

Method of operating an internal combustion engine of a
watercraft

DESCRIPTION

The invention relates to the utilisation of methanol, in particular produced in a globally CO₂ neutral manner, as a fuel for an internal combustion engine of a watercraft. The invention also relates to a method for operating an internal combustion engine of a watercraft, and to a watercraft with a sustainable drive system.

Mobility, especially of goods, is one of the most important prerequisites for economic success, employment, and prosperity. At the same time, however, mobility also means a heavy environmental burden due to transport systems, and to the continuous increase in global transport volumes over the past decades. The efficiency of combustion engines has indeed improved significantly and they have become cleaner and quieter. However, due to the increased transport volumes, large quantities of greenhouse gases and air pollutants continue to be produced and released into the atmosphere. With the increase in transport volumes, the energy consumption of transport in Germany, for example, has more than tripled since 1960. Currently, transport is responsible for about one fifth of the greenhouse gas emissions in Germany. What applies to environmental and climate pollution in Germany also applies to the global climate situation, which suffers significantly from the burning of fossil fuels in shipping. What applies to environmental and climate pollution in Germany also applies to the global climate situation, which suffers significantly from the combustion of fossil fuels in shipping. This not only applies to commercial shipping, but also to recreational shipping to a considerable extent.

In order to counteract this negative development and limit

climate damage, the Climate Protection Plan 2050 adopted in Germany, for example, aims to reduce annual greenhouse gas emissions in the transport sector from the current level of around 160 million tonnes of CO₂ equivalents to between 95 and 98 million tonnes of CO₂ equivalents in 2030. The European Commission is also pursuing the goal of decarbonising the European mobility system by the year 2050, that is to say, making it greenhouse gas neutral. Success depends on whether the measures taken to achieve these goals are supported by broad sections of society, and on whether these measures are economical. The central goal is to ensure that the mobility needs of broad sections of the population today are met in the future in a manner that is as environmentally compatible as possible. This means that a successful mobility solution must not only be technically feasible and target-oriented, but must also be measured against the costs of current mobility solutions.

The utilisation of synthetically produced fuels is an important component in the development of new mobility concepts. Here methanol plays an important role as a fuel. Methanol is produced by synthesising hydrogen and carbon dioxide, which are obtained regeneratively, that is to say, in a greenhouse gas-neutral manner. For this purpose, a method is described in WO 2018/112654 A1, for example, in which hydrogen is produced by electrolysis, and carbon dioxide is obtained by direct separation out from the ambient air; these are utilised to produce methanol. However, the method of known art is not suitable for providing an energy source in sufficient quantity with the necessary economic efficiency to reduce climate pollution to a noticeable extent, and which at the same time meets current mobility needs.

The invention is based on the object of providing a possible means for the operation of watercraft in a climate-friendly manner, without a significant reduction of their payload.

Furthermore, it is the object of the invention to specify a climate-friendly operating method for watercraft, together with a watercraft with a climate-friendly drive system.

In accordance with the invention, this object is achieved by an operating method in accordance with Claim 1, a utilisation in accordance with Claim 5, and a watercraft in accordance with Claim 8.

Thus, the invention is based on the concept of specifying a utilisation of methanol as a fuel for an internal combustion engine, in particular a power generator, of a watercraft, in particular a hybrid-electric-powered watercraft, wherein the methanol is produced in a process in which

- in an electrolysis unit for the production of hydrogen, water is split into hydrogen and oxygen,
- a carbon dioxide sorption unit extracts carbon dioxide from the ambient air,
- the hydrogen and the carbon dioxide are fed to a methanol synthesis unit for the production of methanol, and are synthesised therein to methanol, and
- a photovoltaic unit absorbs solar energy and converts it into electrical energy.

The electrolysis unit, the carbon dioxide sorption unit, and the methanol synthesis unit, are thereby operated by the electrical energy generated in the photovoltaic unit.

By the utilisation of methanol produced by the process steps described above, a watercraft can be operated in a climate-friendly manner, in particular in a climate-neutral manner. In this respect, this technology offers the potential for achieving climate-neutral recreational mobility and climate-

neutral goods transport. The methanol, which is preferably produced in regions with high annual solar radiation in a CO₂-neutral manner, for example in Saudi Arabia, Oman, Australia, or other regions that have continuously high solar radiation, is easy to transport and store. Methanol is therefore particularly suitable as an energy source that can be utilised worldwide.

Furthermore, methanol has a sufficient energy density such that it can logically be utilised for shipping. Refuelling is also much faster than the charging of an accumulator, so that such a drive concept can be expected to be more widely accepted, especially in commercial shipping. This is especially true for the operation of low tonnage ferries or excursion boats.

In a preferred form of embodiment, it is envisaged that the water is first desalinated in a seawater desalination unit and then fed to the electrolysis unit, wherein the seawater desalination unit is operated mainly, in particular completely, by the electrical energy generated in the photovoltaic unit.

