

Heat Exchange System

The present invention relates to a heat exchange system and in particular to a heat exchange system comprising a Microbial Electrolysis Cell (MEC) for the formation of methane or at least one other synthesis product through methanogenic microorganism.

Methane has the highest energy density per carbon atom among fossil fuels and its potential for energy conversion is far greater than any other natural gas obtained directly by combustion in presence of oxygen or using fuel cells to produce electricity. Methane's potential for energy generation has become increasingly relevant in the global market.

- 5 Methane hence constitutes a sustainable and renewable energy source and already today increasingly substitutes coal and other fossil fuels.

- A methanation process can be based on microbial electrochemical technology (MET) devoted to bio-electromethanation. This process is realized in a microbial electrolysis cell (MEC), which is a unique system capable of converting chemical energy into electrical energy (and vice-versa)
- 10 while employing microbes as catalysts. The system achieves the combination of electrolysis and methane production in one single reactor, the MEC. Within the MEC, the methanogenic microorganisms reside e.g. at the cathode ("bio-cathode"). The reactor may comprise a single compartment, or the cathodic compartment, or chamber, may be separated from the anodic compartment, or chamber, e.g. via a semipermeable membrane. In some embodiments of the
- 15 state of the art, methanogenesis by the methanogenic microorganisms (methanogens, archaea) takes place directly in the (bio)cathode compartment, while the electron flow required for the cathodic reduction of classical CO₂ to methane is formed in the anode compartment by water oxidation.

- In more detail, within this process, electrical power is used to enhance the potential difference
- 20 between the anode and the cathode of MEC to enable the bio-electromethanation reaction.

The production of hydrogen and/or methane and/or other synthesis product is still, nonetheless, a rather energy costly process in which high amounts of energy are required. Unfortunately, in the MEC of the prior art energy inefficiencies is a recurring problem.

A MEC comprises various elements with different properties and requirements. Some elements of the MEC can be considered heat generating elements which therefore may require active cooling to maintain a stable temperature and prevent overheating. Other elements instead can be considered heat requiring elements, i.e. elements which require heat to operate.

- 5 During its operation, the heat requiring elements of MECs of the prior art have a heating demand which is usually covered by stand-by heating utilities as for example a gas boiler. Symmetrically, the cooling requiring elements have a cooling demand, which in the prior art are covered by stand-by cooling utilities as for example an air-fin cooler.

- The operation of these stand-by heating or cooling utilities represents a parasitic energy
10 consumption of the MEC, as these external elements require substantial amount of energy to operate. This has a negative environmental impact due to higher energy requirements and associated energy waste and therefore also cause additional costs.

Additionally, the heat requiring element needs to be heated prior to start-up, which involves the use of an additional heater only for a short period of time with respect to the entire operation.

- 15 This represents an additional parasitic energy consumption and slows the start-up process.

Thus, although methane is an energy source which in respect to fossil fuel is more environmentally friendly, its production still comprises inefficiencies which have a negative impact on the environment.

- It is therefore an aim of the current invention to provide a system which solves, at least partially,
20 the problem of the prior art such as involuntary energy loss and higher impact on the environment. It is further an aim of the current invention to provide a method for minimising energy inefficiencies.

- The invention is defined as in current claim 1, further embodiments are specified in the dependent claims. The method is defined in current claim 8, further embodiments are specified
25 in the subsequent and dependent claims.

A heat exchange system according to the current invention, comprises a Microbial Electrolysis Cell (MEC) with an anode side comprising an anode electrode and an anolyte, and a cathode side comprising a cathode electrode and a catholyte.

5 The heat exchange system of the current invention further comprises an anolyte reservoir fluidly connected with the anode side of the MEC and a catholyte reservoir fluidly connected with the cathode side of the MEC. The anolyte reservoir and the anode side of the MEC are fluidly connected by an anolyte circuit in which anolyte is circulated and the catholyte reservoir and the cathode side of the MEC are fluidly connected by a catholyte circuit in which a catholyte is circulated.

10 The heat exchange system further comprises a heat storage system comprising a heat buffer tank to store at least a first portion of heat generated in the cathode side of the MEC. The heat exchange system is characterized in that the first portion of heat generated in the cathode side of the MEC comprises heat extracted from the cathode electrode and/or heat extracted from the catholyte of the cathode side of the MEC.

15 The heat storage system further comprises a heat managing system configured to selectively feed a second portion of stored heat from the heat buffer tank to the anolyte reservoir and/or to the catholyte reservoir.

In the context of the present application, steps and features are regularly disclosed concerning the production of methane without always explicitly adding that they are regularly also
20 concerning the production of the at least one synthesis product different from methane. This application is hence not limited to the production of methane and other synthesis product produced by methanogenic microorganism, like isoprene, geraniol, vitamin A, cholesterol, carotenoids, natural rubber or similar, are also incorporated in this invention.

The advantages of the here proposed heat exchange system apply hence both for the production
25 of methane and/or of other synthesis products by methanogenic microorganism.

In the following application, the anolyte and catholyte reservoirs are being defined as being comprised in the heat exchange system. The reservoirs however can indeed be considered both being part of the MEC and/or being part of the more general heat exchange system.

In particular, the MEC of the current invention comprises an anode side comprising an anode electrode and an anolyte. The anode side of the MEC can be considered as being a first heat requiring element. The term “heat requiring” can be understood as “requiring a certain amount of heat to operate, or at least properly fulfil its function, for longer periods of time”.

- 5 Similarly, the MEC also comprises a cathode side comprising a cathode electrode and a catholyte. The cathode side of the MEC can be considered as a first cooling requiring element. The term “cooling requiring” can be understood as “needing a certain amount of cooling to operate, or to at least properly fulfil its function for a longer period of time”.

- 10 In particular, the term “cooling” does also encompass the displacement of heat from the element itself. By deporting heat from the cooling requiring element, the temperature in or of the element is decreased and the element is cooled down. Indeed “cooling requiring” has not to be interpreted exclusively in the strict sense e.g. that the element requires an active cooling input such as a cooling fluid or similar in order to be cooled down.

