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(54) **Title:** POWER PLANT WITH CO2 CAPTURE AND COMPRESSION

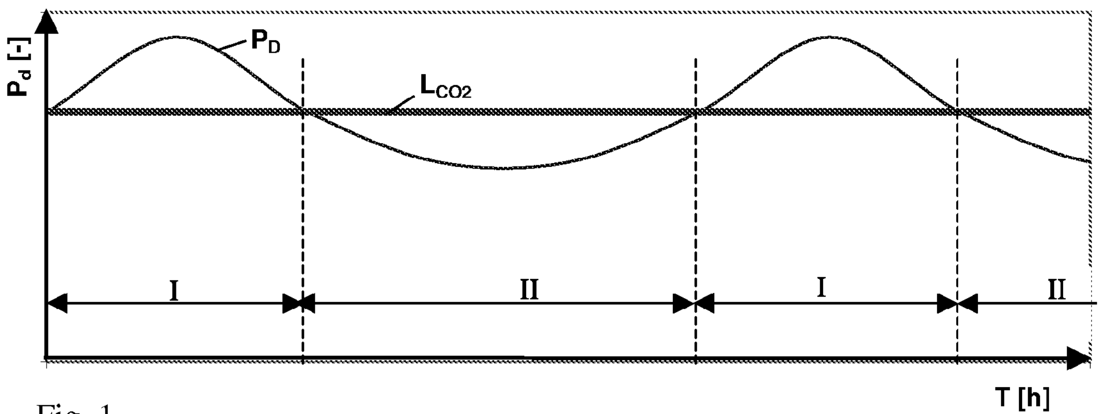

Fig. 1

(57) **Abstract:** Since C02 is identified as a main greenhouse gas, its capture and storage is essential to control of global warming. Flexible operation of CO2 capture and compression equipment will increase the competitiveness of power plants (1) designed for CO2 capture and compression and will allow earlier introduction of this kind of plants. The main objective of the present invention is to improve the plant operating characteristics by taking advantage of the additional flexibility, which can be realized by controlling the power consumption of the CO2 capture and compression system. One particular aim is to minimize the impact of CO2 capture and compression on the capacity of a power plant (1), i.e. to maximize the electric power the plant can deliver to the power grid. Further, the impact of CO2 capture and compression on the average plant efficiency shall be reduced. Both are achieved by an operating method, in which the power consumption of the CO2 capture system is used to control the net output (D) of the plant. Besides the method a power plant (1) designed to operate according to this method is subject of the present invention.

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Power plant with CO2 capture and compression

FIELD OF THE INVENTION

The invention relates to power plants with CO2 capture and compression as well as their operation.

BACKGROUND OF THE INVENTION

In recent years it has become obvious that generation of greenhouse gases lead to global warming and that further increase in greenhouse gas production will further accelerate global warming. Since CO2 (carbon dioxide) is identified as a main greenhouse gas, CCS (carbon capture and storage) is considered one potential mayor means to reduce the release of greenhouse gases into the atmosphere and to control global warming. In this context CCS is defined as the process of CO2 capture, compression, transport and storage. Capture is defined as a process in which CO2 is removed either from the flue gases after combustion of a carbon based fuel or the removal of and processing of carbon before combustion. Regeneration of any absorbents, adsorbents or other means to remove CO2 of carbon from a flue gas or fuel gas flow is considered to be part of the capture process. There are several possible approaches to CO2 capture in power plants. The main technologies under discussion for CO2 capture are so called pre-combustion capture, oxyfiring, chemical looping and post-combustion capture.

Pre-combustion carbon capture involves the removal of all or part of the carbon content of a fuel before burning it. For natural gas, this is typically done by reforming it with steam, followed by a shift reaction to produce CO2 and hydrogen. The CO2 can be captured and removed from the resulting gas mixture. The hydrogen can then be used to produce useful energy. The process is also known as synthesis gas or syngas approach. The same approach can be used for coal or any fossil fuel. First the fuel is gasified and then treated in the same way as natural gas. Applications of this approach in combination with IGCC (Integrated Gasification Combined Cycle) are foreseen.

Oxyfiring (also known as oxyfuel firing or oxygen combustion) is a technology that burns coal or other fossil fuel in a mixture of oxygen and recirculated CO2 rather than air. It produces a flue gas of concentrated CO2 and steam. From this, CO2 can be separated simply by condensing the water vapor, which is the second product of the combustion reaction.

Chemical looping involves the use of a metal oxide as an oxygen carrier, typically a metal oxide, which transfers oxygen from the combustion air to the fuel. Products from combustion are CO2, reduced metal oxide and steam. After condensation of the water vapor, the CO2 stream can be compressed for transportation and storage.

The CCS technology currently considered closest to large-scale industrial application is post combustion capture combined with compression, transportation and storage. In post-combustion capture the CO2 is removed from a flue gas. The remaining flue gas is released to the atmosphere and the CO2 is compressed for transportation and storage. There are several technologies known to remove CO2 from a flue gas such as absorption, adsorption, membrane separation, and cryogenic separation.

All known technologies for CO2 capture and compression require relatively large amounts of energy. There are many publications on the optimization of the different processes and the reduction of the power and efficiency penalty by integrating these processes into a power plant.

For CCS with post combustion capture, the CO2 capture and the compression of CO2 for further processing, i.e. transport and storage are the main two power consumers.

The EP1688173 gives an example for post combustion capture and a method for the reduction of power output penalties due to CO2 absorption, respectively the regeneration of the absorption liquid. Here it is proposed to extract steam for regeneration of the absorbent from different stages of the steam turbine of a power plant to minimize the reduction in the turbine output.