The photovoltaic unit can have a power, in particular a peak power, of at least 1.0 gigawatts, in particular at least 1.3 gigawatts, in particular at least 1.5 gigawatts, for the conversion of solar energy into electricity. The seawater desalination unit for the production of desalinated water preferably has an intake capacity of at least 900,000 tonnes of seawater per year. For the production of hydrogen, the electrolysis unit can be connected to the seawater desalination unit for the supply of water, in particular desalinated water, through at least one pipeline. The carbon dioxide sorption unit for the sorption of carbon dioxide from ambient air can have an extraction capacity of at least 400,000 tons of carbon dioxide per year, in particular at least 600,000 tons of carbon dioxide per year, from ambient

air. For the production of methanol the methanol synthesis unit can be connected to the electrolysis unit for the supply of hydrogen through at least one pipeline, and to the carbon dioxide sorption unit for the supply of carbon dioxide through at least one pipeline.

The seawater desalination unit, the electrolysis unit, the carbon dioxide sorption unit, and the methanol synthesis unit, can each be connected to the photovoltaic unit for purposes of power supply, and arranged in an area of the plant contiguous with the photovoltaic unit.

It is particularly preferred if the methanol is produced in a region with high solar irradiation, in particular a solar irradiation of more than 2,000 kWh/m²a, in particular more than 2,300 kWh/m²a, in particular more than 2,500 kWh/m²a. For this purpose, the photovoltaic unit can be customised to receive at least 1,500 kWh/m²a, in particular at least 2,000 kWh/m²a, in particular at least 2,300 kWh/m²a, in particular at least 2,500 kWh/m²a, in particular at least 2,700 kWh/m²a of solar energy.

The methanol synthesis unit can have a delivery capacity of at least 300,000 tonnes, in particular at least 450,000 tonnes, of regeneratively-produced methanol per year. A delivery capacity of 450,000 tonnes of regeneratively-produced methanol per year is particularly preferred.

The process-relevant units of the system can each be connected to the photovoltaic unit for purposes of power supply, and arranged, together with the photovoltaic unit, in a contiguous plant area. This means that the individual units are arranged in spatial proximity to each other and are consolidated in a unitary plant. It is not necessary for the plant area to be enclosed. The individual units can, for example, be separated from each other by supply roads that run through the plant. This ensures that the transport of

material flows and the power supply between the units takes place with the lowest possible losses.

In addition, this ensures that the plant as a whole is constructed in such a manner that it can be positioned in an optimal manner for the location, and operated in an autonomous manner. The particular advantage of the combination of the seawater desalination unit and the photovoltaic unit is that the plant can be set up in geographical regions, such as in the Middle East or Africa, which have both high solar irradiation and access to seawater, so that, on the one hand, the supply of energy to the plant by the photovoltaic unit and, on the other hand, the provision of sufficiently large quantities of water for the electrolysis unit, is made possible in an economical manner.

By means of the power supply to the electrolysis unit, which is carried out exclusively by the photovoltaic unit, the plant produces hydrogen in a regenerative manner. The carbon dioxide required for methanol production can be extracted from the ambient air of the plant by the carbon dioxide sorption unit. By the combination of the two units in the plant, methanol production takes place in a regenerative manner without the generation of carbon dioxide. Instead, by the removal of the carbon dioxide from the ambient air, the carbon dioxide concentration in the atmosphere is reduced. The plant is thus suitable to be a part of a climate-neutral energy system that forms a global carbon dioxide cycle, with regeneratively-produced methanol as the energy source. This means that the carbon dioxide extracted from the ambient air does not have to be disposed of, or dumped, as is usually the case, for example in the storage of known art of carbon dioxide in deep rock strata, although this is not ruled out as an additional measure, for example. The carbon dioxide sorbed from the ambient air is a valuable substance that is utilised in the plant to produce a synthetic fuel, namely

methanol, and can thus be fed into a carbon dioxide cycle.

The economic efficiency of the measures taken, which is necessary for the implementation of the aforementioned climate goals, is made possible by the plant. Compared to the production and utilisation of hydrogen for fuel cells, the conversion losses do indeed increase as a result of the additional process steps required for the synthesis of methanol. However, these are offset by much greater economic advantages with regard to the global infrastructure costs that are incurred in the combustion of methanol, compared to those incurred in purely electrical drives or fuel cell technology. The costs for expensive charging stations or for the technically complex storage of hydrogen do not apply to the combustion of regeneratively-produced methanol. The storage and transport of methanol require no special measures, and are comparable to the handling of conventional fuels. Another advantage of regeneratively-produced methanol, compared to hydrogen or batteries as energy sources, is that the energy density of methanol with 4.35 kWh/litre is much higher than that of high-pressure hydrogen (800 bar) with 1.25 kWh/litre, liquid hydrogen with 2.36 kWh/litre, and batteries with 0.5 kWh/litre.

A comparison of current energy prices, which is intended to give an approximate indication of the energy costs of a plant for the regenerative production of methanol, shows that the photovoltaic unit envisaged as part of the plant is an important component not only for producing synthetic fuel in a regenerative manner, but also for producing it so economically that the fuel can prevail in the competitive battle with other energy sources. The energy prices for wind energy (2.39 EURct/kWh) and hydropower energy (1.71 EURct/kWh) are currently (2020) already far below the energy prices for fossil fuels and, of course, nuclear energy. However, the energy price for electricity production by means of photovoltaics is even lower, at 1.14 EURct/kWh for

electricity produced in regions with high and long solar irradiation, such as the Middle East or Africa. Photovoltaic plants with an installed capacity of 2 gigawatts, for example, already exist there and are able to produce electricity at the aforementioned price.

