

METHOD AND DEVICE FOR PROVIDING HEAT AND CARBON DIOXIDE TO VEGETABLES AND/OR ALGAE USING POWER STATION FLUE GAS

FIELD OF THE INVENTION

[0001] The invention relates to recycling and utilization of exhaust gas from biomass power plant, and more particularly to a method and a device for supplying heat energy and carbon dioxide for vegetables and/or algae using exhaust gas from an electric power plant.

BACKGROUND OF THE INVENTION

[0002] As global coal and petroleum resource become scarce, different countries in the world has increased the investment in the bio-energy industry, and biomass-based power plants have been more and more common. Exhaust gas from the combustion of biomass contains a large amount of water vapor, 12-20% of carbon dioxide, and a small amount of carbon monoxide, sulfur dioxide, nitrogen oxides and dust. Meanwhile, the temperature of the exhaust gas is approximately between 110 and 140°C, so that the exhaust gas contains a large amount of heat energy. Calculation results indicate that during a normal operation of a 30 mW biomass boiler turbine, the exhaust gas discharged from the biomass boiler every hour carries approximately 6628500 kCal (equivalent to 7710 kW) of heat energy; however, this part of heat energy carried by the exhaust gas is wasted accompanying with the direct discharge of the exhaust gas. Furthermore, a large amount of carbon dioxide in the exhaust gas is continuously released into the atmosphere, which induces the global climate warming and the greenhouse effect.

[0003] On the other side, the continental climate characteristics are very obvious in China, especially the relatively long winter season, cold weather, and scarce precipitation. Data

show that the temperature of winter in China is 8-10°C lower than that of other regions of the same latitude in the world, winter climate lasts for 3-4 months in Yangtze River region, for 4-5 months in North China, and for exceeding a half year in NE and NW of China. To ensure the supply of vegetables in winter, vegetable greenhouses are very common in these regions. However, heating systems of most of the vegetable greenhouse use coal as the fuel the combustion of which is extensive and has low heat energy efficiency. The coal fuel combustion results in serious waste and environmental pollution, and gas poisoning accident often happens. Furthermore, as the heat supply is not sufficient, the vegetables in winter grow slowly, thereby resulting in high price of the vegetables.

[0004] Studies has shown that the vegetable greenhouses in China are mainly distributed in regions having a dense population and developed agriculture; while the biomass power plant mainly uses the combustion of the agricultural and forestry waste for power generation. Thus, the distributions of the vegetable greenhouse and the biomass power plant are basically the same. A typical method to solve problems of the vegetable production and the heat supply in winter includes introducing exhaust gas from the biomass power plant directly into the vegetable greenhouse to facilitate the growth of the vegetables by the exhaust heat and carbon dioxide. However, the exhaust gas contains a small amount of poisonous carbon monoxide, which is a problem for the researchers to be tackled.

SUMMARY OF THE INVENTION

[0005] In view of the above-described problems, it is one objective of the invention to provide a method and a device for supplying heat energy and carbon dioxide for vegetables and/or algae using exhaust gas from an electric power plant. The method and the device of the invention target at comprehensively utilizing the exhaust gas from a

coal-fired power plant or biomass boiler to decrease the energy waste and the environmental pollution resulting from the direct discharge of the exhaust gas, and providing heat energy and carbon dioxide to meet the required temperature and the appropriate concentration of carbon dioxide for the growth of the vegetables and/or algae, thereby facilitating the growth of the vegetables and/or the algae, shortening the growth cycle, improving the yield in each area unit, lowering the production cost, increasing the income of the company or the farmer, and solving the problem of short supply of the vegetables.

