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Energetic Evaluation of Different Flow Sheet Modifications of Post-Combustion CO_2 Capture Plant at Coal and Natural Gas Fired Power Plant for a Generic Improved Solvent

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Abstract

The post-combustion capture (PCC) technology is a promising possibility to reduce CO_2 emissions of fossil fuel fired power plants. One of the main concerns for the PCC is the loss in electric power output. A reduction in efficiency penalty for solvent based PCC can be achieved by improving the solvent properties as well as by improving the process design. There are many different process flow sheet modifications with an improvement in process design reported in literature. In this work two of these modifications for a capture plant are evaluated. To be able to compare these process modifications it is necessary to evaluate them on identical solvent and process conditions. The modified processes are compared to base cases processing the flue gas from a supercritical pulverised coal fired power plant as well as a natural gas combined cycle power plant. The solvent used in the capture plant is a generic improved solvent, representing possible future solvents. The main advantages of the flow sheet modifications are pointed out. Subsequent, the specific reboiler heat duty, the specific cooling duty and the specific auxiliary power for the capture plant are shown for the flow sheet modifications. The overall efficiency penalties for the flow sheet modifications are compared and differences are highlighted.

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Keywords: Post combustion capture; process modifications; carbon dioxide

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1. Introduction

As commonly agreed, climate change will be a serious economic and ecologic challenge in the next decades. To limit the global temperature rise to 2 °C, a reduction of greenhouse gas (GHG) emissions by 80%, compared to 1990, until 2050 is recommend by the IPCC (Intergovernmental Panel on Climate Change) [1]. The emissions from fossil-fuelled power plants can first be reduced by increasing the energy conversion efficiency. As this will not be sufficient to reach the mentioned target, it is necessary to separate and store carbon dioxide (CO_2) underground, commonly referred to as carbon capture and storage (CCS). The post-combustion capture (PCC) technology is a promising possibility to reduce CO_2 emissions from fossil fuel fired power plants. One of the main concerns for the PCC is the rather large efficiency penalty. A reduction in efficiency penalty for solvent based PCC can be achieved by improving the solvent properties as well as by improving the process design. There are different process flow sheet modifications reported in literature claiming to reduce the efficiency penalty. A detailed comparison of the overall efficiency for different process flow sheet modifications with an improved solvent is necessary because most evaluations of these processes in literature are based on different boundary conditions and different solvents. Therefore, there is a requirement to evaluate these process modifications on similar solvent and process conditions.

In this work two different CO_2 capture process modifications are evaluated for a supercritical pulverised coal fired power plant (SCPC) and a natural gas combined cycle power plant (NGCC). For both power plants a reference case without PCC was established representing a state-of-the-art new build power plant. Base cases with a standard configuration of the capture plant are used for both power plants to be able to compare the modified processes on a common basis. In a more extensive study prepared by the authors under financing of IEAGHG the process flow sheet modifications vapour recompression, multi-pressure stripper, heat-integrated stripping column, split flow, matrix stripping, overhead condenser heat integration and reboiler condensate heat integration were evaluated on the same basis [2]. Using the example of the process modifications split flow and vapour recompression the procedure of the evaluation is presented in this work in detail. The results for all modifications are shown in Table 7.

2. Process description

2.1. Capture plant

A schematic flow diagram of a typical plant for post-combustion CO_2 capture by chemical absorption is shown in Figure 1. To improve the CO_2 absorption process, the flue gas is first cooled before entering the absorber column at the bottom. As the flue gas rises in the column, the CO_2 is absorbed by a chemical solvent in aqueous solution in a counter-current flow. The column is filled with random or structured packing to increase the interfacial area between gas and liquid phase. A washing section at the top of the absorber reduces the slip of solvent to the environment by contacting the outgoing treated flue gas with cold water. An induced draft (ID) fan is required to overcome the additional pressure losses in the flue gas cooler and the absorber. The treated flue gas at the top of the absorber is released to the atmosphere. At the bottom of the absorber, the CO_2-rich solution is gathered and pumped to the desorber, passing a rich-lean heat exchanger (RLHX) where it is preheated to a temperature close to desorber temperature.

In the desorber, the absorbed CO_2 is stripped from the rich solution at high temperature and the solvent is regenerated. The rich solution flows downwards and releases the captured CO_2. The necessary driving force (partial pressure difference), the sensible heat and the heat for the separation of CO_2 from the solvent is delivered by a counter-current flow of vapour (stripping steam), consisting mainly of steam and CO_2. The required heat duty is provided by the reboiler, in which steam from the power plant is condensed and stripping steam is generated.