In this respect, the plant can be designed to be installed in regions in which large areas cannot be utilised for agriculture because they are deserts or steppes, so that sufficiently large areas are available for a correspondingly large photovoltaic unit. Preferably, the power, in particular the peak power, of the photovoltaic unit is at least 1.0 gigawatts, in particular at least 1.3 gigawatts, in particular at least 1.5 gigawatts. The seawater desalination unit for producing desalinated water is designed for an intake capacity of at least 900,000 tonnes of seawater per year. The carbon dioxide sorption unit is preferably designed for an extraction capacity of at least 400,000 tonnes of carbon dioxide per year, in particular at least 600,000 tonnes of carbon dioxide per year, from the ambient air. The seawater desalination unit and the carbon dioxide sorption unit are thus matched in terms of performance to the methanol synthesis unit, which has a delivery capacity of at least 300,000 tonnes, in particular of at least 450,000 tonnes, of regeneratively-produced methanol per year. The electricity required for the power supply to the aforementioned process units, including the electrolysis unit, is provided by the photovoltaic unit, which is customised to receive at least 1,500 kWh/m²a, in particular at least 2,000 kWh/m²a, in particular at least 2,300 kWh/m²a, in particular at least 2,500 kWh/m²a, in particular at least 2,700 kWh/m²a of solar energy. The unit kWh/m²a means kilowatt hours per square metre and per year.

The plant can form the basic unit for a larger plant complex with a plurality of plants that are designed in accordance with the plant described above. This allows the production

of methanol in larger quantities to be scaled up so that, with a corresponding number of plants, a large energy demand, in particular the entire energy demand of the world's population, can be covered.

The invention is further based on the concept of providing a method of operating an internal combustion engine of a watercraft, in particular on inland waters, in which:

- in an electrolysis unit for the production of hydrogen, water is split into hydrogen and oxygen,
- a carbon dioxide sorption unit extracts carbon dioxide from the ambient air,
- the hydrogen and the carbon dioxide are fed to a methanol synthesis unit for the production of methanol, and are synthesised therein to methanol,
- a photovoltaic unit absorbs solar energy and converts it into electrical energy.

In accordance with the invention, the electrolysis unit, the carbon dioxide sorption unit, and the methanol synthesis unit, are operated by the electrical energy generated in the photovoltaic unit, wherein the methanol produced is transported by means of a distributor system to at least one tank of the watercraft, and is fed from the tank to the internal combustion engine as required, and therein is combusted to generate mechanical energy.

In a preferred form of embodiment, the internal combustion engine is part of a power unit of a hybrid-electrically driven watercraft, wherein in the power unit the mechanical energy of the internal combustion engine is converted into electrical drive energy for the propulsion of the watercraft.

The distributor system is preferably customised to distribute the regeneratively-produced methanol from the delivery device to end users for the combustion of the regeneratively-produced methanol. The distributor system is designed, for example, in the form of a logistics network in which the methanol is transported in tankers to filling stations, preferably in ports. At the filling stations, the tank, in particular a methanol fuel tank, of the watercraft can be filled with methanol.

The distributor system can be preceded by a transport system that is connected, or can be connected, to the methanol synthesis unit of the plant in accordance with the invention, and is customised to transport the methanol regeneratively-produced by the methanol synthesis unit from the methanol synthesis unit to at least one delivery device. The transport system can be stationary or mobile, and can comprise, for example, pumps and pipelines, or transport by tankers. The tankers can also be operated by the method described herein. Transport systems known per se, for example for the transport of crude oil, can be utilised. The delivery device can be a storage tank in a port, or at a pumping station.

The combustion of the regeneratively-produced methanol produces carbon dioxide, which is released into the atmosphere. The desired carbon dioxide cycle is closed by the carbon dioxide sorption unit, which, directly or indirectly, separates out the carbon dioxide that has entered the atmosphere from the latter once again, and uses it in the methanol production process. The methanol produced in this manner, and thus the carbon dioxide utilised for its production, is returned to the carbon dioxide cycle.

The fact that the watercraft using the methanol and the place where the methanol is produced are spatially far apart from each other is irrelevant, since what is at stake is the overall balance of carbon dioxide in the atmosphere, which

remains constant by the formation of the closed carbon dioxide cycle. It is even possible to reduce the carbon dioxide concentration in the atmosphere if the carbon dioxide sorption unit removes an excess of carbon dioxide from the atmosphere, which is not returned to the cycle by methanol as an energy source. The excess carbon dioxide is then disposed of elsewhere, for example by storing it in deep rock strata, as is already the practice in Iceland.

In a preferred form of embodiment of the method in accordance with the invention, the water is desalinated in a seawater desalination unit and then fed to the electrolysis unit, wherein the seawater desalination unit is operated mainly, in particular completely, by means of the electrical energy generated in the photovoltaic unit.

For an insight into the invention, it is essential to understand that the methanol is utilised as the main fuel in the internal combustion engine. That is to say, the methanol does not take the form of an additive that is mixed with another fuel. Rather, the methanol is utilised in such a manner that the combustion engine is operated solely with the latter.

The internal combustion engine is preferably a reciprocating piston engine operated with a compression ratio of at least 14:1, in particular at least 16:1, in particular at least 18:1, in particular at least 20:1. In particular, the reciprocating piston engine can be a four-stroke Otto cycle engine.

