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FIELD OF THE INVENTION

This invention relates to steam generators, and especially to steam generators used in high temperature steam electrolyzers (HTSE). The invention more particularly concerns a device for converting a liquid into steam capable of providing a low steam flow rate, in particular a steam flow rate of between 10 g/h and 10 kg/h, and operating at constant pressure, in particular at atmospheric pressure or at a few tens of bar.

STATE OF THE TECHNIQUE

A high temperature steam electrolyzer (HTSE) is a high temperature steam electrolyzer (HTSE), an electrochemical device for the production of hydrogen from steam by applying an electric current to a stack of electrolytic cells electrically connected in series, each comprising two electrodes, namely a cathode and an anode, with an interposed solid oxide electrolytic membrane. Overall, steam is added at the cathode of each power cell supplied with electric power and an electrochemical reduction reaction of the steam causes hydrogen to form on the cathode.

Generally speaking, for a given operating point of the electrolyzer, electric current has to be applied to it and the flow rate of steam to be added to the electrolyzer is calculated according to the intensity of the electric current applied to the electrolyzer. As the current intensity can generally vary from 0 to 100% of the operating range of the electrolyzer, it is also necessary that the flow of steam to be generated can also change linearly from 0 to 100% of the capacity and comprise steam only. Also, an electrolyzer is a very sensitive system to current/gas flow inconsistencies, as these consistencies can cause the premature aging of the electrolyzer. For example, if the steam flow rate varies around its set value, instability of the operating point of the electrolyzer may be observed, causing variations in the cell voltage, because of premature ageing. Even worse, major variations of the steam flow cause pressure variations of a few tens or hundreds of mbar, sometimes sufficient to damage seals or crack the electrochemical cells themselves. The aim is therefore to achieve the most consistent and regular steam flow possible.

There are off the shelf steam generators available with a regulated flow rate, adapted to generating high steam flows, i.e. several tens of kg/h. Such a steam generator generally comprises a pressurized steam storage coupled to a steam flow control valve to generate constantly the required amount of steam.

Steam generators are also available off the shelf, adapted to lower flow rate ranges, in particular between approximately 10 g/h to 10 kg/h. Since steam flow control valves used for high flow rates are unsuitable for this range of flow rates, one solution is to control the flow of liquid water into the generator so that the steam generated after evaporation corresponds to the desired output of steam.

Depending on the embodiment, these low flow generators use a heating tube or volume of which at least the lower wall is heated, into which a controlled amount of water is injected and heated to evaporation. However, it has been observed that such generators cause steam "bursts" and therefore overpressure. Since the principle of liquid water evaporation is somewhat complex, if we take into account the constraint of the regularity of the steam outlet flow, the difficulty of this solution is to control the heating of the water so that the local boiling of the water drives part of the liquid into a zone that is excessively hot and causes the racing of the boiling reaction. Controlling these phenomena is very difficult, and in practice, low flow evaporators are generally built only to generate a single dry steam flow, while the electrical power and the evaporation area are designed for a single operating point.

In another embodiment, other evaporators adapted for low flow rate ranges use a carrier gas, for instance nitrogen, which facilitates the spreading of the liquid and evacuation of the steam produced. However, this solution does not produce dry steam because it is impossible to separate the steam from the carrier gas. A dry steam generator is for example known as WO 97 33479 Al.

ABSTRACT OF THE INVENTION

The purpose of this invention is therefore to provide a steam generator capable of producing, at constant pressure, a constant flow of steam from a liquid, for example water, for low steam flows, and not requiring the use of carrier gas.

This invention thus concerns a steam generator at constant pressure, capable of providing a controlled flow of steam, including for low steam flow rates, in particular between 10 g/h and 10 kg/h, and for a constant pressure of 0 to several tens of relative bar.

