2O in the mixture of CO_2 and H_2O resulting from the desorption of CO_2 as well as the interstage cooling of the CO_2 compressors. Process integration consists, therefore, in the utilization of waste heat for the purpose of preheating the network water in the district heating systems. Both the additional demand for heat in the integrated cogeneration unit and the generation of waste heat depend on the unit consumption of heat for the regeneration of the sorbent. All over the world investigations concerning its decrease are being intensively under way. Commercial producers are researching on a pilot scale new solvents which use either aqueous pure amines or blends of amines or aqueous ammonium carbonate for bicarbonate reaction. The aim of these investigations is to reduce required energy for regeneration, to reduce absorption solvent loss and to minimize the amount of the degraded products (Global CCS Institute, January 2012). Mitsubishi Heavy Industries announced that energy consumption of a developed solvent, which they used in commercial plants in Abu Dhabi, was run at a guarantee test 2.89 MJ/kg CO_2. Test results from the pilot plant at the Nanko Power Plant indicated that energy consumption for CO_2 recovery per unit was 2.53 MJ/kg CO_2 and 2.44 MJ/kg CO_2 for newly developed absorption solvents (MHI's energy efficiency, March 2011). Hitachi are developing three proprietary solvents the best of which is characterized by specific regeneration heat of 2.8 MJ/kg CO_2. Testing shows that under various loads and inlet CO_2 concentrations, the average CO_2 removal amounts to above 90%. The Hitachi's next generation solvent under development has regeneration energy of 2.5 MJ/kg CO_2 (Eswaran et al., 2010). The results of an European CASTOR project indicate that with new solvents it is possible to reduce energy consumption from 4 MJ/kg CO_2 down to 3.5 MJ/kg CO_2, and with process integration down to 3.2 MJ/kg CO_2 maintaining 90% recovery rate (Final Report -(, April 2011). The updated Econamine FG Plus solvent and process developed by Fluor is characterized by a reduction of the energy consumption from 4.07 MJ/kg CO_2 to 2.76 MJ/kg CO_2 (Advanced Coal Power Syste, 2011). Aker Clean Carbon reduced energy consumption by 30% while testing a variety of amine solvents in its test unit at Scottish