[0006] To achieve the above objective, in accordance with one embodiment of the invention, there is provided a method for supplying heat energy and carbon dioxide for vegetables and/or algae using exhaust gas from an electric power plant, the method comprising the following steps:

[0007] 1) introducing the exhaust gas from the electric power plant to a primary heat exchanger via an exhaust gas supply pipeline to conduct a first indirect heat exchange between the exhaust gas and air from a heat supply system of a vegetables greenhouse and/or a algae culturing house whereby providing heated air for the vegetables greenhouse and/or the algae culturing house;

[0008] 2) introducing part of the exhaust gas after the first indirect heat exchange in the first heat exchanger to a secondary heat exchanger via an exhaust gas transport pipeline to conduct a second indirect heat exchange between the exhaust gas and outdoor air whereby further reducing a temperature of the exhaust gas for facilitating adsorption of carbon dioxide;

[0009] 3) introducing the exhaust gas after the second indirect heat exchange in the second heat exchanger to a CO₂ pressure swing adsorption device, separating carbon dioxide from the exhaust gas and pumping carbon dioxide to a carbon dioxide storage tank for storage; and

[0010] 4) supplying carbon dioxide from the carbon dioxide storage tank to the vegetables greenhouse and/or a carbon-absorption tank of the algae culturing house during a growth period of vegetables and/or algae.

[0011] As an improvement of the invention, in step 2), the outdoor air is heated by the exhaust gas and is introduced to a tertiary heat exchanger for heat exchange with circulating water of a warm water supply system of the carbon-absorption tank to provide warm water for the carbon-absorption tank. Thus, the exhaust heat of the exhaust gas is fully utilized to provide an appropriate temperature of the water for the growth of the algae.

[0012] As an improvement of the invention, in step 1), a temperature of the exhaust gas from the electric power plant is between 110 and 140°C; a temperature of the exhaust gas after the first indirect heat exchange in the first heat exchanger is between 80 and 90°C; and a temperature of the heated air provided for the vegetable greenhouse and/or algae culturing house is between 40 and 50°C.

[0013] As an improvement of the invention, in step 2), a temperature of the exhaust gas after the second indirect heat exchange in the second heat exchanger is between 50 and 60°C; a temperature of the outdoor air heated by the exhaust gas is between 40 and 50°C; and a water temperature of the carbon-absorption tank is between 25 and 35°C.

[0014] As an improvement of the invention, in step 4), carbon dioxide is supplied once every day at sunny time. A concentration of carbon dioxide in the vegetable greenhouse is controlled at between 600 and 1200 ppm. The vegetable greenhouse is sealed for between 1.5 and 2.0 hours for supplying carbon dioxide, and then a ventilating opening thereof is opened for removal of humidity. Thus, an appropriate carbon dioxide concentration is provided for facilitating the growth of the vegetables so that the yield of the vegetables in each area unit is largely increased.

[0015] A device for supplying heat energy and carbon dioxide for vegetables and/or algae,

the device comprises: a draft fan, the exhaust gas supply pipeline connected to the draft fan, the primary heat exchanger, the exhaust gas transport pipeline connected to a chimney, the secondary heat exchanger, the CO₂ pressure swing adsorption device, and the carbon dioxide storage tank.

[0016] The primary heat exchanger employs a shell-and-tube heat exchanger comprising a gas inlet pipeline, a gas outlet pipeline, an air inlet pipeline, and an air outlet pipeline. The gas inlet pipeline is connected to the exhaust gas supply pipeline via a first pressure blower. The gas outlet pipeline is connected to the exhaust gas transport pipeline. The air inlet pipeline is connected to an air recycling pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house via a second pressure blower. The air outlet pipeline is connected to an air outlet pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house.

[0017] The secondary heat exchanger employs a heat pipe exchanger comprising a cold air input end, an exhaust gas input end, and an exhaust gas output end. The cold air input end communicates with the outdoor air via a circulating pump. The exhaust gas input end is connected to the exhaust gas transport pipeline via a compressor. The exhaust gas output end is connected to an input end of the CO₂ pressure swing adsorption device. An output end of the CO₂ pressure swing adsorption device is connected to the carbon dioxide storage tank via a vacuum pump. The carbon dioxide storage tank is connected to the vegetables greenhouse and/or the carbon-absorption tank of the algae culturing house via a CO₂ transport pipe and a control valve disposed thereon.