In the same context, the WO2007/073201 suggests to use the compression heat, which results from compressing the CO2 stream for regeneration of the absorbent.

These methods aim to reduce the power requirements of specific CO2 capture equipments, however the use of the proposed CO2 capturing method will always result in a significant reduction of the plant capacity, i.e. the maximum power a plant can deliver to the grid.

A first attempt to mitigate the impact of CO2 capture on the plant output is described in the EP0537593, which describes a power plant that utilizes an absorbent for CO2 capture from the flue gases, where the regenerator is switched off during times of high power demand and where the CO2 capture continues by use of absorbent stored in an absorbent tank during these times. The EP0537593 describes a simple on/ off mode of one power consumer of the CO2 capture equipment. It adds only very little operational flexibility at relatively high cost.

SUMMARY OF THE INVENTION

The main objective of the present invention is to optimize the operating method for power plants with CO2 capture and compression and a power plant with CO2 capture and compression designed to operate according to the optimized operating method.

One objective is to reduce the impact of CCS (carbon capture and storage) on the plant performance by a flexible operation method of the CO2 capture equipment and compression unit. In particular the impact of CO2 capture and compression on the capacity of a power plant is minimized, i.e. the electric power the plant can deliver to the power grid is maximized. Further, the impact of CO2 capture and compression on the average plant efficiency also shall be reduced.

To this end a method for operating a power plant with CO_2 capture and compression and a plant for execution of said method is proposed.

The essence of the invention is a plant operating method, in which the power consumption of the CO_2 capture system is used to control the net output of the plant. In the context of this invention a CO_2 capture system is defined as the entire CO_2 capture unit plus the compression unit with all their auxiliaries. Further, the electrical power consumption, mechanical power consumption as for example in mechanical CO_2 compressor drives as well as consumption of live steam, which otherwise can be converted into electrical energy in a steam turbine, are considered as power consumption of the capture system. This control method gives additional flexibility in addition to the existing control of the plant. Due to the integration of the CO_2 system into the power plant with this method, the thermal load of the plant can be kept constant during extended periods of operation. Preferably, the plant can be operated at base load for extended periods of time. Influence of changes in the thermal load due to a change in ambient conditions is neglected in this discussion. Further, an operation close to or at the efficiency optimum of the plant can be realized and the rated capacity of the plant can be significantly increased. Most embodiments of this invention can be realized at no or very little additional cost.

The net output of the plant can be changed by an intermittent operation method of the CO_2 capture equipment and compression unit or an operation method where the CO_2 capture equipment and compression unit are operating at reduced capacity.

For control of the power consumption of CO_2 capture and compression several approaches are conceivable.

In a first approach the CO_2 capture and compression equipment or its main power consumers can simply be switched off at times of high power demand (see Fig 1). The CO_2 separation, independent of chosen technology, is stopped and the plant is running like a conventional plant with CO_2 emissions in the flue gases. Correspondingly, no CO_2 compression with its parasitic power demand is required.

Operation of CO2 capture and compression can be carried out on a cost optimized and operating permit related bases: once the price/ benefit for CO2 capture and compression is higher than the benefit of additional power production the CO2 capture and compression comes into operation, and vice versa. Further, the CO2 capture and compression always stays operational as long as regulations and permits require it.

Besides the simple on /off mode, a derating or part load operation of the CO2 capture equipment and compression is proposed during times of high power demand. As a consequence the capture rate will normally be reduced during this period. The cost per ton of CO2 captured and compressed is a function of the capture rate, which is the ratio of CO2 captured from the flue gases to the total CO2 produced by the plant. The optimum, or the minimum in cost per ton of CO2 captured and compressed is estimated to be in the region of 70% to 90% capture rate (Fig. 4). It is estimated that there is a sharp increase in costs for capture rates above approximately 90% but that the minimum shows a relatively flat curve to lower capture rates. Therefore operating at capture rates below design will not lead to a significant increase in operating costs. However, the reduction in power consumption for CO2 captures and compression during peak demand will lead to substantial increase in earnings since the price for electric power can increase significantly during peak demand. Flexible operation of the capture equipment and compression unit will also increase the rated capacity and competitiveness of power plants with CO2 capture and compression. It will allow earlier introduction of this kind of plants beyond mere pilot plant projects into a competitive power market.

In the following, a flexible operation method for CO2 capture and compression is discussed using the example of CO2 absorption. An analogous method is applicable for a CO2 capture method, which consists of CO2 adsorption, regeneration of the adsorbent and compression of captured CO2. Operating concepts using the same principle are conceivable for all CO2 capture methods.

Operation of a CO2 capture and compression process, which consists of CO2 absorption, regeneration of the absorbent and compression of captured CO2 gives three main options to increase the flexibility of the plant operation. They can be performed one by one or all at the same time. They are:

1. Shut down or operation at reduced capacity of CO2 compression unit.

2. Shut down or operation at reduced capacity of regeneration unit
3. Shut down or operation at reduced capacity of absorption unit

While the first option already leads to a significant reduction in parasitic power consumption it will lead to a release of $CO2$ to the atmosphere within a very short time period as large volumes of uncompressed $CO2$ cannot be stored economically. For a safe disposal of the captured $CO2$ it can for example be mixed with the flue gases downstream of the $CO2$ absorption unit and released via the stack of the power plant.

A further significant reduction in parasitic power consumption can be realized by the second option. Regeneration typically is done by "re- boiling" of the absorbent, which means heating the absorbent by steam in order to release the $CO2$. In consequence the steam is no longer available for power production. Once the regeneration is stopped during peak power demand, the surplus steam is available for power production.