The invention is defined by claim 1. In other words, this steam generator comprises:

- a liquid flow regulator configured to generate a quantity of liquid, e.g. water, at a given instant at a constant liquid flow rate comprised within a predetermined range of flow rates, where the maximum flow rate in this range of flow rates is less than or equal to 10 kg/h;
- a liquid to steam conversion device operating at constant pressure and comprising:
  - ○ an enclosure with a liquid inlet connected to the liquid regulator and a steam outlet through which the steam escapes at a flow rate substantially identical to that of the liquid injected at the inlet, the said enclosure being at the said constant pressure;
  - ○ a heating surface in the enclosure, having a downward slope defining a flow route allowing the quantity of liquid to flow by gravity along the route from the inlet, and a temperature rise of the quantity of liquid as it flows along the route until total evaporation of each mole of this quantity of liquid before the end of the said route, with this heating surface being open to allow the direct evacuation of the steam formed,
- an energy source capable of supplying enough energy to the heating surface to apply linear thermal power to the liquid along the route, this linear thermal power being selected as per at least the maximum length of the route and the thermal power necessary to evaporate all of a maximum quantity of injected liquid depending on the maximal flow rate of the flow range.

Or in other words, the invention is the combination of three parameters:

- sizes to ensure a flow of the liquid, especially by gravity. It is understood, for example, that if the liquid is directed& to a tank in which it is stored for evaporation by heating, it is difficult to control accurately the quantity of steam produced. Thanks to the flow, each volume of liquid injected receives "individually" and in a controlled manner, a quantity of heat. This facilitates the controlling of the quantity of steam produced according to the quantity of liquid injected;
- heating of the liquid by an external source of energy which can be electric (heating element) or thermal (heat transfer fluid); and
- a route length adapted to obtain a complete evaporation of each mole of injected liquid before the end of the route.

A steam generator like this ensures control of the vaporization of each quantity of injected water. This vaporization results in particular in the continuous evaporation of the liquid as it flows until it evaporates completely before the end of the route, without a “puff” or flow of liquid on a mattress (or bed) of steam forming in the enclosure. Controlling the evaporation process in this way avoids in particular stagnant water from staying in the enclosure, necessary to obtain a regular flow of steam at the outlet and allows a regular flow of steam to be supplied directly, substantially identical to the flow of liquid injected at the inlet. In practice, the regularization of the water (and thus steam) flow rate can be controlled by a user turning a control knob. For example, the user can set the flow rate of liquid to be injected at the inlet to obtain an approximately equivalent flow rate of steam at the outlet.

A generator like this can thus provide a constant dry steam flow rate in the range of 10 g/h to 10 kg/h, without using either carrier gas or electromechanical devices, such as a steam flow valve for instance. The manufacture of the generator as well as its operation are therefore simplified.

For example, for a steam flow rate in the range 10 g/h to 10 kg/h, the maximum applied heating power can be between 8 and 12 kW and the route can be between 10 and 20 m long. In practice, for a flow rate of less than 300 g/h, the liquid is preferably injected by drip feed. For example, a flow rate of about 10 g/h corresponds to about 1 x 36 µl drop of liquid every 13 seconds.

According to the invention, the conversion device has a groove extending along the route and in which the heating surface is housed, while the groove allows the liquid to flow by gravity and capillarity along the route.

In other words, the groove is sized to form a capillary channel, drawing in the injected liquid. Gravity flow combined with capillary flow allows the injected liquid to be uniformly spread over a long length of the heating surface along the entire length of the route, especially for low flow rates, and in particular, by drip feed. This forms a continuous stream of water. The formation of trains of drips on the heating surface is thus avoided, so that steam generation is more regular and the steam flow at the outlet is constant even when the water injection is discontinuous. This solution makes it possible, in particular, to obtain a regular flow of steam from a non-linear injection of liquid, especially by drip feed.

Naturally, the liquid inlet can also be sized to allow capillary injection of the liquid directly into the groove and to prevent the drips from forming at the end of the liquid water injection tube. In one embodiment, the end of a liquid water injection tube is, in this case, placed in contact with the groove.

In practice, the heating surface is arranged in a channel open on at least a lower portion of the route, preferably over the entire route, to allow the free escape of the steam generated.