- 15 Because heat is an energy, when discussing a circulation of heat, it is implicitly meant that a medium carrying the energy is circulated, creating a “heat flow” or a “hot stream”.

- The anolyte and catholyte reservoirs, are reservoirs such as fluid tanks, capable of storing a fluid such as the anolyte and catholyte. The anolyte and catholyte reservoir are in particular fluidly connected with the anode side and the cathode side of the MEC, respectively. The fluid connection is achieved e.g. through conduits in which the anolyte and the catholyte, respectively
20 circulate.

- The heat storage system further comprises a buffer tank in which heat is stored. The storage and circulation of heat (e.g. in form of hot streams) occurs through a fluid which is contained in the heat buffer tank and/or through a fluid being circulated in and out of the buffer tank in the heat exchange system. The fluid can for example be water or any fluid with a high heat capacity. Other
25 means for heat transportation are however also encompassed. The buffer tank could also comprise solid material in addition or instead of a fluid, the solid material having heat detaining characteristics (e.g. ceramics).

The buffer tank can for example be sized to provide 12 hours of heat supply to the heat requiring

elements before an external heat source is required. In absence of other heat demands, active cooling, for example with an air-fin cooler, might be required to evacuate the excess heat. The buffer tank can for example be sized for accumulating 5 to 7 hours. In particular, the difference between supply and accumulation capacity is specific to each design of the MEC of the current invention.

The design for the supply capacity and the size of the buffer tank can be based on the expected duty cycle of the MEC and in particular, on how long the idle period and hence the lack of heat input to the heat requiring element will last.

The heat exchange system is being characterized in that the first portion of heat generated in the cathode side of the MEC comprises heat extracted from the cathode electrode and/or heat extracted from the catholyte. The transfer of heat being generated in the cathode side of the MEC can for example occur through a single conduit in which both the heat extracted from the cathode electrode and/or the heat extracted from the catholyte is being fed to the buffer tank. Alternatively, also two separate conduits, one for the heat extracted from the cathode electrode and one for the heat extracted from the catholyte are envisaged – together they define the first portion of heat, according to the current invention.

The extraction of heat from the cathode electrode or from the catholyte or from both has proven to be extremely advantageous: it guarantees high quantity of heat to be stored in the buffer tank, it represents an effective and energy-saving way of cooling the heat generating element therefore preventing overheating and simultaneously provides a more precise regulation of the temperature in the cathode side of the MEC.

The heat exchange system is further characterized in that it comprises a heat managing system. The heat managing system among other things, controls and regulates the circulation of heat (e.g. as hot streams) deriving both from inside and outside of the heat exchange system through the entire heat exchange system. It particularly regulates the circulation of heat from and into the MEC and/or buffer tank. The heat managing system can be an integral part of the buffer tank. The heat managing system can also be an independent single system not part of the buffer tank.

The heat managing system of the current invention further controls and manages the heat transfer from the cathode side of the MEC to the heat buffer tank as a mean to cool down the

cathode. The heat managing system hence regulates the amount of heat being extracted from the cathode electrode and/or from the catholyte dependent on many factors such as the temperature requirement in the cathode side of the MEC and/or the temperature in the buffer tank.

- 5 With this further possibility of fine tuning the extraction of heat from the cathode side of the MEC the regulation of the temperature in the cathode side is enhanced. As such also the whole operation of the MEC is enhanced, while simultaneously optimizing heat transfer and minimizing energy inefficiency.

- 10 The heat managing system also controls and manages the input of heat into the anolyte and/or catholyte reservoir, by selectively feeding a second portion of the stored heat from the heat buffer tank to the anolyte reservoir and/or to the catholyte reservoir. The exchange of heat occurs through incorporated heat exchanger in the respective reservoir; it is however not limited to that precise way.

- 15 The heat transferred from the heat buffer tank to the anolyte and/or catholyte reservoir can be used to regulate the temperature of the anolyte and/or catholyte of the anolyte and/or catholyte reservoir.

The heat managing system therefore also regulates and controls the temperature in the anode and/or cathode side of the MEC by regulating the temperature of the anolyte and/or catholyte in the reservoirs.

- 20 Indeed, according to one embodiment, the heat managing system is configured to measure the temperature of the anolyte and/or catholyte. Once measured or once the heat managing system has been provided with data regarding the various temperature, it can regulate the extraction of heat from the cathode electrode and/or the catholyte as well as the heat input at the anolyte and/or catholyte reservoir.

- 25 Consequently, a substantially ideal temperature for operation is being maintained in the anode and/or cathode side of the MEC through the heat managing system and the extraction of heat from the cathode side of the MEC.

The system further minimises use of parasitic energy as the cooling requiring element, e.g. the cathode side of the MEC, does not require an additional apparatus for cooling (because the generated heat is extracted and transferred to the buffer tank). Additionally, no additional utility is required to heat up the anode side of the MEC, hence further minimizing parasitic energy consumption.

After an idle period of the MEC, the stored heat in the buffer tank can be used to heat up the system and re-start operation without requiring additional heating utilities – therefore minimizing energy consumption overall.

The heat exchange system of the current invention therefore also minimises production costs of methane or other synthesis products through minimization of energy consumption by storage of excessive heat.

Consequently, the heat exchange system of the current invention demonstrates benefits for the environment through heat recycling, making a green technology such as a methanation process and/or synthesis process through electrolysis even more environmentally friendly. This results in an improved carbon footprint for example by avoiding unwanted flue gaseous emissions to the environment.

In particular, according to a further embodiment of the current invention, the second portion of heat, hence the portion of hot stream leaving the buffer tank and being fed to the anolyte reservoir, corresponds substantially to a quantity of heat required to achieve a desired temperature at the first heat requiring element (e.g. the anode side of the MEC).