At the head of the desorber, the gas is led to the overhead condenser (OHC) where the CO_2-rich gas stream is cooled and part of the water vapour is condensed. The CO_2 stream is led to CO_2 compression. The CO_2-lean solution is gathered at the bottom of the reboiler and is returned to the absorber, passing the RLHX and another heat exchanger (solution cooler), in which the temperature is lowered to the desired absorber temperature. The lean solution is dispersed at the top of the absorber column, closing the process cycle.

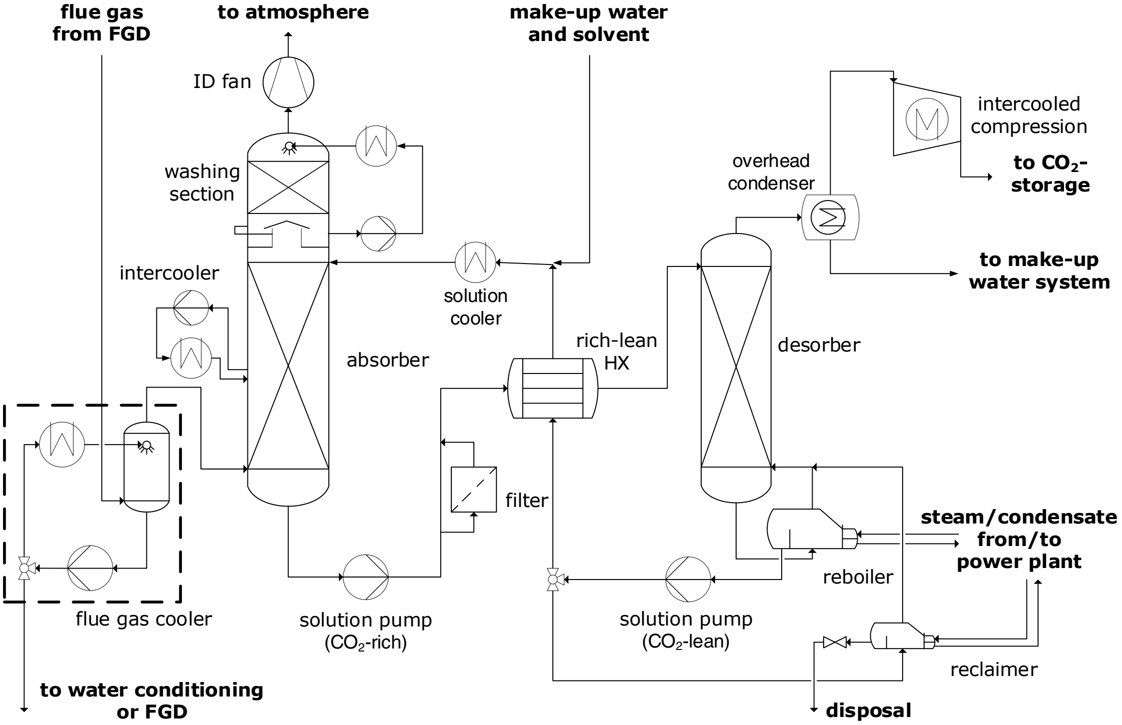

Figure 1: Process flow sketch [3].

The solvent used in the capture plant is a generically improved artificial solvent and is called Solvent2020. It was developed to be able to show how the process modifications could influence a possible future solvent. Solvent2020 has the same absorption mechanisms as amines (carbamate and bicarbonate formation) and is assumed to have similar thermodynamic properties as a solution with 7 mol MDEA and 2 mol PZ per kg H_2O. The reaction kinetics of Solvent2020 are enhanced compared to 7MDEA/2PZ, which results in chemical reactions that are not kinetically hindered. Due to the high temperatures, which catalyse the chemical reactions of CO_2 desorption, this is found to be a reasonable approach. The absorber is generally not assumed to be in chemical equilibrium, though. Despite the chemical equilibrium, the columns are not in total equilibrium, since mass and heat transfer are calculated by rate based modelling. This approach would overestimate the absorption rate of a slower solvent but is assumed to be reasonable for fast solvents. Solvent2020 is assumed to be thermally stable up to approximately 150 °C, which is the same temperature as for PZ. Thus, thermal degradation is not expected to occur when operated at temperatures below this limit. Oxidative degradation and corrosion are assumed to be negligible, as well.