In the embodiment corresponding to capillary and gravity flow, the bottom of the channel is provided with the groove described above. In practice, this groove is open along its entire length towards the inside of the channel, and preferably has sizes adapted to capillary flow. For example, for a 3.5 mm diameter heating surface and a flow range of 0 to 5 l/h, the main channel is 8.5 mm high and 17 mm deep and the groove is 3.5 mm high and 3.5 mm wide to allow the peening of the heating surface.

In order to direct the liquid towards the bottom of the channel, and thereby concentrate the liquid on the heating surface at the bottom of the channel, the walls of the channel are preferably inclined, with the inclination of each wall being at an angle of inclination (a) greater than or equal to 30° from horizontal.

In other words, the angle between the wall in contact with the flowing liquid, in the direction from the bottom of the channel to the opening of the channel, and the direction of gravity is non-zero and preferably less than or equal to 60°. This ensures that the circulating liquid remains in contact with the heating surface which is preferably located as close as possible to the bottom of the channel.

The channel is preferably made of a material neutral to the liquid, especially stainless steel, which is particularly appreciated for its corrosion resistance.

In addition, this channel has a helical shape when compactness is an issue.

Depending on a variant, the heating surface can be on the outer perimeter of a cylinder.

The conversion device can thus be in the shape of a threaded part, with the thread forming the channel. For instance, the part could be a cylinder extending in the direction of gravity and in the perimeter of which the helical channel is machined. The helical channel preferably has a suitable width, depth, length, and pitch for the total evaporation of the injected liquid before the end of the route combined with the linear thermal power applied to the heating surface, as explained above. Furthermore, the channel opening is preferably sized to ensure direct steam evacuation and to limit steam accumulation above or in the channel which would be likely to interfere with the heating or the gradual rise of the liquid temperature. In particular, it is preferable that the steam does not push the liquid to an area that is too hot to release the pressure surges. For example, steam can be evacuated substantially radially without disturbing the water flow. Thus, the channel opening can be advantageously directed in a different direction from that of gravity. Advantageously, the enclosure can be formed of a heat insulating outer shell and a metallic inner shell maintained at a predefined temperature, for example between 150 and 250° C for steam generation at atmospheric pressure, to prevent condensation on the inner walls of the enclosure. This inner shell will be sized and qualified to operate up to the maximum pressure defined during the design of the steam generator. Preferably, this metal inner shell is designed to operate at a pressure higher than atmospheric pressure or in the atmospheric pressure range of a few tens of bar. In one variant, during operation, the pressure in the enclosure is that of the steam.

In an embodiment adapted to a production flow rate of 0 to 5 kg/h at atmospheric pressure, the inner shell has a diameter of 220 mm and a height of 470 mm in 2 mm thick sheet metal. The 10 m long spiral is machined from a having a diameter of 200 mm and a height of 400 mm, while the distance between the channel opening and the inner wall of the enclosure is 8 mm. The volume in which the steam prevails is about 6 liters.

In another embodiment, the thermal power of the heating surface can be regulated by means of, for example, a temperature sensor able to measure the temperature of at least one point of the heating surface, coupled to an energy regulator of the energy to be supplied to the heating surface according to the measured temperature and a set temperature generally greater than or equal to 100° C.

In practice, a table showing the correspondence between the thermal power, the water flow rate and the temperature of the heating surface is used for regulating the thermal power.

In another embodiment, the heat source can be changed. For example, it is possible to use a heat transfer liquid, such as an oil, which is made to run through a metal pipe. This pipe can be installed instead of the electrical element, for example using the same peening technique. Knowing the heat capacity of the heat transfer fluid, it is possible to calculate the nominal temperature which guarantees that the maximum liquid flow rate can be evaporated. In addition, to ensure an even flow of evaporation, it is advantageous to circulate the heat transfer fluid in the opposite direction to the flow of liquid water.

Further, although the device described is capable of producing dry steam, it is also possible to add, if necessary, one or more gases to produce a mixture. In this case, these gases must be preheated before being added to the steam. Preheating can be obtained for example by a simple technique which consists in welding the spiral gas line to the generator enclosure.