A third option, in which also the absorption process is stopped, leads to further reduction in auxiliary power consumption. This reduction in power consumption is significantly smaller than the savings achieved in the first two options.

There are different ways to realize part load operation of components. For example the mass flow of the $CO2$ compression unit can be reduced by control means such as inlet guide vanes. In case of a compression unit consisting two or more parallel compressor trains, the shut down of at least one compressor would obviously also lead to a reduction of the $CO2$ compression unit's power consumption. In case of two parallel compressor trains operating at full capacity, shut down of one compressor train would lead to a reduction in power consumption by 50% but also implicate that 50% of the captured $CO2$ cannot be compressed and would typically be bypassed to the stack. Alternatively the resorption rate can be reduced. This can for example be realized by reducing the flow of absorbent through the regeneration unit and bypassing the remaining flow and mixing the two flows before they enter the absorption unit. As only part of the flow passes through the regeneration unit, the steam required for regeneration is reduced and the surplus steam can be used for power production. As a consequence of mixing regenerated with unregenerated absorbent, the capacity of the resulting mixture to absorb $CO2$ is reduced and a lower percentage of $CO2$ is captured from the flue gases and less CO2 is released for compression in the regeneration unit. As it is not very economical to first capture CO2 and then bypass it, a simultaneous reduction in the capacity of all capture systems components is proposed.

Operation of the absorption process itself does not make any sense without further measures, as the absorbent in conventional arrangements will be saturated quickly and cannot capture any more CO2.

Here, a further embodiment of the invention comes into force to further increase the flexibility of the plant and CO2 capture and compression method with reduced or no impact on the CO2 release: In order to allow further CO2 capture without regeneration and CO2 compression, the operation of the capture process with storage of the absorbent is proposed.

In this operating mode the CO2 is captured by the absorbent, which is taken from an absorbent storage tank and not regenerated but recirculated to the absorbent tank or stored in tank for saturated absorbent.

As a consequence not only a sufficiently sized storage tank is required but also a regeneration unit, which has an increased capacity is proposed. The regeneration unit will typically be sized to regenerate absorbent flows from the plant operation plus additional capacity to regenerate saturated absorbent, which was stored during peak power demand. The size of regeneration units depends on the expected operating profile. For example if high power demand is expected during 1 hour in a given 24 hours operating period close to 5% over capacity is required to regenerate all saturated absorbent during the period of low power demand. An overcapacity of the regeneration unit might not be required in case the operating profile of the plant foresees extended part load operation of the plant, during which the stored absorbent can be regenerated.

Power optimized operation and overcapacity in regeneration units allows an efficiency optimized plant operation. The plant efficiency is highest during operation close to base load. Except for time periods of peak power demand, plants typically have to operate at part load during periods of low demand and are consequently forced to operate at reduced efficiency. The proposed new operating concept, which takes advantage of the additional flexibility in power output to the grid by varying the power consumption of the CO2 capture system allows the plant to be operated at its optimum. This flexibility is further increased with oversized regeneration units as it allows the plant operator to increase the gross output and to use the excess energy for absorbent regeneration and therefore also increase the plant efficiency during periods of low grid power demand.

A further benefit of varying the power consumption of the CO2 capture system to meet changes in the grid demand is the possibility to run the power plant at constant load and therefore avoid load variations in the gross output and the consequential thermal stresses and wear and tear.

One special application of the operation with CO2 capture and compression off is the demonstration of so-called power reserve. A power reserve is additional power beyond the normal base load power, which can be delivered if requested. For many power grids it is beneficial if the plant can demonstrate a power reserve, which can be called upon in case of a sudden rise in demand or in case that other plants have to reduce their output or even be shut down for an unplanned outage. The ability to demonstrate a power reserve is commercially valuable. Depending on the grid some plants might be required to operate at part load, for example 90% load in order to keep a power reserve. Operation at 90% can lead to reduced efficiency and increases the capital and operational cost per MWh produced.

For some grids the possibility to deliver peak power can also be sold as so called spinning reserve. Any back-up energy production capacity, which can be made available to a transmission system within ten minutes' notice and can operate continuously for at least two hours once it is brought online, is typically considered as spinning reserve.

A further subject of this invention is a thermal power plant for the combustion of carbon-based fuels with a CO2 capture system designed for the operation according to the described flexible operating method.

One embodiment of the invention is a power plant burning a carbon-based fuel, which has at least one flue gas stream. A plant in accordance with the present invention typically includes, in addition to the conventional components known for power generation, a CO2 capture unit for removing CO2 from the flue gas stream, and a compression unit. The capture unit typically includes capture equipment, in which the CO2 is removed from the flue gas, a regeneration unit, in which the CO2 is released from the absorbent, adsorbent or other means to bind the CO2 from the flue gas, and a treatment system for conditioning the CO2 for transportation. The compression unit consists of at least one compressor for CO2 compression. Typically the compression unit also consists of at least one cooler or heat exchanger for re- cooling compressed CO2 during and/or after the compression.

To allow operation according to the proposed operating concept a steam turbine of the plant is designed to convert the maximum steam flow into energy, which can be produced by the plant with the CO2 capture system switched off.

In a further embodiment, the generator and electrical systems are designed to convert the maximum power, which is produced with the CO2 capture system off, into electrical power and to transmit this electric power to the grid.

In order to facilitate the above described operation of such a plant it can further comprise a bypass of the CO2 compressor, which can safely vent the CO2, and for example leads into the flue gas stack downstream of the CO2 capture device.

In a second embodiment the CO2 capture unit is designed to withstand the flue gases even when it is not in operation, for example an absorption tower, which is designed to run dry.