2.2. Supercritical pulverised coal fired power plant

The model used in this work is based on a state-of-the-art supercritical pulverised coal (SCPC) power plant. The power plant is modelled with the commercial software tool EBSILON$^{®}$*Professional*. The coal-fired power plant with high-pressure and high-temperature steam (295 bar, 600 °C) has a gross electrical power output of 900 MW. At its design point (full load operation without CO_2 capture), the net efficiency is 45.2%, related to LHV. The preheating train consists of five LP-preheaters, the feed water tank and three HP-preheaters. Just before entering the boiler unit, the feed water is heated to 300 °C. The cooling system is based on a natural draught cooling tower which supplies cooling water at 16 °C. With a temperature increase in the condenser of 10 K and a temperature approach of 3 K the condenser pressure is determined to be 40 mbar.

For the integration of the capture plant into the power plant two different integration options are evaluated for the SCPC plant, a basic integration and an advanced waste heat integration. The steam needed for the heating of the reboiler is for both options extracted from the IP/LP crossover. The reboiler condensate is returned to the preheating route where the feed water shows the closest temperature. For the basic integration option this is the only integration of heat from the capture plant. For the advanced waste heat integration option additional heat from the capture plant as well as from the intercoolers of the compressor is transferred to the feed water preheating train. Part of the condensate from the condenser is used as cooling water in the overhead condenser and in the intercoolers of the compressor. Afterwards it is returned to the preheating train where the feed water shows the closest temperature. Both integration options are evaluated for all process modifications.

2.3. Natural gas combined cycle

The modelled natural gas combined cycle (NGCC) plant consists of two gas turbines, each of which is equipped with a heat recovery steam generator (HRSG) to use the heat of the flue gas downstream the gas turbine. The steam produced in the two HRSGs is led to a common steam turbine. The whole plant has a gross electrical output of 883 MW, consisting of 278 MW from each of the gas turbines and 327 MW from the steam turbine. The net efficiency of the power plant at full load operation without CO_2 capture is 58.2%, related to LHV. The gas turbine is a sequential combustion gas turbine delivering high flue gas temperature for the subsequent HRSG. The water-steam cycle is a three pressure level process (live steam 585 °C, 159 bar) with a reheat (585 °C, 40 bar). The cooling system is based on a mechanical draught cooling tower which supplies cooling water at 19 °C. With a temperature increase in the condenser of 11 K and a temperature approach of 3 K the condenser pressure is determined to be 45 mbar. Part of the flue gas downstream the HRSG is recirculated back to the compressor, cooled down in a direct contact cooler and mixed with fresh air in order to increase the CO_2 concentration in the flue gas from 4.2 Vol.% to 9.1 Vol.% and reduce the O_2 concentration from 11.9 Vol.% to 3.2 Vol.%.

For the NGCC case only one integration option is evaluated. The steam needed for the heating of the reboiler is extracted from the IP/LP crossover. The reboiler condensate is partially returned to the water steam cycle upstream the economiser of the heat recovery steam generator to increase the temperature to 60°C and thus prevent condensation of vapour on the flue gas side of the heat exchanger tubes. The rest of the condensate is returned downstream the economiser. A more complex integration of waste heat is not applied, since there is no feed water preheating train in the water steam cycle and thus no heat sink available.

2.4. CO_2 compressor

For CO_2 compression an integrally geared multi-stage radial compressor is considered. The optimal number of stages depends on the CO_2 inlet pressure and is thus different for varying reboiler pressures. Between the stages of the compressor the CO_2 is cooled down in intercoolers and the condensing water is drained. This reduces the compression work in the following stages and thus the electrical energy needed for the compression. The number of intercoolers and their position is varied as well to reach the lowest overall efficiency penalty. The position of the intercoolers is of particular importance for the advanced waste heat integration of the SCPC case since the available temperatures depend on the position of the intercooler. The electrical duty of the motor as well as the cooling duty of the intercoolers is taken into account for the overall efficiency penalty.

3. CO_2 capture process flow sheet modifications

3.1. Base case

First, base cases for both power plants are defined to have a common basis for the comparison of the process modifications. The configuration of the base cases can be seen in Figure 1. The flue gas is cooled down to 40 °C in the flue gas cooler before entering the absorber. The absorber intercooler has the same temperature at its outlet. The solution mass flow and the lean loading are varied to reach the operating point with the lowest specific heat duty at a fixed capture rate of 90%. The RLHX has an LMTD of 5 K. The desorber pressure is set to 5 bar. The interface quantities for both power plant cases are shown in Table 1 for the operating point with the lowest specific heat duty. The usable waste heat is given for the SCPC case only since it is only needed for the advanced waste heat integration option. It can be seen that the specific energy demands are higher for the NGCC case. This is due to the lower CO_2 concentration in the flue gas, since the lean loading for the NGCC case has to be lower compared to the coal case to reach the optimum point for the same capture rate.