The invention is also designed to convert liquid into steam at a constant pressure with all or part of the characteristics defined above.

In particular, the liquid to steam conversion device is capable of providing a controlled flow of steam, in particular between 10 g/h and 10 kg/h, at a constant pressure of 0 to several tens of relative bar.

For instance, this constant pressure liquid to steam conversion device includes:

• a liquid inlet through which a quantity of liquid is injected at a given instant at a constant liquid flow rate falling within a predetermined range of flow rates, where the maximum flow rate in this range of flow rates is less than or equal to 10 kg/h;

• a heating surface having a downward slope defining a flow route allowing the quantity of liquid to flow by gravity along the route from the inlet, and a temperature rise of the quantity of injected liquid as it flows along the route until total evaporation of each mole of this quantity of liquid before the end of the route.

Furthermore, the heating surface is open in order to allow a direct evacuation of the steam thus formed, and the linear thermal power applied by this heating surface to the liquid along the route is selected according to at least the maximum length of the route and the thermal power needed to evaporate all of a maximum quantity of injected liquid according to the maximum flow rate of the flow range.

In terms of the method, the generation of steam or the conversion of liquid to steam at atmospheric pressure or at a constant pressure with the generator or device described above includes in particular:

• the supply of energy to the heating surface described above so that the heating surface has a linear thermal power sufficient for the evaporation of a quantity of liquid to be injected at a predefined flow rate;

• the injection of the quantity of liquid at moment t, depending on the predefined flow rate;

• flowing, at least by gravity, of the quantity of liquid along the heating surface defining a flow route and heating the quantity of liquid as the liquid flows, until it has all evaporated before reaching the end of the flow path.

BRIEF DESCRIPTION OF THE FIGURES.

The invention will be better understood from reading this description, given simply as an example, and produced in relation to the attached illustrations, among which:

• Figure 1 is a schematic representation of a device for converting a liquid into steam according to one embodiment of the invention in which the channel is helical;

• Figure 2 is a partial schematic representation showing an axial half-section of the steam generator helical channel of Figure 1; and

• Figure 3 is a sectional perspective view of the steam generator according to one embodiment of the invention.

DETAILED DESCRIPTION OF AN EMBODIMENT OF THE INVENTION

The steam generator according to one embodiment of the invention is illustrated in figure 3 and comprises in particular:

• a liquid flow regulator 6;

• a liquid to steam conversion device 10; and a regulated energy source 7;

The liquid flow regulator **6** is configured to supply the conversion device **10** with an amount of liquid **50** at a given instant at a constant flow rate of between 10 g/h and 10 kg/h, for example. In practice, the flow rate of the liquid is set by the user by means of a setpoint **60** and corresponds substantially to the steam flow rate to be produced by the conversion device **10.** The liquid water flow regulator **6** can be an off-the-shelf regulator, e.g. a thermal mass flow regulator or Coriolis.

The liquid to steam conversion device **10** is configured to evaporate all the liquid **50** and to generate steam **51** at a regular flow rate corresponding substantially to the injected liquid flow rate.

The structure of the conversion device **50** for converting liquid, especially water, into steam **51** according to a particular embodiment illustrated in Figure 1, is described below.

This conversion device is specifically in the form of an enclosure **4** with a steam outlet **42** and a liquid inlet **40** designed to be coupled to the water flow regulator **6**.

The enclosure **4** is in particular made up of an outer shell **43** which is lagged and an inner shell **44** which retains the steam produced in the enclosure **4** and channels that steam to the steam outlet **42** so that it can be used. This inner shell **44** is made more particularly of metal and is heated to be kept at a high enough temperature, e.g. 200° C, to prevent condensate from forming on the inner walls of the enclosure. This shell **44** is also designed to resist the maximum operating pressure of the steam generator. For instance, for a production flow rate of 0 to 5 kg/h at atmospheric pressure, the inner shell has a diameter of 220 mm and a height of 470 mm in 2 mm thick sheet metal.