Alternatively a bypass of the CO2 capture unit can be foreseen, which allows to operate the power plant independent of the CO2 capture unit. This bypass can also be advantageous for start-up or shut down of the plant as well as for plant operation during maintenance of the CO2 capture system.

In a further embodiment a storage tank dimensioned to supply CO2 absorbent for a defined period of time is provided and the regeneration unit is has a capacity, which is larger than the capacity required for continuous operation at design of the power plant in order to have extra capacity to regenerate stored absorbent during times of low power demand. Depending on the required size of the storage tank and capacity of the regeneration unit this embodiment can lead to significant additional costs.

Different control methods of the CO2 capture system are possible. One example is an open loop control of the different components of the CO2 capture system. This is particularly suitable in the case that only on/ off control of the different components is used.

Open loop control is also conceivable for a more sophisticated operating process in which a continuous control of the power consumption of the CO2 capture system, i.e. without sudden steps in the power output due to on / off switching of different components, is realized. In this example continuous control of the power consumption of the CO2 capture system is realized by the variation of one component's power consumption at a time, while the remaining components operate at constant load. However, closed loop control can be advantageous for example for transient operation or operation under changing boundary conditions.

In case that operation at reduced capacity of the different components is foreseen, a closed loop control will allow better optimization of the load distribution. This is especially advantageous if a control of the CO2 capture rate is implemented. In this case the power consumption of the CO2 capture system is not varied by the control of one single component at a time, while the remaining components operate at constant load. The reduction in capacity of the different components has to be coordinated. For this a feed back of the current operating conditions of each component is advantageous and a closed loop control is preferable.

As CO2 capture system is a complex system, an appropriate control system is required as discussed for the different operating methods above. This control system is depending on and affecting the power control of the plant. As the power control is an essential part of the plant control system it is advantageous to integrate the control of the CO2 capture system into plant control system or to coordinate the control of the CO2 capture system by the plant control system and to connect all the relevant data lines to the plant control system. If the plant consists of several units and the plant control system has a hierarchical structure consisting of plant controller and unit master controllers, it is advantageous to realize such an integration or coordination of the CO2 capture system's control into each units´ master controller.

Alternatively the CO2 capture system has its own controller, which is connected to the plant control system via a direct data link. The plant control system or the unit master controller has to send at least one signal to the controller of the CO2 capture plant. This signal can for example be a commanded power consumption signal or a commanded capture rate.

In the above-described cases the CO2 capture controller is not necessarily one hardware device but can be decentralized into drive and group controllers coordinated by one or more control units.

In case the control of the CO2 capture system is coordinated by the plant control system, the high-level control unit can for example send the total commanded mass flow to the CO2 compression unit's group controller and receive the total actual mass flow as input from this group controller. The compression unit in this example contains several compressor trains. Each of the compressor trains has its own device controller. The group controller has an algorithm to decide how to best distribute the commanded total CO2 compression mass flow on the different compressor trains and sends a commanded mass flow to each individual compressor train's device controller. In return, the group controller gets the actual CO2 compression mass flow of each compressor train. Each compressor train device controller can again work with depended controllers on lower levels.

The same kind of hierarchy can be applied to the control of all components of the CO2 capture system.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention, its nature as well as its advantages, shall be described in more detail below with the aid of the accompanying drawings. Referring to the drawings.

Fig. 1 schematically shows an operation method for intermittent CO2 capture.

Fig. 2 is a schematic view of a power plant with CO2 capture.

Fig. 3 schematically shows the relative cost c_r of ton of CO2 avoided as function of capture rate r_{CO2}.

Fig. 4 schematically shows the relative power output P_r variations over time T for a power plant with a flexible operation method for CO2 capture and compression.

DETAILED DESCRIPTION OF THE DRAWINGS AND THE INVENTION

A power plant for execution of the proposed method consists mainly of a conventional power plant 1 plus a CO2 capture unit 2 and a CO2 compression unit 9.

In Fig. 1 an electrical grid's power demand P_d is shown over time T. An operation method for intermittent CO2 capture is shown over time T in Fig. 1. The CO2 capture system is running during times II when the power demand P_d is lower than the limit for CO2 capture L_{CO2} and it is switched off during times I of high power the power demand P_d is lower higher than the limit for CO2 capture L_{CO2}.

A typical arrangement with post combustion capture is shown in Fig. 2. The power plant 1 is supplied with air 3 and fuel 4. Its main outputs are the plant gross electric power A and flue gas 15. Further, steam is extracted from the plant 1 and supplied via the steam line 13 and the steam control valve 14 to the CO2 capture unit 2. The steam is returned to the plant 1 at reduced temperature or as condensate via the return line 6 where it is reintroduced into the steam cycle. A

CO2 capture unit 2 typically consists of a CO2 absorption unit, in which CO2 is removed from the flue gas by an absorbent, and a regeneration unit, in which the CO2 is released from the absorbent. Depending on the temperature of the flue gas and the operating temperature range of the CO2 absorption unit a flue gas cooler might also be required.

The CO2 depleted flue gas 16 is released from the CO2 capture unit to a stack. In case the CO2 capture unit 2 is not operating, it can be bypassed via the flue gas bypass 11.

In normal operation the captured CO2 will be compressed in the CO2 compressor 9 and the compressed CO2 10 will be forwarded for storage or further treatment.

Electric power 7 is required to drive auxiliaries of the CO2 capture unit 2 and electric power 8 is used to drive the CO2 compressor 9. The net power output to the grid D is therefore the gross plant output A reduced by the electric power for plant auxiliaries 17, reduced by the electric power for CO2 compression unit 8, and by the electric power for the CO2 capture unit 7.