Currently, the diesel engine has a high market share in watercraft. However, the utilisation of methanol makes it possible to operate an Otto cycle engine with an otherwise unusually high compression ratio. With the high compression, a significant increase in efficiency is achieved, especially in an operation with a balanced combustion air ratio ($\lambda=1$).

This enables a high power to be achieved in a four-stroke Otto cycle engine with low fuel consumption. At the same time, a large part of the very complex exhaust gas after-treatment required in diesel engines is omitted, which saves space and weight and thus further increases the efficiency of the watercraft. In particular, this provides space for the integration of a drive battery for a hybrid drive train into the watercraft.

Part of the methanol can be split in a splitting unit into a synthesis gas, which comprises or consists of hydrogen and carbon monoxide, and the synthesis gas alone, or together with the methanol, can be fed into the reciprocating piston engine, wherein the splitting unit is arranged in the watercraft, in particular between a tank and the reciprocating piston engine. The synthesis gas can increase the ignitability of the methanol fuel, and can thus contribute to an even more efficient operation of the reciprocating piston engine.

Another aspect of the invention relates to a watercraft with a drive system, wherein the drive system comprises a power unit, at least one drive battery, and at least one electric motor, which draws electrical energy from the drive battery. The power unit comprises a two-cylinder reciprocating piston engine with two cylinder-piston units in a tandem arrangement, and at least one generator for the generation of electrical energy, wherein each cylinder-piston unit has a crankshaft, and the crankshafts of both cylinder-piston units are mechanically coupled to one another, and wherein at least one crankshaft, in particular both crankshafts, is in each case mechanically connected to the at least one generator.

The two-cylinder reciprocating piston engine is preferably customised for operation with methanol, in particular regeneratively-produced methanol, as the main fuel. The

electric motor preferably operates, via a gearbox or directly, on a drive shaft of a propeller. The propeller can rotate freely in the water during operation of the watercraft, or can be integrated into a water jet drive.

Furthermore, a tank can be provided, which is fluidically connected to the two-cylinder reciprocating piston engine, and is at least partially, preferably completely, filled with regeneratively-produced methanol. It is possible that the drive system has a plurality of power units, each of which is electrically connected to a common drive battery, or to a plurality of separate drive batteries.

It is particularly preferred if the two-cylinder reciprocating piston engine of the above-described watercraft is operated in accordance with the above-described method.

The invention is explained in more detail by means of examples of embodiment with reference to the attached schematic drawings that have further details.

In these:

Fig. 1 shows a perspective view of a plant for the production of a globally usable energy source, in accordance with a preferred example of embodiment of the invention;

Fig. 2 shows a perspective view of a plant for the production of a globally usable energy source, in accordance with a further preferred example of embodiment in accordance with the invention;

Fig. 3 shows a plan view onto a planar plant area of the plant shown in Fig. 2;

Fig. 4 shows a schematic cross-section through the planar plant area of the plant shown in Fig. 3;

Fig. 5 shows a flow diagram of the method for the production of a globally usable energy source with the plant shown in Fig. 1, or the plant shown in Fig. 2, and

Fig. 6 shows a cross-sectional view of a power unit of a watercraft in accordance with the invention, in a preferred example of embodiment.

In what follows, the same reference numbers are utilised for the same parts, and for parts operating in the same manner.

Fig. 1 shows the example of embodiment of a plant 10 that is designed for the production of a globally usable energy source in the form of methanol. The plant 10 comprises an electrolysis unit 11, a carbon dioxide sorption unit 12, a seawater desalination unit 27, and a methanol synthesis unit 34. A photovoltaic unit 24 is provided for the supply of power to the aforementioned units; this is electrically connected to the corresponding units 11, 12, 27, 34.

As can be seen in Fig. 1, the aforementioned plant components are arranged on a contiguous plant site, such that the exchange of material and energy flows between the various units and the power supply takes place with the lowest possible losses. The shape of the plant is not limited to the shape shown in Fig. 1.

The electrolysis unit 11 is connected to the seawater desalination unit 27 by at least one pipe (not shown) for the supply of water, in particular desalinated water. The desalinated water is fed to the electrolysis unit 11 through the pipeline. The methanol synthesis unit 34 is connected, on the one hand, to the electrolysis unit 11 by at least one

pipeline, and, on the other hand, to the carbon dioxide sorption unit 12 by at least one further pipeline. The hydrogen produced in the electrolysis unit 11, and the carbon dioxide separated out in the carbon dioxide sorption unit 12, are fed to the methanol synthesis unit 34 through the two pipelines. Methanol is thereby produced in the methanol synthesis unit 34.

The seawater desalination unit 27 can be designed to receive and desalinate at least 900,000 tonnes of seawater per year. The carbon dioxide sorption unit can be customised to have an extraction capacity of at least 400,000 tonnes of carbon dioxide per year, in particular at least 600,000 tonnes of carbon dioxide per year, extracted from the ambient air. The methanol synthesis unit 34 is customised to produce at least 300,000 tonnes, in particular 450,000 tonnes, of regeneratively-produced methanol per year.

The photovoltaic unit 24 can have a power of approx. 1.5 GW and, depending on the solar radiation, can absorb at least 1,500 kWh/m²a. For the location in the Middle East selected in Fig. 1, the photovoltaic unit 24 is preferably customised to absorb at least 2,500 kWh/m²a.