The term “substantially” here, considers the loss of heat during feeding of the anode side, particularly the loss during transportation of the hot stream through conduits. Consequently, slightly more heat than the heat required by the heat requiring element might be released by the buffer tank through the heat managing system, to cope with this loss.

Furthermore, a heat flow through the membrane dividing the cathode side from the anode side of the MEC can occur, meaning that slightly less heat is required to be transferred from the buffer tank to the anolyte and consequently to the anode side of the MEC.

The heat requirement at the anode side of the MEC is based on the required reductive power to reduce CO₂ to methane. Considering an anode flow range of 0.5-2 l/min and the required reductive power to reduce a Nm³ CO₂ to methane, between 0.1 kW and 0.6 kW and in particular around 0.4 kW would for example compensate the endothermic anodic reaction. The amount of
5 heat required at the anode side of the MEC can therefore vary between 1% and 5%, in particular between 1% and 3% of the total heat generated at the cathode side of the MEC.

It is therefore extremely advantageous that this required heat by the anode side of the MEC can be supplied through the extraction of heat from the cathode side and through the (re)circulation of heat from the buffer tank to the anolyte as described above. This approach does not require
10 the use of external heating elements which would cause further parasitic energy waste.

In addition, no excessive heat is being fed to the anode side of the MEC resulting in an efficient energy usage and related cost saving through the minimisation of wasted heat. Saving more heat results also in higher amount of stored heat in the buffer tank, which can be used for the heat exchange system and/or can be exported for other purposes.

15 According to a further embodiment of the current invention the heat exchange system comprises a first heat exchanger through which the catholyte of the cathode side of the MEC is being circulated, wherein the first heat exchanger is fluidly connected to the buffer tank to circulate the removed heat from the catholyte to the buffer tank.

As mentioned earlier the cathode side of the MEC can be considered as a heat generating
20 element (being simultaneously the cooling requiring element). Cooling of cathode side of the MEC can advantageously be achieved by extracting heat from the cathode electrode and/or by extracting heat from the catholyte.

Extracting heat from the cathode electrode can for example be achieved by providing the electrode with one or more perforations and/or one or more channels through which fluid (e.g. a
25 first fluid) passes and extracts the generated heat of the electrode. The fluid could also be a cooling fluid hence also acting as a cooling element for the electrode. The fluid can then for example be sent to the first heat exchanger, or to further heat exchanger or even to the buffer tank directly.

Extracting heat from the catholyte can be achieved by using of a first heat exchanger through which the catholyte circulates. In this regards it is indifferent at what stage of the circulation of the catholyte the heat is being extracted by the first heat exchanger from the catholyte.

According to one embodiment, for example, the catholyte is passed through the first heat exchanger when circulating towards the catholyte reservoir. The catholyte hence reaches the catholyte reservoir with a lower temperature than when leaving the cathode side of the MEC.

According to another embodiment, the catholyte is extracted from the catholyte circuit connecting the cathode side of the MEC with the catholyte reservoir; the heat is subsequently extracted by the first heat exchanger and fed to the buffer tank. Afterwards the catholyte is fed back to the catholyte circuit or to the catholyte reservoir or to the cathode side of the MEC.

The embodiments are particularly advantageous as the total heat produced at the cathode side of the MEC which can be removed from the catholyte using the heat exchanger is at least 14.5 kW/ Nm³ methane at 1 Volt overpotential and at least 20.6 kW/ Nm³ methane at 2 Volt overpotential.

According to a further embodiment of the heat exchange system the anolyte reservoir and/or the catholyte reservoir both can act as de-gassing elements for the product gasses of the MEC, wherein the heat exchange system further comprises a second heat exchanger and means for passing the output product gasses through the second heat exchanger to extract heat from the product gasses.

In operation, the MEC produces gasses which circulate with the catholyte and the anolyte to the anolyte and/or catholyte reservoir, respectively. In the reservoirs the de-gassing process occurs and the product gases of the MEC are extracted. Once extracted, these gasses can for example be sent to outside utilities and/or to a gas grid network. However, the output gases carry with them heat captured from the MEC – this heat can be extracted by circulating the output product gasses from the reservoirs through a second heat exchanger. The output product gasses of the MEC can for example be oxygen (O₂) and/or methane (CH₄) and/or carbon dioxide (CO₂), and/or combination thereof.

The degassing process takes place in the headspace of both reservoirs. The temperature of the

gas therefore can have a similar temperature to that of the anolyte and/or catholyte at the reservoir. The temperature can range from between 20°C and 90°C, between 30°C and 80°C, particularly between 40°C and 70°C, in particular between 50°C and 65°C, in particular from between 55°C and 64°C, and especially around 63°C.

- 5 The heat extracted by the second heat exchanger, if not sent to the buffer tank, could directly be sent to private heating grids and/or to different heat requiring elements.

According to a further embodiment the second heat exchanger is fluidly connected to the buffer tank to circulate the removed heat from the output product gasses to the buffer tank.

- 10 According to a further embodiment at least two heat exchangers are used to extract the heat from the output gasses. One heat exchanger is used for the gas extracted from the anolyte reservoir, e.g. oxygen. The other heat exchanger is used for the gas extracted from the catholyte reservoir, e.g. methane.

- 15 In the heat exchange system of the above embodiment, it becomes possible to extract and recycle heat deriving from the output gasses leaving the reservoirs, from the cathode electrode and from the catholyte circulating in the system.

This gives flexibility in the storage and extraction of heat in the heat exchange system. The heat managing system permits the selective choice from where to extract heat and if to store it in the heat storage system or to reuse it for any other heat requiring element.

- 20 According to a further embodiment the heat exchange system further comprises an input gas being fed to the catholyte, a third heat exchanger and means for passing the input gas through the third heat exchanger prior to being fed to the catholyte.