The corresponding control system 18, which integrates the control of the additional components needed for the CO2 capture and compression with the control of the power plant is also depicted in Fig. 2. The control system has the required at least one control signal 22 line with the power plant 1, and at least one control signal line with the CO2 compression unit 9. Further, the at least one control signal line 19 with the CO2 capture unit 2 including the flue gas bypass 11 is indicated. In case the capture unit 2 is based on absorption or adsorption a regeneration unit is part of the system and correspondingly at least one signal line 20 to the regeneration unit is required. If the capture unit 2 also includes at least one storage tank for an adsorbent/ absorbent control signal lines 21 to the storage system is required. For the example shown, in which steam 13 is used for regeneration, the steam control valve 24 is controlled via the control signal lines 24. This control line is connected to the resorption unit, which is part of the capture unit 2, or directly to the control system 18.

The continuous control of net power output D is explained using two examples in which an increase in net power output D is required starting from an operating point where all components operate at full capacity:

In a simple approach the net output is first increased by a controlled reduction in the power consumption of the CO2 compressor unit 9. As the power consumption of the compressor unit 9 is reduced, the amount of CO2 released from the CO2 regeneration unit 2 stays constant. As a consequence part of the CO2 flow has to bypass the CO2 compressor unit 9 through the CO2 compression unit bypass 12. Once the CO2 compressor unit 9 is completely switched off, the net output is increased by a controlled reduction in the power consumption of the CO2 regeneration unit. Finally, when the CO2 regeneration unit is completely switched off, the net output is increased by a controlled reduction in the power consumption of the CO2 absorption unit and, if applicable, of a flue gas cooler. In case the CO2 absorption unit 2 is not designed to run dry, i.e. it cannot be exposed to the flue gases 15 without the flow of absorbent and/ or additional flue gas cooling, the flue gas bypass 11 for the CO2 capture unit 2 has to be opened as a function of the power available for the absorption unit.

In a more sophisticate approach the net output is increased by a controlled coordinated reduction in the power consumption of all components of the CO2 capture unit 2 and compression unit 9. The target is to maximize the CO2 capture rate at reduced power consumption. To this end the capacity of all components is reduced simultaneously at the same rate and the CO2 flow through all components is the same. In consequence the power consumption is varied as a function of the capture rate. To assure that the flow rates of different components match, a feedback form these components are required and a closed loop control is advantageous. At very low capture rate, and if the CO2 absorption unit 2 is not designed to run dry, e.g. it cannot be exposed to the flue gases without the flow of absorbent and/ or additional flue gas cooling, the flue gas bypass for the CO2 capture unit 11 has to be opened as a function of the power available for the absorption unit 2.

The expected normalized cost c_r per ton of captured CO2 is shown in Fig. 3 as a function of CO2 capture rate r_{CO2}. The cost per ton of captured CO2 is normalized with the cost at 90% capture rate r_{CO2}. It is obvious that a capture above 90% capture rate becomes very expensive and that a plant should be designed for 80 to 90 % capture rate. At lower than 80% capture rates the cost per captured ton of CO2 increases slightly. A decrease in capture rate with a plant designed for 90% capture rate can be realized without significant penalty in cost per CO2 captured.

If the capture rate is reduced during operation a significant amount of power can be saved and therefore fed to the grid if required.

The impacts of the main power consumers of the CO2 capture system on the normalized plant power P_r output is shown in Fig. 4. The impact of the auxiliary power consumption of the plant itself is also indicated in this Figure.

Fig. 4 further shows the optimized operation method of a power plant with CO2 capture and compression over time T. The impact of the plant auxiliaries and main power consumers of the CO2 capture system on the net plant power output D is show by indicating the relative output P_r at different stages of the plant. All power outputs shown in this Figure are normalized by plant gross power output A at base load with steam extraction for resorption. A' is the gross output without steam extraction for resorption. B is the gross output reduced by the plant auxiliaries B. C is the output after the output B is further reduced by CO2 compression. D is the resulting plant net power output after D is reduced by the power consumption of the absorption. According to the proposed operating method the power reductions from B to C, C to D as well as the gross power increase from A to A' are variable and used to control the net output D. D is typically controlled to met the power requirements P_D of the electric grid. For maximum net output X all consumers of the CO2 capture system are switched off and no steam is extracted for resorption.

In the given example the required variations in net power output during the day are met by controlling the power consumption of the different consumers of the CO2 capture system. As a result the heat input and thermal load of the plant can be kept constant during the day, in this example from 7:00 hours to 22:00 hours. Only during the night, when the net output is reduced to 50% of the maximum net output delivered during the mid day peak, the gross output is reduced to about 62% of the base load net output.

In this example variations of net output in the order of 15% can be met by control of the power consumption of CO2 capture and compression. This can be seen for example between the morning operation at 11:00 hours and the peak demand at 12:30 hours.

The gross power has to be reduced only to 62% in order to achieve a 50% drop in net power output. The changes in heat input and thermal load to a will be even smaller as the efficiency typically drops at part load. This is particularly true for a gas turbine or a combined cycle power plant Therefore even if a change in thermal load is required to meet large changes in the required net power output D, the relative change in thermal load can be reduced compared to conventional operating methods.

Depending on the operating regime, it is conceivable that constant gross power can be kept as long as the plant is operating.

Exemplary embodiments described above and in the drawings disclose to a person skilled in the art embodiments, which differ from the exemplary embodiments and which are contained in the scope of the invention.