The electrolysis unit 11 is designed to separate a quantity of water M_{H_2O} by electrolysis into an oxygen component M_{O_2} , and a hydrogen component. The electrolysis unit 11 thus forms a unit for water electrolysis. The electrolysis unit 11 is connected to a water supply line 13 for the reception of the quantity of water M_{H_2O} . As can be seen in Fig. 1, a pump unit 25 is arranged between the electrolysis unit 11 and the water supply line 13. The pump unit 25 has at least one pump for the transportation of water from a water reservoir 26. The water reservoir 26 can be a sea with seawater. Alternatively, the water reservoir 26 can be a lake with fresh water. It is also possible that the water supply line 13 is connected to a river so as to draw fresh water for water electrolysis. In

the plant 10 shown in Fig. 1, the water supply line 13 is connected to a sea for the extraction of seawater. The plant 10 is preferably located near the coast so as to keep the distance to be covered for the water supply short, in particular to keep the water supply line 13 short.

The pump unit 25 is designed for the purpose of pumping seawater from the sea and making it available to further sub-plants or units for further processing. In order to prepare the seawater for the electrolysis process undertaken by the electrolysis unit 11, the plant 10 has a seawater desalination unit 27. The seawater desalination unit 27 is connected to the pump unit 25 by at least one pipe. The seawater desalination unit 27 is customised to separate out a certain amount of salt from the quantity of seawater M_{H_2O} delivered, so that the seawater has a reduced salt content after the desalination process by the seawater desalination unit 27. The desalinated quantity of seawater M_{H_2O} corresponds to the quantity of water M_{H_2O} , which is separated into an oxygen component M_{O_2} and a hydrogen component by the electrolysis unit 11. The electrolysis unit 11 is connected to the seawater desalination unit 27 by at least one pipe. In order to convey the desalinated seawater from the seawater desalination unit 27 to the electrolysis unit 11, at least one further pump can be connected in between.

As described above, the electrolysis unit 11 is customised to separate the absorbed quantity of water M_{H_2O} into a hydrogen component and an oxygen component M_{O_2} . The hydrogen component is fed to the methanol synthesis unit 34. The oxygen component M_{O_2} is discharged into the environment. The electrolysis unit 11 is preferably customised to separate out an oxygen component M_{O_2} of at least 1.2 kg and a hydrogen component of at least 0.15 kg, in particular of 0.19 kg, from an absorbed quantity of water M_{H_2O} of at least 1.5 kg. For purposes of discharging the produced oxygen component M_{O_2} , the electrolysis unit 11 has an oxygen outlet 16 which

opens out into the external atmosphere. The plant 10 has a hydrogen transport device (not shown) for the supply of the hydrogen to the methanol synthesis unit 34.

It is possible for the plant 10 to have a hydrogen storage unit, such that the methanol synthesis unit 34 can be fed with hydrogen as continuously as possible.

As shown in Fig. 1, the carbon dioxide sorption unit 12 has an air inlet 14 for the supply of ambient air UL, and a downstream sorber device 15. It is possible for the carbon dioxide sorption unit 12 to have one or a plurality of air inlets 14. The sorber device 15 is connected to the air inlet 14. The sorber device 15 is customised so as to extract a quantity of carbon dioxide from the ambient air UL. The carbon dioxide sorption unit 12 furthermore has an air outlet 17 that is oriented upwards in the vertical direction. The air outlet 17 serves to discharge the exhaust air UL', whose carbon dioxide concentration is lower than the carbon dioxide concentration of the ambient air UL. The air outlet 17 is part of a stack 19.

More specifically, the sorber device 15 is arranged between the air inlet 14 and the air outlet 17. In operation, the ambient air UL flows through the air inlet 14 to the sorber device 15, which separates out, in particular filters out, a certain amount of carbon dioxide from the air UL, wherein downstream of the sorber device 15 the filtered exhaust air UL' flows through the air outlet 17 into the external atmosphere. In general, it is possible for a plurality of air inlets 14, a plurality of sorber devices 15, and a plurality of air outlets 17, to be provided.

More specifically, Fig. 1 shows a single stack 19 with a height H of 200 metres, which shows in an exemplary manner the external structure of the carbon dioxide sorption unit 12. The air outlet 17 opens into the external atmosphere, as

shown in Fig. 1, in the same manner as the oxygen outlet 16.

The plant 10 further comprises a carbon dioxide transport device (not shown), which is designed for purposes of making the carbon dioxide quantity separated out from the ambient air UL available to a carbon dioxide storage unit, and/or to the methanol synthesis unit 34, for further processing. The carbon dioxide storage unit serves to ensure as continuous a supply of carbon dioxide as possible to the methanol synthesis unit 34.

The carbon dioxide sorption unit 12 can have an extraction capacity of an amount of carbon dioxide per year of at least 400,000 tonnes, in particular 600,000 tonnes. In other words, the carbon dioxide sorption unit 12 can be customised to process an ambient quantity of air per year of at least 1,500 megatonnes. More specifically, the carbon dioxide sorption unit 12 is preferably customised to extract a carbon dioxide quantity of at least 1.4 kg from an ambient quantity of air of at least 3,300 kg.