- 25 The input gas can comprise carbon dioxide (CO₂) which is fed to the catholyte and assists in the methanation process. The input gas can have a relatively low temperature, which if introduced directly to the catholyte would cause a temperature drop. This temperature drop would need to be balanced by an increased input of heat through the buffer tank to the catholyte reservoir. This causes excessive energy consumption and unnecessary energy waste.

According to the above embodiment, the input gas is being circulated through a third heat

exchanger where it is heated up. The means for passing the gas through the heat exchanger can range from common conduits passing through the third heat exchanger to more complex pump systems.

In this way, the input gas being fed to the catholyte already has a temperature which doesn't
5 bring the system in the catholyte side of the MEC out of balance.

In particular, it is therefore possible to feed the input gas at any location into the catholyte, meaning that in some embodiment the input gas is being fed directly to the catholyte in the cathode side of the MEC, while in other embodiments for example it might be fed directly to the catholyte reservoir. Also, other locations and means for feeding the input gas to the catholyte are
10 envisaged.

In particular, according to a further embodiment of the current heat exchange system, the third heat exchanger is connected to the buffer tank and acts as a heat feeding device to the input gas. As mentioned earlier, it might be necessary or at least advantageous to heat up the input gas before it is fed to the catholyte. In this sense the third heat exchanger might be connected to the
15 buffer tank and work in the opposite way as the first and second heat exchanger, namely, not to extract heat, but to introduce heat to the input gas.

According to a further embodiment the heat exchange system comprises a first return cold stream circulating to the buffer tank. In particular a cold stream can enter the bottom portion of the buffer tank as the tank is stratified with hot fluid at the top and bottom portion. The
20 circulation of cooling (e.g. in the form of cold streams) occurs through a fluid which for example can be water or any fluid with a high heat/cooling capacity.

According to some embodiments the fluid arriving from the third heat exchanger is used as a first return cold stream circulating to the buffer tank. The fluid passing through the third heat exchanger, as mentioned earlier, transmits heat to the input gas. Therefore, the temperature
25 itself is lower when leaving the third heat exchanger than when re-entering the buffer tank acting as a cold stream.

According to a further embodiment of the current invention the buffer tank is fluidly connected to auxiliary elements requiring heat in or outside of the heat exchange system, e.g. close by

utilities, e.g., anaerobic digester, or a private heating grid or a more widespread heating network of a town. The list of auxiliary elements is however not limited and other heat requiring elements can be comprised in the heat exchange system which might be connected to the buffer tank and might receive a portion of hot stream for regulation of its temperature, such as a biogas
5 production facility and/or a power-to-gas plant.

Furthermore, several other elements which generate heat, and which are usually present in an MEC and/or in a process plant can be connected to the heat storage system and can contribute in heating and circulating heat through the system.

Accordingly, also solar, or geothermal sources can be used, which have the advantages of
10 limiting further the necessity of external “parasitic” source, as renewable sources cannot be considered parasitic. The buffer tank can also act as a renewable heat buffer, thereby having further positive environmental effects and minimising further parasitic energy required by the MEC. The heat stored in the buffer tank can be used during start-up of the heat exchange system, where preheating is required.

15 The heat managing system of the invention regulates all or just some of these heat exchanges as well as the circulation of heat and/or of the cold streams from and to the buffer tank. In this way a centralised managing system can control the whole heat exchange system.

Furthermore, to achieve an electrolytic reaction in the MEC it is necessary to feed the system with an additional voltage from an outside source. The outside voltage source can be generated by
20 any environmentally friendly energy source such as wind power and/or solar power, but is not limited to these.

The central arrangement of a buffer tank in which heat produced in a MEC is stored and recycled can further be used with multiple MECs connected with one or more buffer tanks. In such a system a heat managing system would manage the heat circulation, input and output of the
25 several MECs as described above for a single MEC.

According to the current invention also a method for recycling heat within a heat exchange system is envisaged. According to the embodiment of the invention the heat exchange system comprises a MEC comprising an anode side comprising an anode electrode and an anolyte and a

cathode side comprising a cathode electrode and a catholyte. The method comprises the steps of:

- a. Generating at least a first portion of heat in the cathode side of the MEC;
- b. Storing the first portion of heat in a buffer tank of a heat storage system;
- 5 c. Providing circuits of anolyte between an anolyte reservoir and the anode side of the MEC and providing a circuit of catholyte between a catholyte reservoir and the cathode side of the MEC;
- d. Circulating a second portion of heat from the buffer tank to the catholyte reservoir and/or to the anolyte reservoir to regulate the temperature of the catholyte and/or the anolyte,
10 respectively.

The method is characterized in that the step of storing the first portion of heat in the buffer tank comprises the steps of extracting heat from the cathode electrode and/or from the catholyte and circulating the extracted heat e.g. in the form of hot streams, to the buffer tank.

- The method is further characterized in that the circulation of the first and/or second portion of
15 heat is regulated by a heat managing system of the heat storage system.

According to an embodiment of the current invention step a. mentioned above (i.e. generating at least a first portion of heat in a cathode side of the MEC) comprises generating exothermic heat through the bio-methanation reaction and/or generating electrochemical heat by electrical inefficiencies.

- 20 An exothermic reaction is a reaction that releases energy usually in the form of heat. In the current invention it is the production of methane and/or of a further synthesis product that causes an exothermic reaction whereby heat is generated. This heat is extracted and fed to the buffer tank as explained above.

- During operation of the MEC, the cathode side of the MEC generates heat. The cathode side of the
25 MEC can be defined as being a cooling requirement element. Hence in order to minimize the possibility of overheating, minimize the amount of wasted heat and minimize the number of apparatuses required for cooling, heat is extracted from the cathode side of the MEC.

According to the embodiment of the current method at least a first portion of the heat generated in the cathode side of the MEC is fed to the buffer tank to be stored. Advantageously, according to the method of the current invention feeding the buffer tank with the first portion of heat comprises extracting heat from the cathode electrode of the cathode side of the MEC and/or from the catholyte.