For example, the power used for recompression of flue gasses, as used in case of cryogenic CO2 separation or in case of absorption on elevated pressure levels can be saved or reduced during times of high power demand. Or, in case of CO2 separation with chilled ammonia, the cooling power can be saved or reduced during times of high power demand. Further, the method and a corresponding plant without CO2 compression is conceivable. In one embodiment a storage tank for cooling medium is provided, which is used for chilling during periods of high power demand. Further, analogue to the over sizing of regeneration units described above, the chilling equipment can be oversized to have capacity to cool down stored cooling medium during periods of low power demand.

List of reference symbols

1	Power Plant
2	CO2 capture unit
3	Air
4	Fuel
6	return line
7	Electric power for CO2 capture unit
8	Electric power for CO2 compression unit
9	CO2 compression
10	Compressed CO2
11	Flue gas bypass for CO2 capture unit
12	CO2 compression unit bypass
13	Steam to CO2 capture unit
14	Steam control valve
15	Flue gas to CO2 capture unit
16	CO2 depleted flue gas
17	Electric power for plant auxiliary excluding CO2 capture and compression
18	Control system
19	Control signal exchange with CO2 capture unit and flue gas bypass
20	Control signal exchange with regeneration unit (if applicable)
21	Control signal exchange with absorbent/ adsorbent storage system (if applicable)
22	Plant control signals exchange as for conventional plant without CO2 capture including gross and net power
23	Control signal exchange with CO2 compression unit and compressor bypass
24	Control signal exchange to steam control valve – directly from control system or via the regeneration unit (if applicable)

I	times of high power demand with CO2 capture off
II	times of low power demand with CO2 capture on

A	Plant gross power output with steam extraction for CO2 resorption
A'	Plant gross power output without steam extraction for CO2 resorption
B	A reduced by plant auxiliaries without CO2 capture and compression
C	B reduced by power requirements for CO2 compression – varied depending on grid power demand.
c_r	relative cost of CO2 capture
D	CO2 capture plant net power output (C reduced by power requirements for absorption – varied depending on grid power demand).
P_d	power demand of the electric grid
P_r	Power output relative to the plant's base load gross power
r_{CO2}	CO2 capture rate
T	Time
X	Time of peak net power output with CO2 capture and compression off

Patent claims

1. A method for operating a power plant (1) with a control system (18) and CO2 capture system, characterized in that the power consumption of the CO2 capture system is used as a control parameter for the net power output (D) of the plant.

2. A method according to claim 1, characterized in that the CO2 capture system is controlled by a closed loop control system (18), which is integrated into the plant control system or coordinated by the plant control system or has a direct data link (22) to the plant control system.

3. A method according to claim 1 or 2, characterized in that the CO2 capture system is operated at reduced capacity or is shut down in order to supply additional power to the grid, and that this additional power is used to increase the rated plant capacity.

4. A method according to one of the preceding claims, characterized in that the power plant (1) is operated close to or at design point when the CO2 capture system is in operation, the power consumption of the CO2 capture system is used as capacity reserve and a part load operation of the power plant (1) to assure a capacity reserve is avoided and which is therefore operated at the optimum plant efficiency.

5. A method according to one of the claims 1 to 4, characterized in that the thermal load of the plant (1) is kept constant and that variations in the net power output (D) to the grid are realized by the control of the power consumption of the CO2 capture system.

6. A method according to one of the claims 1 to 5, characterized in that the CO2 capture rate is varied to control the power consumption of the CO2 capture system.

7. A method according to one of the claims 1 to 6, characterized in that the CO2 compression unit (9) is shut down or operated at reduced capacity.

8. A method according to one of the claims 1 to 7, characterized in that the CO2 compression unit (9) is shut down or operated at reduced capacity and that part or all of the captured CO2 is released via a bypass (12) of the CO2 compression unit (9).

9. A method according to one of the claims 1 to 8, characterized in that a regeneration unit comprised in the capture system (2) is shut down or operated at reduced capacity.

10. A method according to one of the claims 1 to 9, characterized in that the absorption or adsorption unit comprised in the capture system (2) is shut down or operated at reduced capacity.

11. A method according to one of the claims 1 to 10, characterized in that an absorption or adsorption unit comprised in the capture system (2) is shut down or operated at reduced capacity and that part of or all the flue gas is bypassed around the capture equipment.

12. A method according to one of the claims 1 to 11, characterized in that regeneration unit comprised in the capture system (2) is shut down or regeneration takes place at reduced capacity at times of high power demand, and that stored absorbent or adsorbent is used for CO2 capture during this time.

13. A method according to one of the claims 9 or 12, that the steam (13) consumption of the regeneration unit comprised in the capture system (2) is reduced due to the shut down or operation at reduced capacity, and that the surplus steam is fed to at least one existing steam turbine of the plant (1).

14. A method according to one of the claims 11 or 13, characterized in that regeneration of the absorbent or adsorbent takes place at times of low power demand (P_D).

15. A power plant (1) with a CO2 capture system, characterized in that the power plant (1) is designed for operation according to the method of claim 1.

16. A power plant (1) according to claim 15, characterized in that the at least one steam turbine is designed to convert the maximum steam flow into energy, which can be produced by the plant with the CO2 capture system switched off.

17. A power plant (1) according to claim 15 or 16, characterized in that at least one generator and electrical systems are designed to convert the maximum power, which is produced with the CO2 capture system off, into electrical power and to transmit this electric power to the grid.

18. A power plant (1) according to one of the claims claim 15 to 17, characterized in that a bypass (12, 11) of the CO2 compression unit (9) and/ or the absorption unit is provided.