[0018] As an improvement of the invention, the device of the invention further comprises a tertiary heat exchanger. The tertiary heat exchanger employs a gas-liquid heat exchanger comprising an air inlet, an air outlet, a warm water output end, and a warm water return end. The air inlet is connected to a heated air output end of the heat pipe exchanger via an air transport pipeline, and the air outlet communicates with the air via

an exhaust pipeline. The warm water output end is connected to a water inlet of the carbon-absorption tank via a circulating water pump, and the warm water return end is connected to a water outlet of the carbon-absorption tank via a magnetic valve.

[0019] The heat energy carried by the exhaust gas is extracted by the indirect heat exchange between the exhaust gas and the air, and carbon dioxide carried by the exhaust gas is extracted using the CO₂ pressure swing adsorption device. Advantages of the invention are summarized as follows:

[0020] First, the indirect heat exchange is used for supplying heat for the vegetable greenhouse and/or the algae culturing house. Not only does the waste heat in the exhaust gas is fully utilized to decreased the operation cost of the heat supply system, but also the consumption of the coal fuel for supplying heat is effectively lowered thereby realizing the energy conservation. The indirect heat exchange is particularly applicable to the biomass power plant distributed close to the agriculture production area.

[0021] Second, the carbon dioxide carried by the exhaust gas is extracted and supplied to the vegetable greenhouse and/ or the carbon-absorption tank of the algae culturing house, so that a small amount of the poisonous component in the exhaust gas is prevented from polluting the vegetables and/ or the algae, the growth of the vegetables and/ or the algae is greatly facilitated, and the problem of the shortage of the winter vegetables is solved.

[0022] Finally, after the waste heat and the carbon dioxide in the exhaust gas are extracted by the vegetables and other biomass, the energy waste and the environmental pollution resulted from direct discharge of the exhaust gas is effectively prevented, and the greenhouse effect is alleviated. Besides, the biomass produced from the vegetable greenhouse and the algae culturing house is then used as the fuel of the power plant so that a beneficial cycle is formed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] The invention is described hereinbelow with reference to the accompanying drawings, in which:

[0024] FIG. 1 is a structure diagram of a device for supplying heat energy and carbon dioxide for vegetables and/or algae;

[0025] FIG. 2 is a structure diagram of a primary heat exchanger in FIG. 1;

[0026] FIG. 3 is a structure diagram of a tertiary heat exchanger in FIG. 1; and

[0027] FIG. 4 is a structure diagram of a CO₂ pressure swing adsorption device in FIG. 1.

DETAILED DESCRIPTION OF THE EMBODIMENTS

[0028] The invention is further described hereinbelow combined with the drawings.

[0029] As shown in FIGS. 1-4, a device for supplying heat energy and carbon dioxide for vegetables and/or algae comprises: first, a draft fan 3 and an exhaust gas supply pipeline 4 connected to the draft fan 3 for extracting the exhaust gas from the boiler of the biomass power plant; second, an exhaust gas transport pipeline 1 connected to a chimney 2 for discharging the superfluous exhaust gas after the heat exchange treatment; third, a primary heat exchanger 5, a secondary heat exchanger 12, and a tertiary heat exchanger 8 for achieving the indirect heat exchange between the exhaust gas with the clean air and the water for providing heat and warm water for the vegetable greenhouse 6 and the algae culturing house 9; and fourth, a CO₂ pressure swing adsorption device 14 and a carbon dioxide storage tank 16. The CO₂ pressure swing adsorption device 14 belongs to the prior art using a silica gel or an activated carbon as an adsorbent. Carbon dioxide is extracted by the CO₂ pressure swing adsorption device 14 by a pressure difference to be

replenished to a vegetable greenhouse **6** or a carbon-absorption tank **10** of an algae culturing house **9**.