According to this method both these heat sources independently or in combination can be extracted and stored in the buffer tank for later use. The recovery of heat minimizes heat inefficiencies and has a positive impact on the environment while simultaneously minimizing costs.

Extracting heat from the cathode electrode can for example be achieved by providing the electrode with one or more perforations and/or one or more channels through which a fluid (e.g. a first fluid) passes and extracts the generated heat of the electrode. The fluid could also be a cooling fluid hence also acting as a cooling element for the electrode. The fluid can then for example be sent to the first heat exchanger, or to further heat exchanger or even to the buffer tank directly.

Extraction of heat from the catholyte can occur, according to a further embodiment of the method, through circulating the catholyte through a first heat exchanger. The first heat exchanger can then be connected to the buffer tank to feed the extracted heat to the buffer tank to be stored.

The first heat exchanger to extract heat from the catholyte can be arranged at any location along the catholyte circuit, such as in the cathode side of the MEC, between the cathode side of the MEC and the catholyte reservoir or even in the catholyte reservoir. The method, however, is not limited to any of these three locations, and can also encompass the possibility of diverging the catholyte from its circuit to extract the heat and possibly feeding the cooled catholyte to the reservoir along another circuit.

The method according to embodiments of the current invention demonstrates good energy recovering and recycling capabilities (e.g. in the form of heat recycling). Indeed, the heat generated in the MEC is stored in the buffer tank and can be recycled to heat up the anolyte and/or the catholyte in the anolyte reservoir and/or in the catholyte reservoir, respectively. This

is achieved through step c. of the method in which an anolyte circuit between the anolyte reservoir and the anode side of the MEC and a catholyte circuit between the catholyte reservoir and the cathode side of the MEC is provided, and step d. in which a second portion of the heat stored in the buffer tank is selectively circulated to the anolyte and/or catholyte reservoir.

- 5 By circulating the second portion of heat into the first and/or catholyte reservoir the temperature of the anolyte and/or catholyte can be regulated. This is particularly advantageous as it further permits a substantially constant temperature regulation of the anode side and cathode side of the MEC through regulation of the temperature of the anolyte and catholyte.

- 10 According to the method the heat managing system regulates among others, the intake of heat in the buffer tank as well as the output of heat to the reservoirs. Further to that according to further embodiment of the method the heat managing device can assess different parameters inside and/or outside of the MEC in order to regulate the amount of heat transferred.

- 15 Indeed, according to one further embodiment, the heat managing system measures the temperature of the anolyte and catholyte, calculates the required heat input to arrive at a desired temperature in the anode part and cathode side of the MEC and regulates the circulation of heat to the anolyte and/or catholyte reservoir. The heat managing system further regulates the extraction of heat from the catholyte at any given location of the heat exchange system.

- A further embodiment of the method comprises the step of degassing the anolyte and/or catholyte reservoir from the product gasses of the MEC and circulating the product gasses
20 through a second heat exchanger to extract the heat from the product gasses.

The output product gasses of the MEC can for example be oxygen (O₂) and/or methane (CH₄) and/or carbon dioxide (CO₂), and/or combination thereof. The product gasses are however not limited by these alternatives.

- These product gasses carry with them substantial amount of heat which used to be lost.
25 According to the above embodiment, the product gasses can be degassed in the anolyte and/or catholyte reservoir and circulated through a second heat exchanger such as to extract the heat the gasses are carrying.

Recycling heat from the product gasses is a further way in which the current heat exchange

system minimises energy inefficiencies.

According to a further embodiment the extracted heat by the second heat exchanger is circulated to the buffer tank.

Therefore, according to the above embodiment, it becomes possible to extract heat from the cathode electrode, from the catholyte and/or from the product gasses. Simultaneously the extracted heat can be stored in the buffer tank and, for example, be used to heat up the catholyte in the catholyte reservoir, but especially the anolyte in the anolyte reservoir.

According to a further embodiment of the method, the heat managing system regulates the extraction and circulation of heat from the product gasses.

10 The method, according to a further embodiment, comprises also the steps of circulating an input gas through a third heat exchanger to heat up the input gas, and injecting the heated input gas into the catholyte.

In some operation situation the MEC might require an input gas such as carbon dioxide. This input gas usually has a very low temperature, or at least a temperature which is lower than the catholyte in which the gas is injected. The injection of the cool gas to the catholyte would cool down directly the catholyte. It would then be necessary to heat up the catholyte again through the store head in the buffer tank. Directly heating the gas injected to the catholyte is an alternative and efficient way of counteracting the cooling effect of the input gas.

According to this embodiment, the gas is firstly circulated through a heat exchanger to collect heat and afterwards injected to the catholyte. The third heat exchanger, can, for example, be connected to the buffer tank, such that heat from the buffer tank is passed through the third heat exchanger and transferred to the input gas. The cooled stream of the heat exchanger can then be reinjected to the bottom portion of the buffer tank as the tank is stratified with hot water at the top and bottom portion.

25 According to a further embodiment of the current invention at least a third portion of heat stored in the buffer tank is circulated to at least one auxiliary utility outside of the heat exchange system. The heat generated in the cathode side of the MEC and in particular the heat stored in the buffer tank can additionally be used for outside utilities such as other MECs and/or biogas

plants and/or power-to-gas plant as well as private heat networks. In this way the generated heat during the process of the MEC is recycled, energy is saved, and costs are reduced.

In order to achieve substantially optimal temperature ranges for the electrolyses process and the methanation process the current method can comprise keeping the temperature of the cathode and the anode at a range of 20°C to 90°C, in particular 30°C to 80°C, particularly between 40°C and 70°C, in particular between 50°C and 65°C, in particular from between 55°C and 64°C, and especially around 63°C. As mentioned earlier the temperature may be measured, calculated and/or regulated by the heat managing system.

Clearly the advantage described with respect to the heat exchange system also apply to the current method and vice versa. Any of the embodiment of the heat exchange system can be used with the respective method for recycling heat.