19. A power plant (1) according to one of the claims claim 15 to 18, characterized in that the absorption unit comprised in the capture system (2) is designed to withstand the flue gases even when it is not in operation.

20. A power plant (1) according to one of the claims claim 15 to 19, characterized in that a storage tank for the absorbent or adsorbent is provided, which allows the capture of CO2 even if the regeneration unit comprised in the capture system (2) is operating at reduced capacity or is off.

21. A power plant (1) according to claim 20, characterized in that a regeneration unit comprised in the capture system (2) has a capacity, which is bigger than required for steady state operation of the power plant (1) in order to have additional capacity to regenerate stored absorbent or adsorbent.

22. A power plant (1) according to one of the claims claim 15 to 21, characterized in that chilled ammonia is used for the CO_2 capture system and wherein a storage tank for cooling medium is provided, which is used for chilling during periods of high power demand and wherein the chilling equipment is oversized to have capacity to cool down stored cooling medium during periods of low power demand.

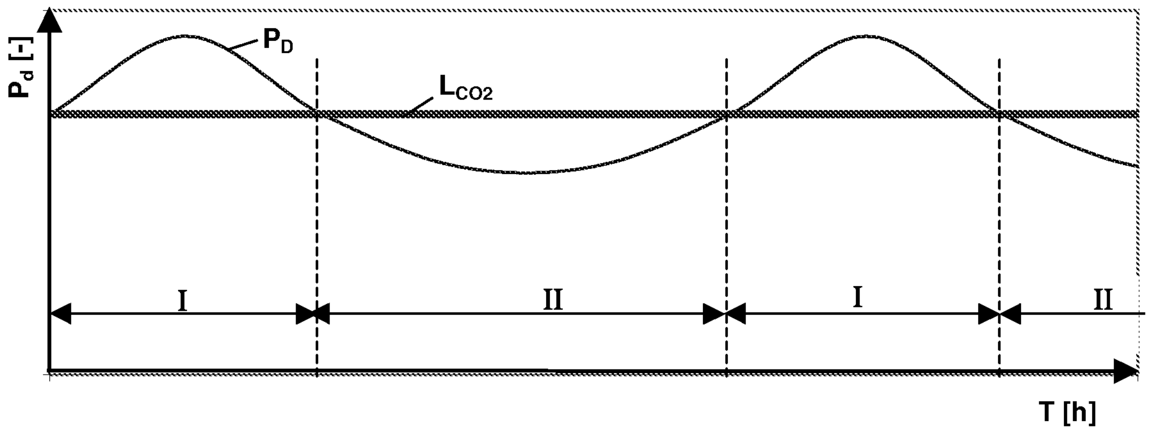

P_d [-]
P_D
L_CO2
I
II
I
II
T [h]