In one variant, the internal volume of the enclosure **4** being connected, via the steam outlet **42,** with the outside, the inside pressure of the enclosure is therefore governed by the outside pressure. For example, the outlet **42** is connected directly to the inlet of an electrolyzer operating at atmospheric pressure, so that the inside pressure of the enclosure **4** equals the atmospheric pressure and is therefore approximately constant. Naturally, the outside pressure determining the inside pressure of the enclosure can be different, and especially higher. Similarly, a pressure regulator can be included to directly regulate the inside pressure of the enclosure to obtain a substantially constant pressure. In another variant, during operation, the inside pressure of the enclosure remains approximately the same as the pressure of the steam produced.

An open helical channel **2**, thus shaped for reasons of compactness, is arranged in this enclosure **4.** This channel **2** is in particular machined into the outer perimeter of a part **1,** for instance a stainless steel cylinder, resting on a base **41** supporting the enclosure **4.** This support base is notably horizontal, i.e. substantially perpendicular to the direction **G** of gravity.

This channel, according to this embodiment, slope downward, for example between 1 and 4%, so that the liquid water **50** flows by gravity from the liquid inlet **40**. In addition, a wired electric heating element **3** having, for example, a round cross-section, is inserted into the channel **2** and acts as a heating surface.

This heating element **3** is placed in the channel, and in particular as close as possible to the bottom of the channel, to extend along the entire length of the channel to define a route for the circulation of the liquid. This heating element **3** is supplied with power by the regulated energy source 7 and is also intended to be put in contact with the circulating liquid to bring it up to its evaporation temperature. In practice, to efficiently transmit the thermal energy to the liquid to be evaporated, the contact surface between the heating element and the liquid must be big. According to one embodiment, comprising an electric element 10 m long and 3.5 mm in diameter, the contact surface area is estimated at 550 cm2.

More precisely, as shown in Figure 2, this channel 2 includes a channel bottom opposite an opening and sloping walls. In particular, the opening is oriented so to allow a substantially radial evacuation of the steam produced. The angle of inclination formed between the horizontal H and each of the channel walls 20 in the direction from the channel bottom to the opening is at least 30°. This inclination allows the liquid to be directed towards the bottom of the channel and ensures permanent contact of the circulating liquid with the heating surface.

The bottom of channel 2 also has a groove 21 in which the heating element is inserted. This groove 21 is open and extends as an extension of the channel. Groove 21 has a width and depth that are smaller than those of the channel and are sized in particular to allow the heating element to be inserted by peening and the liquid to flow into the channel by capillary action. For example, for a 3.5 mm diameter heating surface and a flow range of 0 to 5 l/h, the channel 2 is 8.5 mm high and 17 mm deep and the groove is 3.5 mm high and 3.5 mm wide to allow the peening of the wired electric element 3.

Capillary flow is particularly enhanced in the case of a low liquid flow rate, and especially for oil, where the liquid is injected by drip feed. The capillary flow allows the liquid to be evaporated to be spread evenly over the heating surface, without the formation of a train of drips, guaranteeing a regular steam flow at the outlet. In addition, water can also be injected into the channel by capillary action. For instance, the liquid inlet can be a stainless steel pipe positioned to be in contact with the channel and the heating element and sized to allow capillary suction of the liquid into the channel, without drips forming.

Naturally, depending on the type of liquid injection, by drip feed or continuous methods, and the liquid flow rate to be added, the device can be built without the groove. In this case, the heating element is placed as close as possible to the bottom of the channel and the liquid flows by gravity alone.

In another variant, the wired heating element can be flat, e.g. inserted in the bottom of the channel or in the groove or by a coat of a metallic material covering one or more walls of the channel and/or groove.

The heating element 3 is also coupled to the energy source 7, a regulated voltage source (not shown) for instance, to provide the necessary energy to heat the water as it flows down the channel until it evaporates. The steam 51 produced is then evacuated peripherally through the opening of the channel without disturbing the flow, to guarantee the regular operation of the heater.