According to a further embodiment the use of the current system in any of its embodiments and/or of the current method in any of its embodiment to produce a final product comprising methane and/or any other synthesis product produced by methanogenic microorganism, like Isoprene, geraniol, Vitamin A, cholesterol, carotenoids, natural rubber or similar, is provided.

Exemplary Data

The heat exchange system as well as the method for recycling heat according to the current invention have proven to be particularly advantageous with regards to its environmental impact.

In the following two cases several assumptions are made, such as the energy input deriving from 100% renewable energy with a Global Warming Potential (GWP) of 0 for the entire system and no material impacts (e.g. given by the length or material of the conduits).

Case 1

Supposing a heat production per Nm³ of methane of 14.5kW, a MEC Voltage of 2.5V and an energy efficiency of 30 g CH₄/KWh, following results are given:

- Emission intensity of ca. 0.00788 kg CO₂e/Nm³ CH₄, which corresponds to ca. 0.000198 kg CO₂e/MJ;

- Heat credit of -1.6671 kg CO₂e/Nm³ CH₄ displacement assuming all heat is used for district heating.

Case 2

Supposing a heat production per Nm³ of methane of 9.5kW, a MEC Voltage of 2V and an energy
5 efficiency of 30 g CH₄/KWh, following results are given:

- Emission intensity of ca. 0.007993 kg CO₂e/Nm³ CH₄, which corresponds to ca. 0.000201 kg CO₂e/MJ;

- Heat credit of -1.0922 kg CO₂e/Nm³ CH₄ displacement assuming all heat is used for district heating.

10 As can be seen from the above cases, the emission intensity according to the current invention are extremely low. Of course, the actual emission intensities will depend also on material impact and other factors. However, the above examples already show how the inventive heat exchange system and method for recycling heat further has a positive impact on the global warming potential (GWP) of the technology. This is self-evident by comparing to the current GWP values
15 for district heating (0.027-0.13 kg CO₂/MJ F Neirotti · 2020) to the benefit of displacement.

Further features of the invention will be apparent from the following detailed description in conjunction with the drawing and the claims.

Fig. 1 shows a schematic view of a first exemplary embodiment of the invention;

Fig.2 shows a further development of the embodiment of invention according to Fig. 1;

20 **Fig. 3** shows a schematic view of an exemplary degassing system in a heat exchange system according to the current invention;

Fig. 4 shows a schematic view of an embodiment of the heat exchange system according to Fig.3;

Fig. 5 shows an exemplary embodiment of a buffer tank in a stack MEC environment;

Fig. 6 is a flow chart of an exemplary embodiment of a method according to the invention.

In the figures, identical reference signs correspond to same elements. In the figures, solid lines represent a fluid communication, dashed lines represent heat migration and dotted lines represent gas migration of the product gasses.

As shown in **Figure 1**, an exemplary embodiment of the heat exchange system comprises MEC 10 comprising an anode side 12 and a cathode side 14. The anode side comprises an anode electrode and an anolyte (not shown). The cathode side comprises a cathode electrode and a catholyte (not shown).

The heat exchange system further comprises a buffer tank 16 with a heat managing system 18. In this example the buffer tank 16 is configured to store heat in form of a hot stream 11 entering the buffer tank 16 through a conduit. The heat managing system 18 is configured to regulate the intake and output of heat from the buffer tank 16.

In the figures the heat managing system 18 appears to be an integral part of the buffer tank 16 or at least being partially connected to it. This however does not necessarily have to be and the heat managing system may for example be an independent element of the heat exchange system.

The heat exchange system of **Fig. 1** further comprises an anolyte reservoir 22 and a catholyte reservoir 24. The anolyte reservoir 22 and the catholyte reservoir 24 are fluidly connected to the anode side 12 and cathode side 14 of the MEC 10, by an anolyte circuit 26 and a catholyte circuit 28, respectively. The anolyte circuit 26 comprises anolyte F1 and the catholyte circuit 28 comprises catholyte F2.

As can be understood from these figures, the MEC 10 and in particular the cathode side 14 of the MEC 10 generates heat which is circulated (dashed line 11) to the buffer tank 16 where it is stored for further use. The cathode side 14 is a heat generating, cooling requiring, element of the MEC 10. The anode side 12 instead is a heat requiring element as it requires heat for proper operation.

The first portion of heat which is collected from the cathode side 14 of the MEC 10 and circulated to the buffer tank 16 comprises heat from the cathode electrode and/or heat from the catholyte F2.

The heat managing system 18, regulates both the intake of heat 11 in the buffer tank 16 as well as the output of heat (e.g. in the form of hot streams of fluid 19a, 19b) from the buffer tank 16 to the anolyte reservoir 22 and/or catholyte reservoir 24 through conduits, respectively. This migration of heat regulates the temperature of the anolyte F1 and/or the catholyte F2 and consequently of
5 the anode side 12 and the cathode side 14 of the MEC 10.

Both the anolyte circuit 26 of the anolyte F1 and the catholyte circuit 28 of the catholyte F2 are not closed circuits between the anolyte reservoir 22 and the anode 12 and the catholyte reservoir 24 and the cathode 14. Both addition and extraction of anolyte F1 and/or catholyte F2 can occur within the heat exchange system.

10 Alternatively, if for example excess heat is stored in the buffer tank 16, which is not required to regulate the temperature of the anolyte F1 and/or of the catholyte F2, the heat managing system may control and regulate an output of heat 17 to auxiliary elements being part or being near to the heat exchange system and/or to outside entities such as a private heat network.

Figure 2 shows a further development of the invention according to Fig. 1 In this embodiment a
15 first heat exchanger 42 is positioned on the catholyte circuit 28. The cathode side of the MEC 14 generates heat and therefore warms the catholyte F2. The catholyte F2 is then fed to the catholyte reservoir 24. The first heat exchanger 42 collects heat from the catholyte F2 and circulates it to the buffer tank 16. In this way the temperature of the catholyte F2 being circulated to the catholyte reservoir 24 is reduced and the excessive heat is stored in the buffer tank 16 for a
20 later reuse.