As shown in Fig. 1, the plant 10 has a planar plant area 23. The planar plant area 23 is directly adjacent to the electrolysis unit 11. A power generation unit 31, which is a photovoltaic unit 24, is arranged on the planar plant area 23. The photovoltaic unit 24 is connected to the respective units of the plant 10 for purposes of power supply. The photovoltaic unit 24 is customised in such a manner that the entire installation 10 can be operated self-sufficiently in terms of energy. This is to be understood as meaning that the electrical power for operating the entire plant 10 can be provided exclusively by solar energy by means of the photovoltaic unit 24. In other words, it is preferable that no fossil energy sources are utilised for the operation of the plant 10.

The planar plant area 23 can have a longitudinal extent 32

of approximately 5,000 metres and a transverse extent 33 of approximately 2,000 metres. In other words, the planar plant area of the plant 10 preferably covers an area of 10 square kilometres. The plant area shown in Fig. 1 containing the electrolysis unit 11 can have a longitudinal sub-extent 29 of approximately two kilometres. Other longitudinal sub-extents, and longitudinal and transverse extents, 29, 32, 33 are possible.

The seawater desalination unit 27 described above is connected to a water return line 28, through which a returnable quantity of seawater M'_{H_2O} with an increased salt content is returned to the sea. More specifically, a certain salt content is extracted from the extracted quantity of seawater, and is then returned to the sea with a proportion of the extracted quantity of seawater as a returnable quantity of water M'_{H_2O} . This provides a water cycle that is not damaging to nature.

The preferred installation site of the plant 10 is near the coast of a sea. Particularly preferably, the plant 10 is set up in a desert. A methanol delivery line 35 can connect the plant 10 to a methanol delivery point, for example in a port.

The plant 10 as shown in Fig. 1 is a large power plant. The plant 10 can have at least one installation area 18 that is connected to a foundation of a building and/or a structure. In general, it is possible for the electrolysis unit 11 and/or the carbon dioxide sorption unit 12 to be arranged in a common building, or in separate buildings.

The power supply unit 31 preferably has a power storage unit (not shown), which is customised to supply power to the plant 10 during night-time operation.

In contrast to Fig. 1, Fig. 2 shows a plant 10 in which the single carbon dioxide sorption unit 12 is replaced by a

plurality of carbon dioxide sorption units 12. The particular carbon dioxide sorption unit 12 shown in Fig. 2 has a stack 19 and a flow channel 21 extending transversely to the stack 19. This is clearly visible in Fig. 4, for example. The flow channel 21 is connected to the stack 19 in a region of the stack arranged at the bottom of the structure when installed. A sorber device 15 is arranged between the flow channel 21 and the stack 19; this is designed to extract a quantity of carbon dioxide from the ambient air UL. The sorber device 15 is formed by an amine exchanger. Other types of sorber devices are possible.

As Figures 2, 3 show, the stacks 19 are arranged along the longitudinal extent 32 of the planar plant area 23. The planar plant area 23 has a surface 22 arranged at the top of the structure when installed. The surface 22 arranged at the top of the structure is dark in colour, at least in some sections, in order to absorb solar energy. The flow channels 21 are arranged below the upper surface 22 when installed. A plurality of air inlets 14 are formed in the upper surface 22 to supply ambient air UL into the flow channels 21. The air inlets 14 form passage openings through the upper surface 22. For the sake of clarity, these are only shown on the first flow channel 21 in Fig. 3. The number of air inlets 14 is also variable.

In operation, ambient air flows through the air inlets 14 into the flow channel 21 and then through the sorber device 15. Downstream of the sorber device 15, the exhaust air UL' with reduced carbon dioxide concentration flows into the stack 19, and through the air outlet 17 into the external atmosphere. By virtue of the dark-coloured surface 22 arranged at the top of the structure, the ambient air located below the surface 22 in the flow channel 21 heats up during operation. The temperature of the ambient air UL in the flow channel 21 is preferably approx. 60 °C. With an external temperature of the ambient air UL of approx. 40 °C, natural

ventilation is created by the arrangement of the stack with the flow channel 21, together with the dark-coloured surface 22. In other words, no fan or blower is necessary for the supply of the ambient air UL into the flow channel 21, or for the flow through the sorber device 15, or for the outflow of the purified ambient air UL' from the stack 19.

Fig. 3 shows a plan view onto the planar plant area 23 of the plant 10 shown in Fig. 2. The numbering from 1 to 40 shown along the longitudinal extent 32 represents the number of stacks 19 arranged along the longitudinal extent 32. The lines running transversely to the longitudinal extent 32 show schematic separations between the individual flow channels 21. The individual flow channels 21 are in each case assigned to a stack 19. At the same time a sorber device 15 is in each case arranged between the flow channel 21 and the stack 19. The longitudinal extent 32 of the two-dimensional plant area 23 is approximately 5,000 metres and the transverse extent 33 of the planar plant area 23 is approximately 2,000 metres. A total of forty stacks 19 with a total of forty flow channels 21 are provided in the planar plant area 23. These have a combined delivery of exhaust air UL' of at least 1,800 megatonnes per year.

To achieve this, the stacks 19 have a diameter D that is 25 metres. The diameter D refers to the region of the stack 19 in which the air outlet 17 is formed. The air outlet 17 is formed at a free end of the stack 19. Furthermore, the stack in question 19 has a height H of 100 metres. By this means an optimal shape is formed for the stack so as to provide natural ventilation. Other dimensions of the stacks 19 are possible.