To ensure efficient evaporation of all the liquid added to the channel with or without boiling, the liquid must be heated consistently. In practice, the heating element is calibrated in such a way as to ensure a rise, preferably regular, of the temperature of a quantity of standing water in the channel until its total evaporation before reaching the end of the route. The electric power to be supplied to the heating element can be optimized according to the quantity of water added, so as to distribute the water as evenly as possible over the whole length of the channel and to have very stable steam production with the lowest energy expenditure. This optimization can be done by calculating the energy needed to heat the water and then vaporize it, while allowing for the heat losses.

In practice, a maximum flow rate of liquid to be injected into the channel is defined, e.g. 10 kg/hour. This maximum flow rate defines a maximum quantity of liquid to be evaporated which, in this case, is 10 kg. The total thermal power required to vaporize this maximum quantity of liquid is calculated, naturally allowing for the initial temperature of the liquid and the pressure at which heating is carried out. For example, the total thermal power can be calculated to bring liquid water from 20° C to the state of superheated steam at 150° C at atmospheric pressure. This calculation is made, for example, according to the relations:

$$P = \dot{m}.Cp_1.(100 - 20) + \dot{m}.L + \dot{m}.Cp_2.(150 - 100)$$
$$P = \dot{m}.(Cp_1.(100 - 20) + L + Cp_2.(150 - 100))$$
$$P = \dot{m}.(4195.(100 - 20) + 2{,}258.10^6 + 2030.(150 - 100))$$
$$P = \dot{m}.2695100$$
$$P = 2{,}77.10^{-3}.2695100$$
$$P = 7486\ W$$

With:

- *P 48 Minimum required heating capacity [W];*

- *$\dot{m}$ water mass flow rate [2.77.10^{-3} kg/s] ;*

- *Cp_1:* Average specific heat of water between 20° C and 100° C [4195 J/(kg.K)] ;

- *Cp_2 :* Average specific heat of steam between 100° C and 150° C [2030 *J/(kg.K)] ;*

- *L : Latent heat of water vaporization [2,258,10^6 J/(kg.K)].*

Depending on the embodiment, the power of the heating element should preferably be chosen with a minimum of 30% additional heating capacity to obtain better reactivity when changing the evaporation setpoints. In the present case with a steam production rate of 10 kg/h, the recommended power for the heating element is (1.3.P)=9732 W, rounded to 10 kW.

The length of this element is calculated to limit the linear thermal power within the efficiency limit of the linear heat transfer to liquid water, preferably in the range 0.5 to 1 kW/m. In the present case with a steam production rate of 10 kg/h, i.e. 10 kW total power, the recommended length for this heating element is therefore between 10 and 20 m.

In other words, the method of calculating the linear thermal power consists of the following steps:

• define a maximum flow rate of liquid to be injected which maximum flow rate gives the maximum quantity of liquid to be evaporated;

• calculate the total thermal power required to vaporize that maximum amount of liquid, i.e. to raise the temperature of the amount of liquid from an initial temperature to at least its evaporation temperature, to perform the actual evaporation and to superheat the steam produced; and calculate the linear thermal power to be produced for a route length equal to the maximum route length.

For example, the minimum total heating power P required to vaporize an amount of liquid can be obtained by summing the energy P_1 required to heat the amount of liquid to its boiling point, the energy P_2 to carry out the actual vaporization and the energy P_3 to superheat the steam produced:

$P = P_1 + P_2 + P_3$

In particular, the calculation of the power required to raise a given flow of liquid from an initial temperature to a final temperature, e.g. its evaporation temperature, is, for example, given by the relation:

$$P_1 = \dot{m}.Cp_1.\Delta T_1$$

With:

- P_1 the power in Watt [W];
- $\dot{m}$ the flow rate of the liquid to be heated [kg/s];
- Cp_l the thermal mass capacity at constant liquid pressure [J/(kg.K)];
- ΔT_l the temperature difference between the final temperature to be reached and the initial temperature [K].