Table 1: Interface quantities for the base cases.

	SCPC base case	NGCC base case
Specific heat duty in MJ/kg CO_2	2.14	2.37
Specific cooling duty in MJ/kg CO_2	2.75	3.48
Specific auxiliary power in MJ/kg CO_2	0.07	0.10
Reboiler temperature in °C	128.0	132.4
Usable waste heat from OHC in MJ/kg CO_2	0.52	
Temperature level of usable waste heat in °C	116.2	

The overall efficiency penalty is achieved by evaluating the integrated overall process and comparing it to the reference case. It can be broken down into different contributors. The results for both power plant cases are shown in Table 2. For the SCPC case the basic integration (BI) and the advanced waste heat integration (WH) option are shown.

Table 2: Contributors to the overall efficiency penalty for the base cases.

	SCPC base case (BI)	SCPC base case (WH)	NGCC base case
Steam extraction	4.16%-points	4.21%-points	3.45%-points
Compressor duty	1.90%-points	2.06%-points	1.20%-points
Cooling water pumps	0.23%-points	0.21%-points	0.12%-points
Auxiliary power	0.62%-points	0.60%-points	0.53%-points
Waste heat integration		-0.97%-points	
Flue gas recirculation			0.62%-points
Overall efficiency penalty	**6.91%-points**	**6.11%-points**	**5.93%-points**

The largest contributor to the overall efficiency penalty is the steam extraction required for the reboiler. Due to the extracted steam, the steam mass flow to the LP turbine is reduced which results in lower power rating of the generator. The other contributors are electrical consumers and are thus directly reducing the electrical net output of the power plant. The CO_2 compressor is the largest of these consumers. The additional cooling duty of the capture plant leads to an additional power demand of the cooling water pumps. The auxiliary power contains the pumps and the ID fan. The difference between the two SCPC cases indicates that the lowest overall efficiency penalty for these cases is reached under different operating conditions. The negative value given for the SCPC case with advanced waste heat integration reduces the overall efficiency penalty and represents the saving that is achieved by preheating the condensate of the power plant with the waste heat from the capture plant.

The flue gas recirculation in the NGCC case improves the flue gas composition and reduces the penalty due to steam extraction from 4.42%-points to 3.45%-points. Still, the efficiency of the reference plant is reduced compared to an NGCC plant without flue gas recirculation by 0.62%-points. This loss is shown in the table as well. The efficiency penalties for the NGCC case are lower despite the higher specific energy consumption of the capture plant (cf. Table 1). This is due to the lower CO_2 content in the flue gas resulting in higher specific values but lower absolute values.

3.2. Split flow

A split flow process is defined by splitting a solvent stream and using it for different means. There are several process concepts in literature which can be defined as split flow processes. In the following, a concept described by Eisenberg and Johnson is evaluated [4]. A schematic flow diagram of the process is shown in Figure 2 a). The rich solution is split upstream the RLHX. A small fraction of the solution bypasses the RLHX and is led directly to the top of the desorber, while the bulk of the rich solution is fed to the stripper 2 m below the top. The split ratio, the ratio between bypass mass flow and total mass flow of rich solution, is varied from 0.01 to 0.2. For each split ratio, L/G is varied to reach the operating point with the lowest specific heat duty. The results for a capture plant in combination with an SCPC plant are shown in Figure 2 b).