Furthermore, more than, or less than, forty stacks 19, in each case with an associated flow channel 21, can be arranged in the planar plant area 23.

As can be seen in Fig. 4, the planar plant area 23 is provided with a photovoltaic unit 24 on the surface 22 arranged at the top of the structure. In other words, a photovoltaic unit 24 is arranged on the upper surface 22 of the planar plant area 23. The photovoltaic unit 24 preferably delivers 1.5 gigawatts per year. In the plant 10 shown in Fig. 2, the carbon dioxide sorption unit 12 and the photovoltaic unit 24 thereby spatially form a common unit. The photovoltaic unit 24 forms a power supply unit 31 for the energy-autonomous operation of the entire plant 10.

It should be noted that the above-described plants 10, shown in Figs. 1 and 2, are identical except for the differences that have been described.

The method that can be carried out with the plant 10 shown in Fig. 1 or Fig. 2 is explained with the aid of the flow chart shown in Fig. 5:

To produce a quantity of 1 kg of methanol, a quantity of approximately 2 kg of seawater is fed to the plant 10 and desalinated in the seawater desalination unit 27. This generates approx. 1.13 kg of desalinated water. The residual salt water (approx. 0.87 kg) is returned to the sea through the water return line 28. In the electrolysis unit, the desalinated water and, if necessary, further quantities of water produced in later process steps, are split into hydrogen (approx. 0.19 kg) and oxygen (approx. 1.5 kg). The carbon dioxide sorption unit 12 takes in a quantity of air of approx. 3,371.75 kg through the air inlet 14 and extracts a quantity of approx. 1.38 kg of carbon dioxide from the unit. Hydrogen and carbon dioxide are fed to the methanol synthesis unit, where they are processed into 1 kg of methanol. The excess heat generated during the synthesis is fed to the carbon dioxide sorption unit 12. The synthesis also produces a quantity of water of approximately 0.56 kg, which is fed to the electrolysis unit. For these process

steps, approx. 51 kWh of solar energy is converted into approx. 12.83 kWh of usable electricity energy by the photovoltaic system.

Fig. 6 shows a power unit 120 for a watercraft in accordance with the invention. The power unit 120 comprises a two-cylinder reciprocating piston engine 121, with a first cylinder-piston unit 122 and a second cylinder-piston unit 123. Each of the cylinder-piston units 122, 123 comprises a piston 124 guided in a cylinder 125. The piston 124 is coupled to a connecting rod 126, which connects the piston 124 to a crankshaft 127. The crankshafts 127 are aligned parallel to each other, and in each case carry spur gears 127a, which have external teeth. The externally-toothed spur gears 127a mesh with each other such that the spur gears 127a rotate in opposite directions.

Each spur gear 127a is coupled to a generator 130 via a toothed belt 128. A total of two generators 130 are provided. The generators 130 also include balance weights 130a, which balance out the mass forces and the mass moments.

The power generator 120 furthermore comprises a cam belt 131, which connects one of the crankshafts 127 to camshafts 132. Each cylinder-piston unit 122, 123 is associated with a respective camshaft 132. The camshafts 132 in each case act on valves 133, wherein each cylinder-piston unit preferably has four valves 133.

Furthermore, an oil sump 134 is provided, in which an oil pump 135 is arranged. The oil pump 135 is driven by an oil pump belt 136, which connects the oil pump 135 to one of the crankshafts 127. The oil pump 135 is preferably connected to another crankshaft 127, rather than the camshafts 132. Furthermore, an oil filter 137 is arranged in the oil sump 134.

As can be seen in Fig. 6, the power unit 120 has a particularly compact design. It has relatively few parts and is therefore easy to maintain and has a low weight. The two-cylinder reciprocating piston engine is particularly low in noise and vibration. In addition, the two-cylinder reciprocating piston engine can be encapsulated in a housing, wherein the housing can additionally contribute to low noise and low vibration. The propulsion system of a watercraft can include a plurality of power units 120 that act together to generate power, and feed drive batteries.

Fig. 6 also shows that the cylinders 125 of the cylinder-piston units 122, 123 are arranged in an interfaced manner. In particular, the central axes of the cylinders 125 have a smaller distance from each other than the central axes of the crankshafts 127. As a result, the connecting rods 126 are slightly inclined to each other at top dead centre of the pistons 124, as shown in Fig. 6. This massively reduces vibrations when the engine is started. In particular, when starting the power generator 120, start-up mass moments are reduced in this manner, so that the otherwise familiar start-up vibrations do not occur.

For the propulsion of a watercraft, the power unit 120 is preferably operated, and provides via the generators 130 the electrical energy that is required in order to use the electric motors in drive mode. A 48 volt, 400 volt or 800 volt, system is preferably integrated as the electrical system. The drive batteries are preferably dimensioned such that the watercraft can travel between 10 km and 120 km, in particular between 20 km and 100 km, in particular between 25 km and 60 km, in an exclusively electrical manner, that is to say, without operation of the power unit.

The power unit 120 is preferably powered by the regeneratively-produced methanol. For this purpose, an appropriate tank is provided, which accommodates the

regeneratively-produced methanol, that is to say, is filled with the latter. In this manner, a particularly economical and at the same time climate-friendly operation of the watercraft is possible.