[0030] The primary heat exchanger **5** employs a shell-and-tube heat exchanger **5.1** comprising a gas inlet pipeline **5.3**, a gas outlet pipeline **5.4**, an air inlet pipeline **5.6**, and an air outlet pipeline **5.7**. The gas inlet pipeline **5.3** is connected to the exhaust gas supply pipeline **4** via a first pressure blower **5.2**. The gas outlet pipeline **5.4** is connected to the exhaust gas transport pipeline **1**. The air inlet pipeline **5.6** is connected to an air recycling pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house via a second pressure blower **5.5**. The air outlet pipeline **5.7** is connected to an air outlet pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house. Thus, the air in the vegetable greenhouse and/or the algae culturing house absorbs heat energy from the exhaust gas by the shell-and-tube heat exchanger **5.1** for supplying heat energy to the vegetables or the algae.

[0031] The secondary heat exchanger **12** employs a heat pipe exchanger comprising a cold air input end, an exhaust gas input end, and an exhaust gas output end. The cold air input end communicates with the outdoor air via a circulating pump **13**. The exhaust gas input end is connected to a branch of the exhaust gas transport pipeline **1** via a compressor **11** for extracting one part of the exhaust gas after the treatment of the primary heat exchanger **5** and cooling the exhaust gas to an appropriate temperature for the CO₂ absorption. The exhaust gas output end is connected to an input end of the CO₂ pressure swing adsorption device **14**. An output end of the CO₂ pressure swing adsorption device **14** is connected to the carbon dioxide storage tank **16** via a vacuum pump **15**. The carbon dioxide storage tank **16** is connected to the vegetables greenhouse and/or the carbon-absorption tank **10** of the algae culturing house via a CO₂ transport pipe **7** and a control valve **19** disposed thereon for replenishing carbon dioxide to the vegetables or the algae. A CO₂ concentration detector **6.1** is arranged inside the vegetable greenhouse for automatically controlling an opening or close of the control valve **19**.

[0032] The tertiary heat exchanger **8** employs a common gas-liquid heat exchanger **8.1** comprising an air inlet, an air outlet, a warm water output end, and a warm water return end. The air inlet is connected to a heated air output end of the heat pipe exchanger via an air transport pipeline **17**, and the air outlet communicates with the air via an exhaust pipeline **18**. The warm water output end is connected to a water inlet of the carbon-absorption tank **10** via a circulating water pump **8.2**, and the warm water return end is connected to a water outlet of the carbon-absorption tank **10** via a magnetic valve **8.3**. Thus, a warm water circulating loop is formed to provide constant warm water to the algae in the carbon-absorption tank **10**. The carbon-absorption tank **10** is provided with a temperature sensor **8.4** and a water level sensor **8.5** for the automatic opening and closing of the magnetic valve **8.3**.

[0033] Workflow of the device for supplying heat energy and carbon dioxide for vegetables and/or algae is as follows:

[0034] 1) exhaust gas having a temperature of 110-140°C from a power plant was extracted by the draft fan **3** to the shell-and-tube heat exchanger **5.1** via the exhaust gas supply pipeline **4** to conduct a first indirect heat exchange with the air from the heat supply system of the vegetable greenhouse **6** and the algae culturing house **9**. The air was heated to a temperature of 40-50°C and was directly transported to the vegetable greenhouse **6** and the algae culturing house **9** for providing heat for the vegetables and the algae. The heat supply system was adjusted to control the vegetable green house at a temperature of 20-28°C in daytime and a temperature of 14-18°C at night to meet the requirement of fast growth of the vegetables.