The calculation of the power needed to vaporize a given flow of liquid is, for example, given by the relation :

$P_2 = \dot{m}. L$

With:

- P_2 the power in Watt [W];
- $\dot{m}$ the flow rate of the liquid to be heated [kg/s];
- L the latent heat of vaporization at constant liquid pressure [J/kg].

In particular, the calculation of the power required to raise a given flow of steam from an initial temperature to a final temperature, e.g. its evaporation temperature, is, for example, given by the relation:

$$P_3 = \dot{m}.Cp_3.\Delta T_3$$

With:

- P_3 the power in Watt [W];
- $\dot{m}$ the flow rate of the steam to be heated [kg/s];
- Cp_3 the thermal mass capacity at constant steam pressure [J/(kg.K)];
- ΔT_3 the temperature difference between the final temperature to be reached and the initial temperature [K].

Naturally, this relationship can be weighted taking into account possible heat losses, preferably by adding a minimum margin of 30% to the total power.

Thus, the water to be evaporated is added into the channel via the liquid inlet and flows into the channel by gravity and/or capillarity. The water heats as it descends until it evaporates. Steam is evacuated from the periphery of the channel without disturbing the flow, which guarantees regularity of operation.

In one variant, the thermal power supplied by the heating element can be regulated. In practice, the power source **7** can be regulated according to one or more measurement parameters or supplied during the operation of the generator. For example, it is possible to couple a temperature sensor to a voltage regulator. The temperature sensor, for instance a thermocouple, measures for instance the temperature **71** of the heating element at the end of the route. The voltage **70** to be supplied to the heating element is then adjusted according to this measured temperature and a setpoint temperature corresponding to the thermal power required to vaporize the water. In practice, there is a table or diagram showing the correspondence between temperature, water flow rate and the electrical energy to be supplied.

The heating element described is a wired electrical heating element. As a variant, the wire element is replaced by a tube through which a heat transfer fluid, for instance oil, flows while the heat transfer fluid is heated so as to provide a thermal output as described above.

In this way, the evaporator proposed in this application is adapted to generate low steam flows, in particular flows between 10 g/h and 10 kg/h and does not require the use of carrier gas.

In particular, the proposed evaporator allows dry steam to be generated at a constant pressure, and the desired steam output is obtained simply by regulating the liquid inlet flow rate. In particular, the injection of liquid by drip feed can be combined with the generation of a steady flow of steam.

This is made possible thanks in particular to:

- gravitational and/or capillary flow to ensure a consistent distribution of the liquid on the heating surface;

- consistent heating of the liquid all along the flow route which ensures a regular temperature rise of the liquid as well as a regular evaporation of the liquid; and an
- optimal evacuation of the steam produced without disturbing the evaporation process.

PATENTKRAV

1. Indretning til konvertering, som fungerer ved konstant tryk, af en væske (50) til damp (51), omfattende:

- en indeslutning (4), som har et væskeindløb (40) til at modtage en konstant strømning af væske, et dampudløb (42) og en indvendig skal (44), som er i stand til at tilbageholde dampen (51), som fremstilles, og til at kanalisere denne damp (51) til det nævnte dampudløb (42);

- et element (1) anbragt indvendigt i indeslutningen (4) på en understøtningsbund (41); og

- en åben skruelinieformet kanal (2) udformet på den udvendige omkreds af det nævnte element (1);

- den nævnte kanal (2) er konfigureret til at dirigere væsken (50) fra væskeindløbet (40) under dennes fordampning;

kendetegnet ved, at konverteringsindretningen (10) også omfatter:

- et varmeelement (3) indsat i den nævnte kanal (2);

• den nævnte kanal (2) har skråtstillede vægge til at dirigere væsken (50) imod bunden af kanalen (2);

- det nævnte varmeelement (3) er anbragt ved den nævnte bund af den nævnte kanal (2) for at tilsikre kontakt imellem væsken (50) og varmeelementet (3).

2. Konverteringsindretning ifølge krav 1, **kendetegnet ved, at** indretningen omfatter organer til at opvarme den indvendige skal (44), hvilken indvendig skal (44) er fremstillet af et metallisk materiale.