The location of the first heat exchange 42 system as shown in this figure is however not limiting. In other embodiments, the first heat exchanger 42 might be located within the cathode side 14 of the MEC 10 or as mentioned earlier in another circuit from which catholyte F2 is being extracted.

Furthermore, the figure does not show how the first heat exchanger 42 is connected to the buffer
25 tank, this is however done by any known mean, such as a fluid circulation from the buffer tank to the heat exchanger 42 and back.

In **Figure 3** only the output gasses are shown (dotted lines), while the rest of the heat exchange system as described in Figures 1 and 2 is only conceptually shown through the end segments of the respective lines/arrows and reference numbers described in Figures 1 and 2.

As can be seen from figure 3, the anolyte reservoir 22 and the catholyte reservoir 24 act as de-gassing element and have gas outputs conduits 41a, 41b. The MEC in this exemplary embodiment produces, among other gasses, methane (CH_4) 41b and parallelly oxygen (O_2) 41a which is degassed in the anolyte and/or catholyte reservoir 22, 24 respectively. Furthermore, in this exemplary embodiment the catholyte F2 is injected with carbon dioxide CO_2 (arrow 45)

The generated output gasses generally have a relative high temperature due to the reaction occurring in the MEC 10. In this embodiment the heat transported within the product gasses in the conduits 41a, 41b is extracted and circulated to the buffer tank 16 by a second heat exchanger 44 via a conduit 47.

In this figure the second heat exchanger 44 is shown as a single element, however respective heat exchangers for the respective gas output can be used and are envisaged. Furthermore, the figure does not show how the second heat exchanger 44 is connected to the buffer tank, this is however done by any known mean, such as a fluid circulation from the buffer tank to the heat exchanger 44 and back.

Furthermore, the figure shows gas streams from the anode side 12 of the MEC to the anolyte reservoir 22 and from the cathode side 14 of the MEC to the catholyte reservoir 24. This is a schematical view of the migration of the gasses and has not to be understood that a specific gas conduit connects the respective parts. During operation of the MEC the gasses are usually included in the anolyte F1 and/or catholyte F2 circulating to the reservoirs and are subsequently degassed in the reservoirs.

Figure 3 further shows an input gas 45 passing through a third heat exchanger 46 connected to the buffer tank 16. Hot stream 48a is sent from the buffer tank 16 to the third heat exchanger 46. The input gas 45 collects the heat from the third heat exchanger 46 and is injected into the catholyte F2.

The resulting colder stream 48b is then fed back to the buffer tank 16 to be heated up again.

Figure 4 shows a combination of the embodiment of figure 3 with the embodiment of figure 1. As can be seen the first heat exchanger 42 is absent in this example, however it could be implemented as described with reference to figure 2. As can be seen the gas outputs and inputs are intertwined with the anolyte F1 / catholyte F2 and the heat transportation network, such as to create the heat exchange system according to one embodiment of the current invention.

The heat managing system 18 controls and regulates both the heat transfer as well as the gas input and output and heat extraction and its heat transfer.

Figure 5 shows a schematic overview of a stack buffer tank 16a, 16b, 16c, 16d, regulated by a single heat managing system 18. The stack buffer tank may be conceptually or physically be divided in 4 sub buffer tanks 16a, 16b, 16c, 16d, each one possibly storing heat deriving from a different MEC (not shown). The heat managing system 18 controls the intake and output of heat from the different MECs to the buffer tank(s).

The buffer tank 16 may also just be one big buffer tank 16. As such all the heat deriving from the different MECs would be stored together.

Figure 6 shows a flow diagram of an exemplary method for recycling heat according to one embodiment of the current invention.

In operation 110 a first portion of heat is generated in the cathode side of the MEC by the cathode. This occurs during normal operation of the MEC and its methanation process. In particular the cathode is the cooling requiring elements of the system as it generates heat and should be kept at a lower temperature.

The heat generated in the cathode is stored in the buffer tank in operation 120. Operation 120 comprises extracting heat from the cathode electrode and/or from the catholyte and circulating the extracted heat in the form of hot streams to the buffer tank. Additionally, the heat generated at the cathode side of the MEC might be collected through extraction of heat from the catholyte and/or from extraction of heat from the product gasses as described with reference to the system in the above figures.

Further step of the method of the current embodiment is to provide the catholyte and the anolyte reservoirs 130 and respective circuits where the anolyte and the catholyte are respectively being circulated between the anolyte reservoir and the anode side of the MEC and between the catholyte reservoir and the cathode side of the MEC.

- 5 In Operation 140, the heat managing system assess the quantity of heat required in the anolyte reservoir and/or in the catholyte reservoir. This is done to achieve a desired temperature of the anolyte and/or the catholyte and hence a desired temperature in the anode side and/or the cathode side of the ME, respectively.

- 10 In operation 150 the required heat, stored in the buffer tank, is circulated either to the anolyte reservoir or to the catholyte reservoir or to both the reservoirs in order to heat up the anolyte and/or catholyte. By doing this the temperature in the anode and in the cathode side of the MEC is regulated.