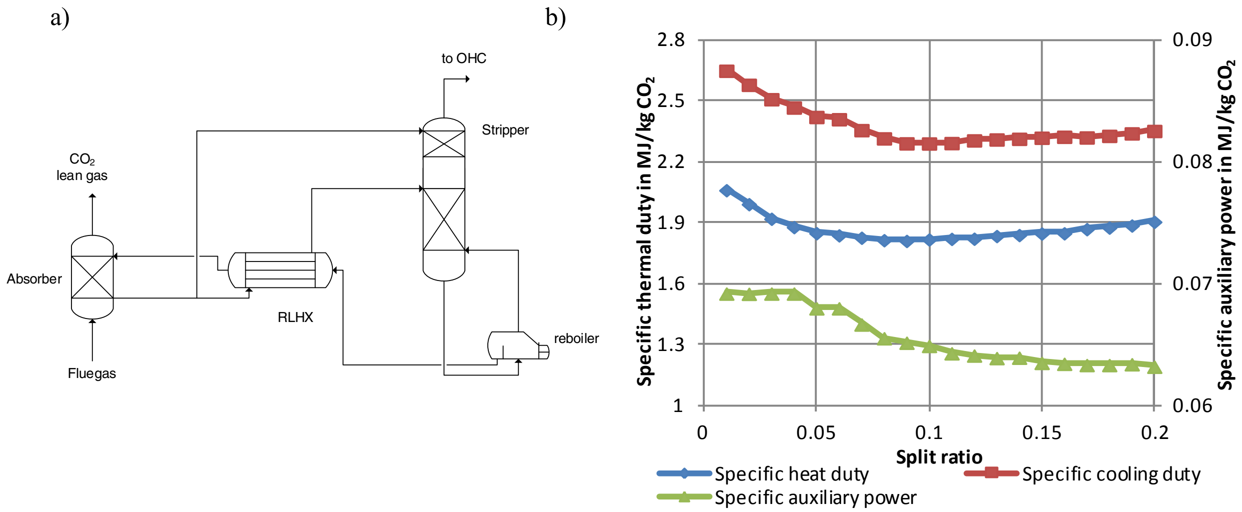

Figure 2: a) Schematic flow diagram of the split flow process by Eisenberg and Johnson [4]; b) Specific energy demands of a capture plant with a split flow configuration by Eisenberg and Johnson in combination with an SCPC plant for optimised L/G.

With increasing split ratio, the specific heat duty decreases until a minimum of 1.81 MJ/kg CO_2 is reached at a split ratio of 0.09. Compared to the base case, this is a reduction by 0.33 MJ/kg CO_2. For higher split ratios, the specific heat duty increases. The specific cooling duty has a similar trend as the specific heat duty. It is reduced by 0.45 MJ/kg CO_2 to 2.3 MJ/kg CO_2 for a split ratio of 0.09 and increases for higher split ratios. For the same operating point, the specific auxiliary power is reduced by 0.004 MJ/kg CO_2 to 0.065 MJ/kg CO_2. This is due to the fact that the operating point with the lowest heat duty for higher split ratios is reached at lower L/G. Thus, the power demand of the rich solution pump is reduced. In Table 3 the interface quantities for the base cases as well as for the split flow cases with the lowest specific heat duty are shown for both power plants.

Table 3: Interface quantities for the base cases and the split flow cases.

	SCPC base case	SCPC split flow	NGCC base case	NGCC split flow
Specific heat duty in MJ/kg CO_2	2.14	1.81	2.37	1.96
Specific cooling duty in MJ/kg CO_2	2.75	2.30	3.48	2.94
Specific auxiliary power in MJ/kg CO_2	0.07	0.065	0.10	0.10
Reboiler temperature in °C	128.0	138.4	132.4	149.2
Usable waste heat from OHC in MJ/kg CO_2	0.52	0.163		
Temperature level of usable waste heat in °C	116.2	88.5		

The specific heat duty is reduced since the rich solution can be heated up further due to the reduced rich solution mass flow to the RLHX. The remaining rich solution is heated up in the stripper head by condensing steam making use of the latent heat as well as the sensible heat.

The reduction in specific cooling duty is caused by the reduced temperature of the vapour downstream the stripper leading to a significantly reduced overhead condenser (OHC). On the contrary the specific cooling duty of the lean solution cooler is increased since the temperature of the lean solution downstream the RLHX is increased, but this increase does not outweigh the reduction in the OHC.

The effect on the overall efficiency penalty can be seen in Figure 3. The values are given for the operating points with the lowest overall efficiency penalty for each split ratio. The operation point with the lowest overall efficiency penalty is reached for a split ratio of 0.05. Higher split ratios lead to higher overall efficiency penalties since the reboiler temperature increases and thus the quality of the steam needed in the reboiler.