[0035] 2) A temperature of the exhaust gas after the heat exchange by the shell-and-tube heat exchanger **5.1** was 80-90°C. One part of the exhaust gas was discharged from the chimney **2** through the exhaust gas transport pipeline **1**. The other part of the exhaust gas was transported to the heat pipe exchanger **12** under the action of the compressor **11**

through one branch of the exhaust gas transport pipeline **1** for conducting a second heat exchange with the outdoor air from the circulating pump **13**. The outdoor air was heated to a temperature of 40-50°C.

[0036] 3) The exhaust gas after the treatment by the heat pipe exchanger **12** had a temperature of 50-60°C and was transported to the CO₂ pressure swing adsorption device **14**. The CO₂ pressure swing adsorption device **14** used the silica gel or the activated carbon as an absorbent. Carbon dioxide was extracted under the intermittent variable pressure and was transported to the carbon dioxide storage tank **16** for storage by the vacuum pump **15**.

[0037] 4) The outdoor air after being heated by the heat pipe exchanger **12** was transported through the air transport pipeline **17** to a gas-liquid indirect heat exchanger **8.1** for heat exchange with the circulating water of the warm water supply system of the carbon-absorption tank **10**. The water temperature of the carbon-absorption tank **10** was maintained at 25-35°C for facilitating the growth of the algae. The temperature sensor **8.4** and the water level sensor **8.5** were used to monitor the water temperature and the water level in the carbon-absorption tank **10**. When the water temperature reached 35°C and the water level reached a preset level, the magnetic valve **8.3** arranged on the circulating water pipeline of the carbon-absorption tank **10** was closed, and the gas-liquid indirect heat exchanger **8.1** was stopped from operation. When the water temperature was lowered to 25°C, the magnetic valve **8.3** opened and the gas-liquid indirect heat exchanger **8.1** started to work again.

[0038] 5) During the growth cycle of the vegetables and the algae, carbon dioxide in the CO₂ storage tank was replenished to the vegetable greenhouse **6** and the carbon-absorption tank **10** of the algae culturing house **9** according to the demand. For the vegetable greenhouse **6**, carbon dioxide was replenished once in sunny period every day. The CO₂ concentration detector **6.1** was used to real time monitor the CO₂

concentration in the vegetable greenhouse **6**, and the CO₂ concentration therein was controlled within a range of 800-1000 ppm by automatic opening or closing of the control valve **19**. After the vegetable greenhouse was closed for 1.5-2.0 h, ventilating opening was opened to remove the humidity. From the cultivation of a small batch of vegetables such as cucumber and celery, it was known that by utilizing the heat energy and carbon dioxide from the exhaust gas of the biomass power plant, the yield per unit area of the cucumber and the celery were improved by 26.6% and 39.9%, respectively.

CLAIMS

1. A method for supplying heat energy and carbon dioxide for vegetables and/or algae using exhaust gas from an electric power plant, the method comprising the following steps:
 - 1) introducing the exhaust gas from the electric power plant to a primary heat exchanger via an exhaust gas supply pipeline to conduct a first indirect heat exchange between the exhaust gas and air from a heat supply system of a vegetables greenhouse and/or a algae culturing house whereby providing heated air for the vegetables greenhouse and/or the algae culturing house;
 - 2) introducing part of the exhaust gas after the first indirect heat exchange in the first heat exchanger to a secondary heat exchanger via an exhaust gas transport pipeline to conduct a second indirect heat exchange between the exhaust gas and outdoor air whereby further reducing a temperature of the exhaust gas for facilitating adsorption of carbon dioxide;
 - 3) introducing the exhaust gas after the second indirect heat exchange in the second heat exchanger to a CO₂ pressure swing adsorption device, separating carbon dioxide from the exhaust gas and pumping carbon dioxide to a carbon dioxide storage tank for storage; and
 - 4) supplying carbon dioxide from the carbon dioxide storage tank to the vegetables greenhouse and/or a carbon-absorption tank of the algae culturing house during a growth period of vegetables and/or algae.