Reference numerals list

10 MEC	24 catholyte reservoir
11 hot stream from cathode side of MEC to buffer tank	26 anolyte circuit
12 anode side of MEC	28 catholyte circuit
14 cathode side of MEC	41a, 41b output gas
16 buffer tank	42 first heat exchanger
16a, 16b, 16c, 16d buffer tanks	44 second heat exchanger
17 output stream to auxiliary elements	45 gas input to catholyte
18 heat managing system	46 third heat exchanger
19a, 19b Hot streams/conduits for heat from buffer tank to anolyte/catholyte reservoir	47 stream for heat from product gasses
22 anolyte reservoir	48a, 48b streams from buffer tank through third heat exchanger
	F1 anolyte
	F2 catholyte

Claims

1. Heat exchange system comprising:
 - a Microbial Electrolysis Cell (MEC) (10) with an anode side (12) comprising an anode electrode and an anolyte (F1), and a cathode side (14) comprising a cathode electrode and a catholyte (F2);
 - an anolyte reservoir (22) fluidly connected with the anode side (12) of the MEC (10) and a catholyte reservoir (24) fluidly connected with the cathode side (14) of the MEC (10);
 - wherein the anolyte reservoir (22) and the anode side (12) of the MEC (10) are fluidly connected by a anolyte circuit (26) in which anolyte (F1) is circulated and
 - wherein the catholyte reservoir (24) and the cathode side (14) of the MEC (10) are fluidly connected by a catholyte circuit (28) in which catholyte (F2) is circulated;
 - the heat exchange system further comprising
 - a heat storage system comprising a heat buffer tank (16) to store at least a first portion of heat (11) generated by the cathode side of the MEC (10),
 - characterized in that**
 - the first portion of heat (11) generated by the cathode side (14) of the MEC (10) comprises heat extracted from the cathode electrode and/or heat extracted from the catholyte (F2) of the cathode side (14) of the MEC (10); and
 - the heat storage system further comprising a heat managing system (18) configured to selectively feed a second portion of stored heat (19a, 19b) from the heat buffer tank (16) to the anolyte reservoir (22) and/or to the catholyte reservoir (24).
2. Heat exchange system according to claim 1, wherein the heat exchange system comprises a first heat exchanger (42) through which the catholyte (F2) of the cathode side (14) of the MEC (10) is being circulated and

wherein the first heat exchanger (42) is fluidly connected to the buffer tank (16) to circulate the removed heat from the catholyte to the buffer tank (16).

3. Heat exchange system according to claims 1 or 2, wherein the cathode electrode comprises one or more perforations and/or one or more channels and wherein a fluid is configured to pass through the one or more perforations and/or the one or more channels to extract heat from the cathode electrode.
4. Heat exchange system according to claim 3, wherein the fluid is configured to be circulated through the first heat exchanger (42) and/or through a further heat exchanger and/or directly to the buffer tank (16).
5. Heat exchange system according to any of the claims 1 to 4, wherein the anolyte reservoir (22) and the catholyte reservoir (24) act as de-gassing elements for the product gasses of the MEC (10),

the heat exchange system further comprising a second heat exchanger (44) and means for passing the output product gasses (41a, 41b) through the second heat exchanger (44) to extract heat from the product gasses.
6. Heat exchange system according to claim 5 wherein the second heat exchanger (44) is fluidly connected to buffer tank (16) to circulate the removed heat from the product gasses (41a, 41b) to the buffer tank (16).
7. Heat exchange system according to any of the above claims, further comprising an input gas (45) being fed to the catholyte (F2), a third heat exchanger (46) and means for passing the input gas (45) through the third heat exchanger (46) prior to being fed to the catholyte (F2).
8. Heat exchange system according to any of the above claims wherein the buffer tank (16) is fluidly connected (17) to auxiliary elements requiring heat.
9. Heat exchange system according to any of the above claims comprising on or more MECs connected with one or more buffer tanks (16a, 16b, 16c, 16d).
10. A method for recycling heat within a heat exchange system comprising a MEC (10)

comprising an anode side (12) comprising an anolyte (F1) and a cathode side (14) comprising a cathode electrode and a catholyte (F2), the method comprising the steps of:

- a. Generating at least a first portion of heat (11) in a cathode side (14) of the MEC (10);
- b. Storing the first portion of heat (11) in a buffer tank (16) of a heat storage system
- 5 c. Providing circuits of anolyte (F1) between an anolyte reservoir (22) and the anode side (12) of the MEC (10) and providing a circuit of catholyte (F2) between a catholyte reservoir (24) and the cathode side (14) of the MEC (10);
- d. Circulating a second portion of heat (19a, 19b) from the buffer tank (16) to the catholyte reservoir (24) and/or to the anolyte reservoir (22) to regulate the
- 10 temperature of the catholyte (F2) and/or the anolyte (F1), respectively;

the method characterized in that

the step of storing the first portion of heat (11) in the buffer tank (16) comprises the steps of extracting heat from the cathode electrode and/or from the catholyte (F2) and circulating the extracted heat to the buffer tank (16), and in that

- 15 the circulation of the first (11) and/or second portion (19a, 19b) of heat is regulated by a heat managing system (18).

11. A method according to claim 10 wherein the step of extracting heat from the catholyte (F2) comprises circulating the catholyte (F2) through a first heat exchanger (42).

- 20 12. A method according to any of claims 10 to 11 wherein the step of extracting heat from the cathode electrode comprises the step of circulating a fluid through one or more perforations and/or one or more channels of the cathode electrode and

circulating the fluid through a first heat exchanger (42) and/or to the buffer tank and/or through a further heat exchanger.

- 25 13. The method according to any of claims 10 to 12 further comprising the step of degassing the anolyte and/or catholyte reservoir (22, 24) from the product gasses of the MEC (10) and

circulating the product gasses through a second heat exchanger (44) to extract the heat from the product gasses.

14. The method according to claim 13 wherein the extracted heat by the second heat exchanger (44) is circulated to the buffer tank (16).

5 15. The method according to any of claims 10 to 14 further comprising the step of:

Circulating an input gas (45) through a third heat exchanger (46) to heat up the input gas (45), and

Injecting the heated input gas (45) into the catholyte (F2).

10 16. A method according to any of the claims 10 to 15, comprising the step of circulating a portion of the stored heat from the buffer tank to at least one auxiliary utility requiring heat.

17. Use of the heat exchange system according to one of the claims 1 to 9 or according to the method according to the claims 10 to 16 for the production of a final product comprising methane and/or other synthesis products produced by methanogenic microorganism, like Isoprene, geraniol, Vitamin A, cholesterol, carotenoids, natural rubber or similar.