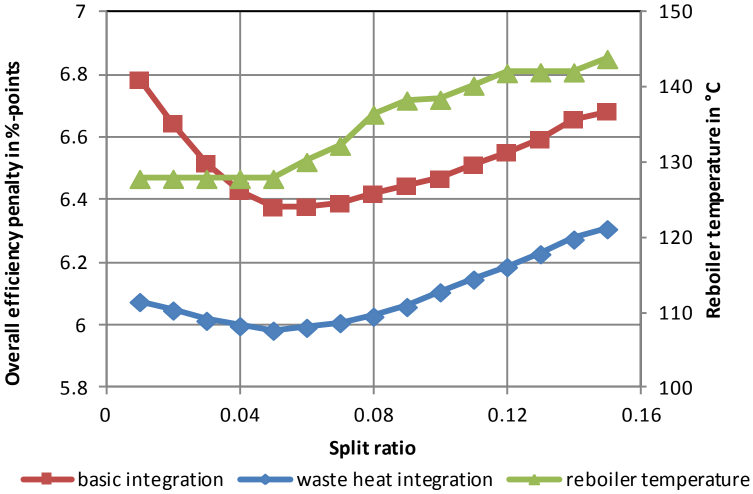

Figure 3: Overall efficiency penalty and reboiler temperature for a capture plant with a split flow configuration suggested by Eisenberg and Johnson in combination with an SCPC plant.

The different contributors to the overall efficiency are shown in Table 4 for the split flow process as well as for the base cases. It can be seen that the reduction of the overall efficiency penalty is mainly caused by the reduced specific heat duty which decreases the penalty due to steam extraction for all cases. The penalty due to auxiliary power of the capture plant and additional cooling water pumps is slightly decreased as well, which is due to the reduced solution mass flow. The positive effect of waste heat integration is significantly reduced by half since the temperature of the usable waste heat in the OHC is reduced (cf. Table 3).

Table 4: Contributors to the overall efficiency penalty for the base cases and the split flow cases.

	SCPC base case (BI)	SCPC split flow (BI)	SCPC base case (WH)	SCPC split flow (WH)	NGCC base case	NGCC split flow
Steam extraction	4.16%-points	3.67%-points	4.21%-points	3.71%-points	3.45%-points	2.99%-points
Compressor duty	1.90%-points	1.90%-points	2.06%-points	2.06%-points	1.20%-points	1.20%-points
Cooling water pumps	0.23%-points	0.21%-points	0.21%-points	0.18%-points	0.12%-points	0.12%-points
Auxiliary power	0.62%-points	0.60%-points	0.60%-points	0.59%-points	0.53%-points	0.52%-points
Waste heat integration			-0.97%-points	-0.55%-points		
Flue gas recirculation					0.62%-points	0.62%-points
Overall efficiency penalty	**6.91%-points**	**6.38%-points**	**6.11%-points**	**5.99%-points**	**5.93%-points**	**5.46%-points**

3.3. Vapour recompression

Vapour recompression (VR) is a process modification that reduces the reboiler heat duty by replacing it with auxiliary power of a compressor. Different process configurations are possible, in which the vapour is extracted from different positions in the stripper. In some cases the vapour is taken directly from the stripper or a liquid solvent stream is flashed to a lower pressure in order to release vapour. In this work the configuration shown in Figure 4 a) is evaluated. The lean solution coming from the reboiler is throttled to a lower pressure thus evaporating part of the solvent. The vapour is compressed to the pressure in the stripper and led back to the stripper bottom, thus reducing the specific heat duty of the reboiler while the specific auxiliary power is increased.