As explained with the aid of the above examples of embodiment, the invention offers a technically feasible and economical solution to the acute climate problem, which can be implemented within a reasonable time frame by virtue of the scalability of the described systems. The invention takes into account the geographical opportunities offered by certain regions of the world, and has an impressive simplicity.

List of reference symbols

10	Plant
11	Electrolysis unit
12	Carbon dioxide sorption unit
13	Water supply line
14	Air inlet
15	Sorber device
16	Oxygen outlet
17	Air outlet
18	Installation area
19	Stack
21	Flow channel
22	Surface arranged at the top of the structure
23	Planar plant area
24	Photovoltaic unit
25	Pump unit
26	Water reservoir
27	Seawater desalination unit
28	Water return line
29	Longitudinal sub-extent
31	Power generation unit
32	Longitudinal extent
33	Transverse extent
34	Methanol synthesis unit
35	Methanol delivery line
120	Power generator
121	Two-cylinder reciprocating piston engine
122	First cylinder-piston unit
123	Second cylinder-piston unit
124	Piston
125	Cylinder
126	Connecting rod
127	Crankshaft
127a	Spur gear
128	Toothed belt
130	Generator

130a Balance weight

131 Cam belt

132 Camshaft

133 Valve

134 Oil sump

135 Oil pump

136 Oil pump belt

137 Oil filter

UL Ambient air with increased carbon dioxide concentration

UL' Exhaust air with lowered carbon dioxide concentration

D Diameter

H Height

M_{H_2O} Quantity of water extracted

M'_{H_2O} Quantity of water recirculated

M_{O_2} Oxygen component

CLAIMS

1. Method for operating an internal combustion engine of a watercraft, in particular on inland waters, in which

- in an electrolysis unit (11) for the production of hydrogen, water is split into hydrogen and oxygen,
- a carbon dioxide sorption unit (12) extracts carbon dioxide from the ambient air,
- the hydrogen and the carbon dioxide are fed to a methanol synthesis unit (34) for the production of methanol, and are synthesised therein to methanol,
- a photovoltaic unit (24) absorbs solar energy and converts the latter into electrical energy, wherein

the electrolysis unit (11), the carbon dioxide sorption unit (12) and the methanol synthesis unit (34) are powered by the electrical energy generated in the photovoltaic unit (24), wherein the methanol produced is transported by means of a distributor system to at least one tank of the watercraft, and is fed from the tank as required to the internal combustion engine, and therein is combusted for the generation of mechanical energy.

2. Method according to Claim 1,

characterised in that,

the internal combustion engine is part of a power unit (120) of a hybrid electrically powered watercraft, wherein in the power unit (120), the mechanical energy of the internal combustion engine is converted into

electrical drive energy for the propulsion of the watercraft.

3. Method according to Claim 1 or 2,

characterised in that,

the water is desalinated in a seawater desalination unit (27), and is subsequently fed to the electrolysis unit (11), wherein the seawater desalination unit (27) is operated mainly, in particular completely, by the electrical energy generated in the photovoltaic unit (24).

4. Method according to one of the preceding claims,

characterised in that,

the internal combustion engine is a reciprocating piston engine (121), which is operated with a compression ratio of at least 14:1, in particular at least 16:1, in particular at least 18:1, in particular at least 20:1.

5. Method according to one of the Claims 1 to 3,

characterised in that,

part of the methanol is split in a splitting unit into a synthesis gas comprising or consisting of hydrogen and carbon monoxide, and the synthesis gas is fed alone, or together with the methanol, into the reciprocating piston engine, wherein the splitting unit is arranged in the watercraft, in particular between a tank and the reciprocating piston engine.

6. Utilisation of methanol as fuel in an internal

combustion engine, in particular a power unit (120), of a watercraft, in particular a hybrid-electrically driven watercraft, wherein the methanol is produced in a method according to one of the preceding claims.

7. Utilisation according to Claim 6,

characterised in that,

the water is desalinated in a seawater desalination unit (27), and is subsequently fed to the electrolysis unit (11), wherein the seawater desalination unit (27) is operated mainly, in particular completely, by the electrical energy generated in the photovoltaic unit (24).

8. Watercraft, in particular a hybrid-electrically driven watercraft, with a drive system, wherein the drive system has a power unit (120), at least one drive battery, and at least one electric motor, which draws electrical energy from the drive battery, wherein the power unit comprises a two-cylinder reciprocating piston engine (121) with two cylinder-piston units (122, 123) in a tandem arrangement, and at least one generator (130) for the generation of electrical energy, wherein each cylinder-piston unit (122, 123) has a crankshaft (127), and the crankshafts (127) of both cylinder-piston units (122, 123) are mechanically coupled to one another, and wherein at least one crankshaft (127), in particular both crankshafts (127), in each case is/are mechanically connected to the at least one generator (130).

9. Watercraft according to Claim 8,

characterised in that,

the electric motor operates, via a gearbox or directly, on a drive shaft of a propeller.

10. Watercraft according to Claim 8 or 9,

characterised by,

a tank fluidically connected to the two-cylinder reciprocating piston engine (121), and at least partially, preferably completely, filled with regeneratively-produced methanol.

11. Method of operating a watercraft according to one of the Claims 8 to 10, wherein the two-cylinder reciprocating piston engine (121) is operated in accordance with the method of one of the Claims 1 to 4.