2. The method of claim 1, **characterized in that** in step 2), the outdoor air is heated by the exhaust gas and is introduced to a tertiary heat exchanger for heat exchange with circulating water of a warm water supply system of the carbon-absorption tank to provide warm water for the carbon-absorption tank.
3. The method of claim 1 or 2, **characterized in that** in step 1), a temperature of the exhaust gas from the electric power plant is between 110 and 140°C; a temperature of the exhaust gas after the first indirect heat exchange in the first heat exchanger is between 80 and 90°C; and a temperature of the heated air provided for the vegetable greenhouse and/or algae culturing house is between 40 and 50°C.
4. The method of claim 2, **characterized in that** in step 2), a temperature of the exhaust gas after the second indirect heat exchange in the second heat exchanger is between 50 and 60°C; a temperature of the outdoor air heated by the exhaust gas is between 40 and 50°C; and a water temperature of the carbon-absorption tank is between 25 and 35°C.
5. The method of claim 1 or 2, **characterized in that** in step 4), carbon dioxide is supplied once every day at sunny time; a concentration of carbon dioxide in the vegetable greenhouse is controlled at between 600 and 1200 ppm; the vegetable greenhouse is sealed for between 1.5 and 2.0 hours for supplying carbon dioxide, and then a ventilating opening thereof is opened for removal of humidity.
6. A device for supplying heat energy and carbon dioxide for vegetables and/or algae using the method of claim 1, the device comprising a draft fan (3), the exhaust gas

supply pipeline (4) connected to the draft fan (3), the primary heat exchanger (5), the exhaust gas transport pipeline (1) connected to a chimney (2), the secondary heat exchanger (12), the CO₂ pressure swing adsorption device (14), and the carbon dioxide storage tank (16), **characterized in that**

the primary heat exchanger (5) employs a shell-and-tube heat exchanger (5.1) comprising a gas inlet pipeline (5.3), a gas outlet pipeline (5.4), an air inlet pipeline (5.6), and an air outlet pipeline (5.7); the gas inlet pipeline (5.3) is connected to the exhaust gas supply pipeline (4) via a first pressure blower (5.2), the gas outlet pipeline (5.4) is connected to the exhaust gas transport pipeline (1), the air inlet pipeline (5.6) is connected to an air recycling pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house via a second pressure blower (5.5), and the air outlet pipeline (5.7) is connected to an air outlet pipeline of the heat supply system of the vegetable greenhouse and/or the algae culturing house;

the secondary heat exchanger (12) employs a heat pipe exchanger comprising a cold air input end, an exhaust gas input end, and an exhaust gas output end, the cold air input end communicates with the outdoor air via a circulating pump (13), the exhaust gas input end is connected to the exhaust gas transport pipeline (1) via a compressor (11), the exhaust gas output end is connected to an input end of the CO₂ pressure swing adsorption device (14), an output end of the CO₂ pressure swing adsorption device (14) is connected to the carbon dioxide storage tank (16) via a vacuum pump (15), and the carbon dioxide storage tank (16) is connected to the vegetables greenhouse and/or the carbon-absorption tank (10) of the algae culturing house via a CO₂ transport pipe (7) and a control valve (19) disposed thereon.

7. The device of claim 6, further comprising a tertiary heat exchanger (8), **characterized in that** the tertiary heat exchanger (8) employs a gas-liquid heat

exchanger comprising an air inlet, an air outlet, a warm water output end, and a warm water return end; the air inlet is connected to a heated air output end of the heat pipe exchanger via an air transport pipeline (17), the air outlet communicates with the air via an exhaust pipeline (18), the warm water output end is connected to a water inlet of the carbon-absorption tank (10) via a circulating water pump (8.2), and the warm water return end is connected to a water outlet of the carbon-absorption tank (10) via a magnetic valve (8.3).

8. The device of claim 7, **characterized in that** the carbon-absorption tank (10) is provided with a temperature sensor (8.4) and a water level sensor (8.5).