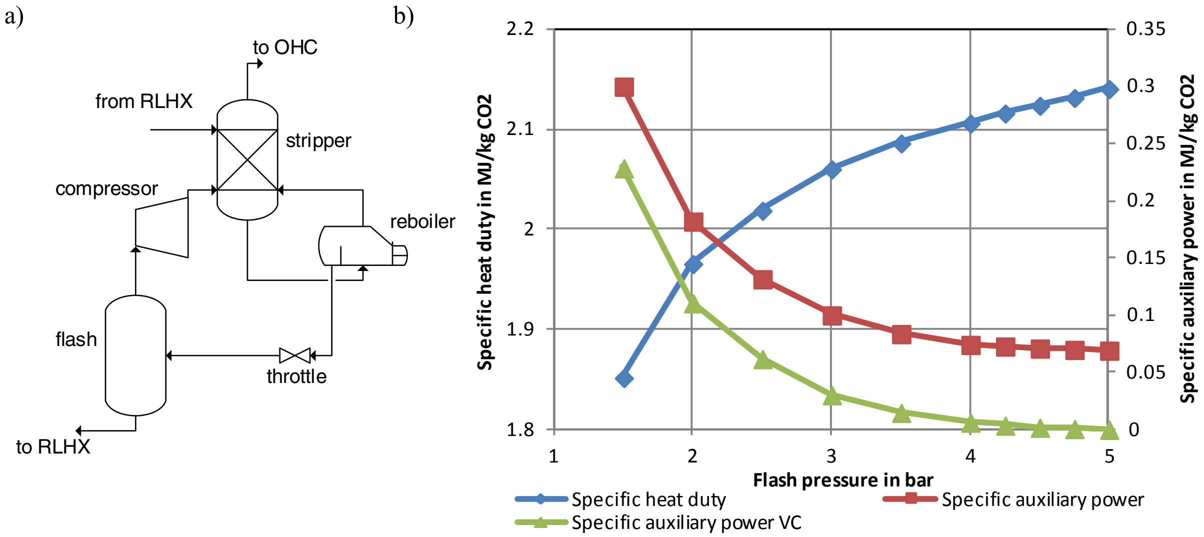

Figure 4: a) Schematic flow diagram of the evaluated vapour recompression configuration; b) Specific heat duty and specific auxiliary power of a capture plant with vapour recompression in combination with an SCPC plant and specific auxiliary power of the vapour compressor for different flash pressures.

In Figure 4 b) the effect of different flash pressures on the specific heat duty and the specific auxiliary power duty are shown. The operating points are the ones with the lowest specific heat duty for each flash pressure. The values shown for a flash pressure of 5 bar are the ones of the base case. As expected the specific heat duty decreases and the specific auxiliary power duty increases for lower flash pressures. The increase in specific auxiliary power is mainly due to the additional electric duty of the vapour compressor which is shown in Figure 4 a) as well. The difference between the overall specific auxiliary power and the specific auxiliary power of the vapour compressor is about the same for all flash pressures. In Table 5 the interface quantities for the base cases as well as for the vapour recompression cases with a flash pressure of 1.5 bar are shown for both power plants.

Table 5: Interface quantities for the base cases and vapour recompression (VR) cases.

	SCPC base case	SCPC VR	NGCC base case	NGCC VR
Specific heat duty in MJ/kg CO_2	2.14	1.85	2.37	1.95
Specific cooling duty in MJ/kg CO_2	2.75	2.50	3.48	3.26
Specific auxiliary power in MJ/kg CO_2	0.07	0.29	0.10	0.38
Reboiler temperature in °C	128.0	129.6	132.4	129.6
Usable waste heat from OHC in MJ/kg CO_2	0.52	0.29		
Temperature level of usable waste heat in °C	116.2	102.6		

For low flash pressures the lowest specific heat duty is reached at reduced solution mass flow in the capture plant compared to the base case which would lead to higher reboiler temperatures for the standard process. Still, the reboiler temperature is increased only slightly for the SCPC case and even reduced for the NGCC case. Due to the vapour mass flow from the compressor being fed to the stripper less water has to be vaporised in the reboiler when using vapour recompression. This leads to a lower temperature at the stripper head as well and thus a reduced potential for the advanced waste heat integration.

The overall efficiency penalty for an SCPC plant is shown in Figure 5 for different flash pressures. Results show that the positive effect on the overall efficiency penalty is very small. The lowest overall efficiency penalty of 6.82%-points for the basic integration case is achieved at a flash pressure of 4 bar. For lower flash pressures the additional compressor duty overcompensates the savings due to the reduced specific heat duty. With waste heat integration the effect is even smaller since the positive effect of waste heat integration is reduced due to the lower temperature at the stripper head.

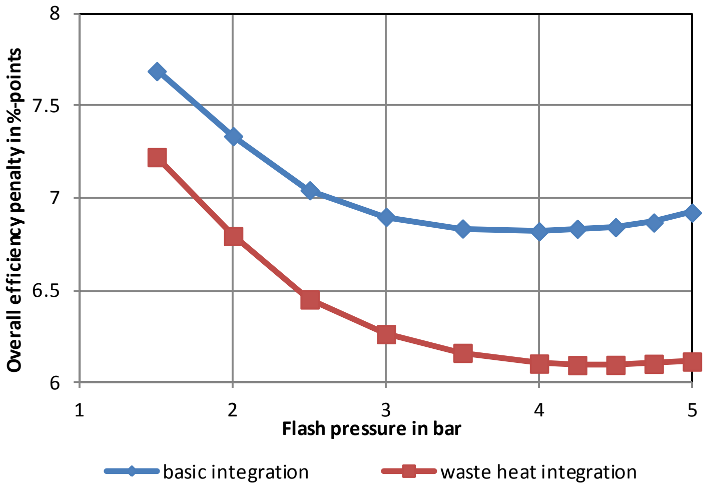

Figure 5: Overall efficiency penalty for a capture plant with vapour recompression in combination with an SCPC plant.