Fig. 1

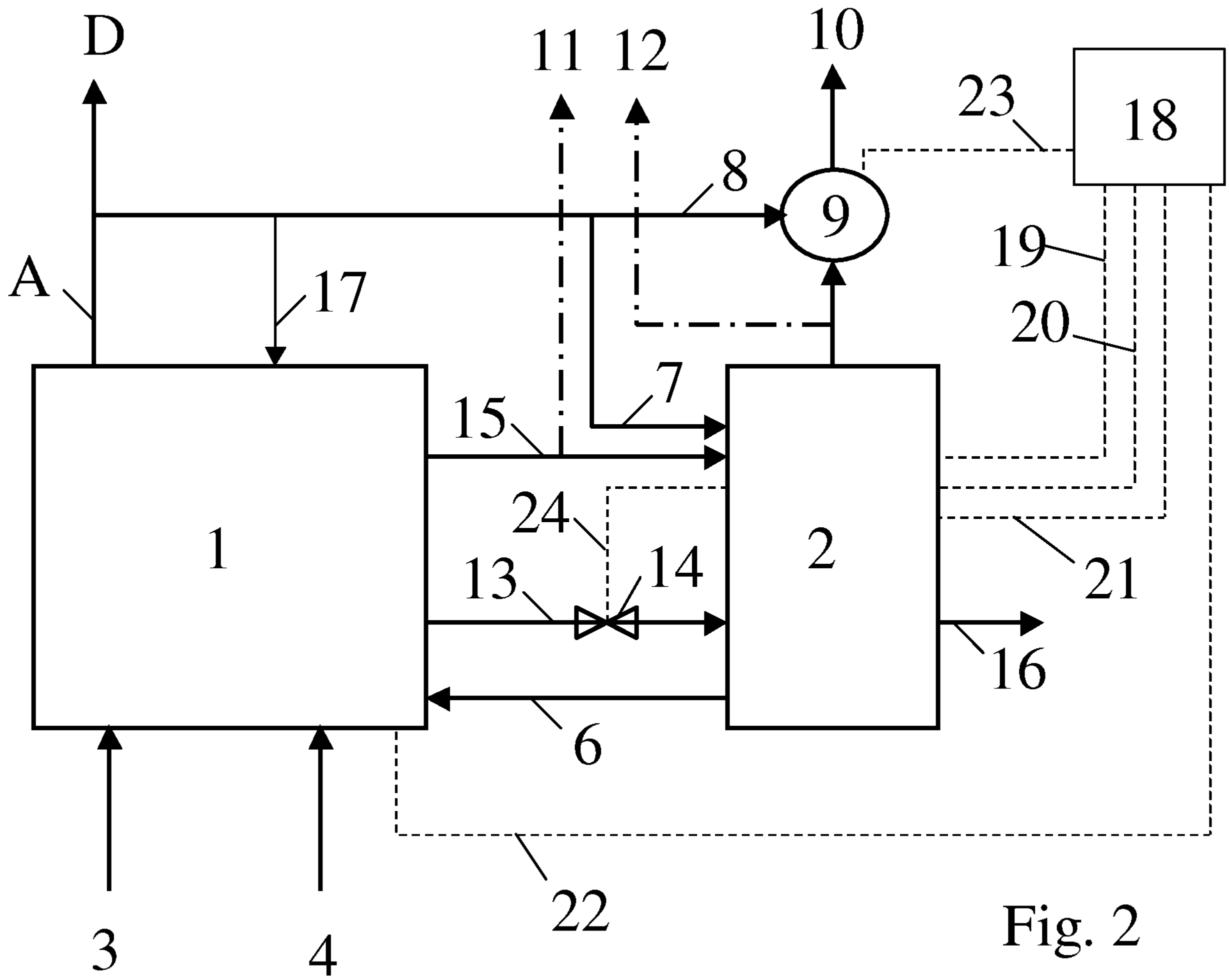

D
11
12
10
23
18
8
9
A
17
19
20
7
15
1
24
2
13
14
21
16
6
22
3
4

Fig. 2

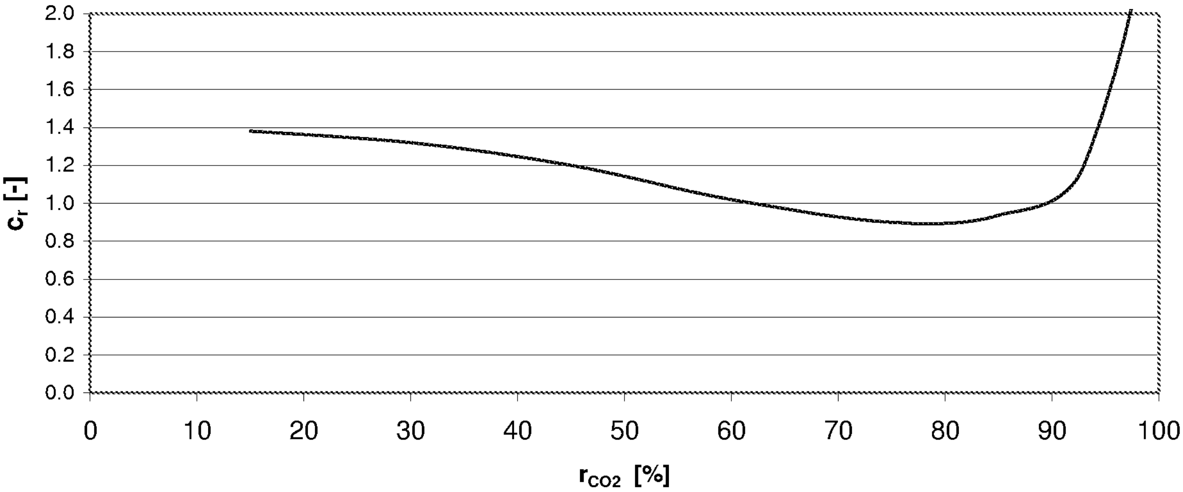
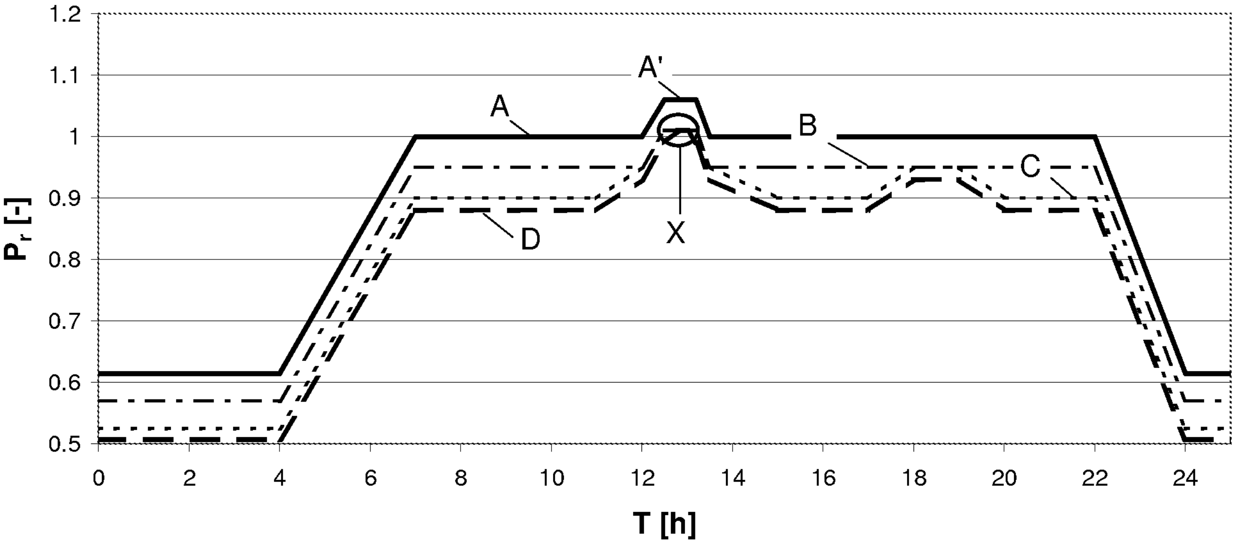

2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
c_r [-]
0
10
20
30
40
50
60
70
80
90
100
r_{CO2} [%]

Fig. 3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1.1
1
0.9
0.8
0.7
0.6
0.5
P_r [-]
A
A'
B
C
D
X
0
2
4
6
8
10
12
14
16
18
20
22
24
T [h]

Fig. 4