The detailed list of contributors to the overall efficiency penalty is shown in Table 6. The positive effect of vapour recompression on the NGCC plant is similar to the SCPC case. For a flash pressure of 3.5 bar the lowest overall efficiency penalty is reached.

Table 6: Contributors to the overall efficiency penalty for the base cases and the vapour recompression cases.

	SCPC base case (BI)	SCPC VR (BI)	SCPC base case (WH)	SCPC VR (WH)	NGCC base case	NGCC VR
Steam extraction	4.16%-points	4.02%-points	4.21%-points	4.08%-points	3.45%-points	3.27%-points
Compressor duty	1.90%-points	1.90%-points	2.06%-points	2.06%-points	1.20%-points	1.20%-points
Cooling water pumps	0.23%-points	0.23%-points	0.21%-points	0.21%-points	0.12%-points	0.13%-points
Auxiliary power	0.62%-points	0.67%-points	0.60%-points	0.63%-points	0.53%-points	0.64%-points
Waste heat integration			-0.97%-points	-0.89%-points		
Flue gas recirculation					0.62%-points	0.62%-points
Overall efficiency penalty	**6.91%-points**	**6.82%-points**	**6.11%-points**	**6.09%-points**	**5.93%-points**	**5.86%-points**

Compared to other solvents the positive effect of vapour recompression is quite low for Solvent2020. This is mainly due to the high CO_2 content in the flashed vapour. Depending on the flash pressure it varies between 40 and 55 Vol%. Using monoethanolamine (MEA) as solvent leads to a CO_2 content of the flashed vapour below 5 Vol%. This is due to the low temperatures in the reboiler since the water partial pressure in the flash is equivalent to the water vapour pressure for the respective temperature. Low temperatures at high pressures result in a low water partial pressure and thus a low water content. Flashing and recompressing of water can have a positive effect on the overall efficiency since the energy of vaporisation can be used in the stripper. Flashing and recompressing CO_2 does not have this advantage. The results obtained for MEA at the pilot plant in Esbjerg, Denmark, confirm that [5].

4. Summary

In this work two process modifications of post combustion CO_2 capture unit have been evaluated for SCPC and NGCC. A generic optimised solvent has been chosen including a solvent property model for the simulation of the process. Reference plants for the SCPC and the NGCC plant were defined and simulated. For each SCPC and NGCC power plant, a CO_2 capture plant base case was simulated to have a common basis for all process modifications.

The most important interface quantities specific heat duty, specific cooling duty, specific auxiliary power and reboiler temperature were obtained from the process energetic evaluation. These were used to conduct an overall process evaluation for both process flow sheet modifications in order to quantify the influence of the modified CO_2 capture plant on the overall process performance. The overall efficiency penalty was used as a characteristic value to rate the effect on the overall process performance. This is defined as the difference between the net efficiency of the reference power plant and the net efficiency of a power plant equipped with a CO_2 capture plant incorporating the respective process flow sheet modification. It was seen that it is important to not only compare the specific heat duty of the modifications but to have a close look at the temperatures in the process, the CO_2 compression and the overall process.

The split flow process has a positive effect on the overall efficiency penalty reducing it from 6.11 to 5.99 %-points for the SCPC case and from 5.93 to 5.46 %-points. The vapour recompression process has only a small influence on the overall efficiency penalty. It is reduced from 6.11 to 6.09 %-points for the SCPC case and from 5.93 to 5.86 %-points for the NGCC case.

In a more extensive study prepared by the authors under financing of IEAGHG more process flow sheet modifications were evaluated on the same basis. The results for these modifications are shown in Table 7.

Table 7: Overall efficiency penalty for process flow sheet modifications evaluated in a more extensive study by the authors [2].

	SCPC case in %-points	NGCC case in %-points
Base case	6.11	5.93
Split flow	5.99	5.46
Vapour recompression	6.09	5.86
Multi-pressure stripper	6.25	5.86
Heat-integrated stripping column	6.18	5.92
Matrix stripping	6.41	6.04
Overhead condenser heat integration	5.84	5.28
Reboiler condensate heat integration	-	5.83
Combination of vapour recompression and split flow process	5.99	5.46
Combination of interheated stripper and overhead condenser heat integration	5.88	5.34

5. Acknowledgement

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