3. Konverteringsindretning ifølge krav 1 eller 2, **kendetegnet ved, at** det nævnte element (1) svarer til en cylinder af rustfrit stål.

4. Konverteringsindretning ifølge ethvert af kravene 1 til 3, **kendetegnet vede, at** den nævnte skråtstilling af hver af væggene i kanalen 2 danner en skråtstillingsvinkel (a) i forhold til horisontalt (H), som er større end eller lig med 30°.

5. Konverteringsindretning ifølge ethvert af kravene 1 til 4, **kendetegnet ved, at** det nævnte varmeelement (3) svarer til et elektrisk varmeelement, eller et rør, igennem hvilket et varmeoverføringsfluid strømmer.

6. Konverteringsindretning ifølge ethvert af kravene 1 til 5, **kendetegnet ved, at** varmeelementet (3) er indsat i en not (21) i bunden af kanalen (2).

7. Konverteringsindretning ifølge ethvert af kravene 1 til 6, **kendetegnet ved, at** varmeelementet (3) har en total minimal termisk effekt *(Pmin)* bestemt i overensstemmelse med følgende relation:

$$Pmin = \dot{m}.(Cp_1.(Te — T_1) + L + Cp_2.\ (T_2 — Te))$$

med:

T_1 svarende til indløbstemperaturen for væsken (50) i indeslutningen (4);

T_2 svarende til den ønskede damptilstandstemperatur (51);

Te svarende til kogepunkttemperaturen for væsken (50);

$\dot{m}$ svarende til massestrømningshastigheden for væsken (50);

Cp_1 svarende til den gennemsnitlige specifikke varme for væsken (50) for væsken (50) imellem indløbstemperaturen Ti og kogepunktstemperatur *Te;*

Cp_2 svarende til den gennemsnitlige specifikke varme for væsken (50) imellem kogepunktstemperaturen *Te* og den ønskede temperatur T2; og

L svarende til den latente varme for fordampning af væsken (50).

8. Konverteringsindretning ifølge ethvert af kravene 1 til 7, **kendetegnet ved, at** varmeelementet (3) har en total minimal termisk effekt *(P)* bestemt i overensstemmelse med følgende relation:

$$P = 1,3 * \dot{m}.\ (Cp_1.\ (Te — T1) + L + Cp_2.\ (T2 — Te))$$

med:

T_1 svarende til indløbstemperaturen for væsken (50) i indkapslingen (4);

T_2 svarende til den ønskede damptilstandstemperatur (51);

Te svarende til kogepunktstemperaturen for væsken (50);

$\dot{m}$ svarende til massestrømningshastigheden for væsken (50);

Cp_l svarende til den gennemsnitlige specifikke varme for væsken (50) imellem indløbstemperaturen Ti og kogepunktstemperaturen Te;

Cp_2 svarende til den gennemsnitlige specifikke varme for væsken (50) imellem kogepunktstemperaturen Te og den ønskede temperatur T2; og

L svarende til den latente varme for fordampning af væsken (50).

9. Dampgenerator (51) omfattende:

- en indretning til konvertering af en væske (50) til damp (51) i overensstemmelse med ethvert af kravene 1 til 8;

- en væske- (50) strømningsregulator (6) forbundet med væskeindløbet (40) og konfigureret til at tilvejebringe en væske med en konstant massestrømningshastighed, som er mindre end eller lig med 10 kg/time; og

- en reguleret effektforsyning (7) forbundet med varmeelementet (3) til at regulere den totale termiske effekt (*P*) for varmeelementet (3) som en funktion af massestrømningshastigheden for strømningshastighedsregulatoren (6).

10. Dampgenerator ifølge krav 9, **kendetegnet ved, at** den regulerede effektforsyning (7) reguleres af en temperaturmåling af varmeelementet (3).

11. Dampgenerator ifølge krav 9 eller 10, **kendetegnet ved, at** strømningshastighedsregulatoren (6) er konfigureret til at generere en massestrømningshastighed på imellem 10 g/time og 10 kg/time.

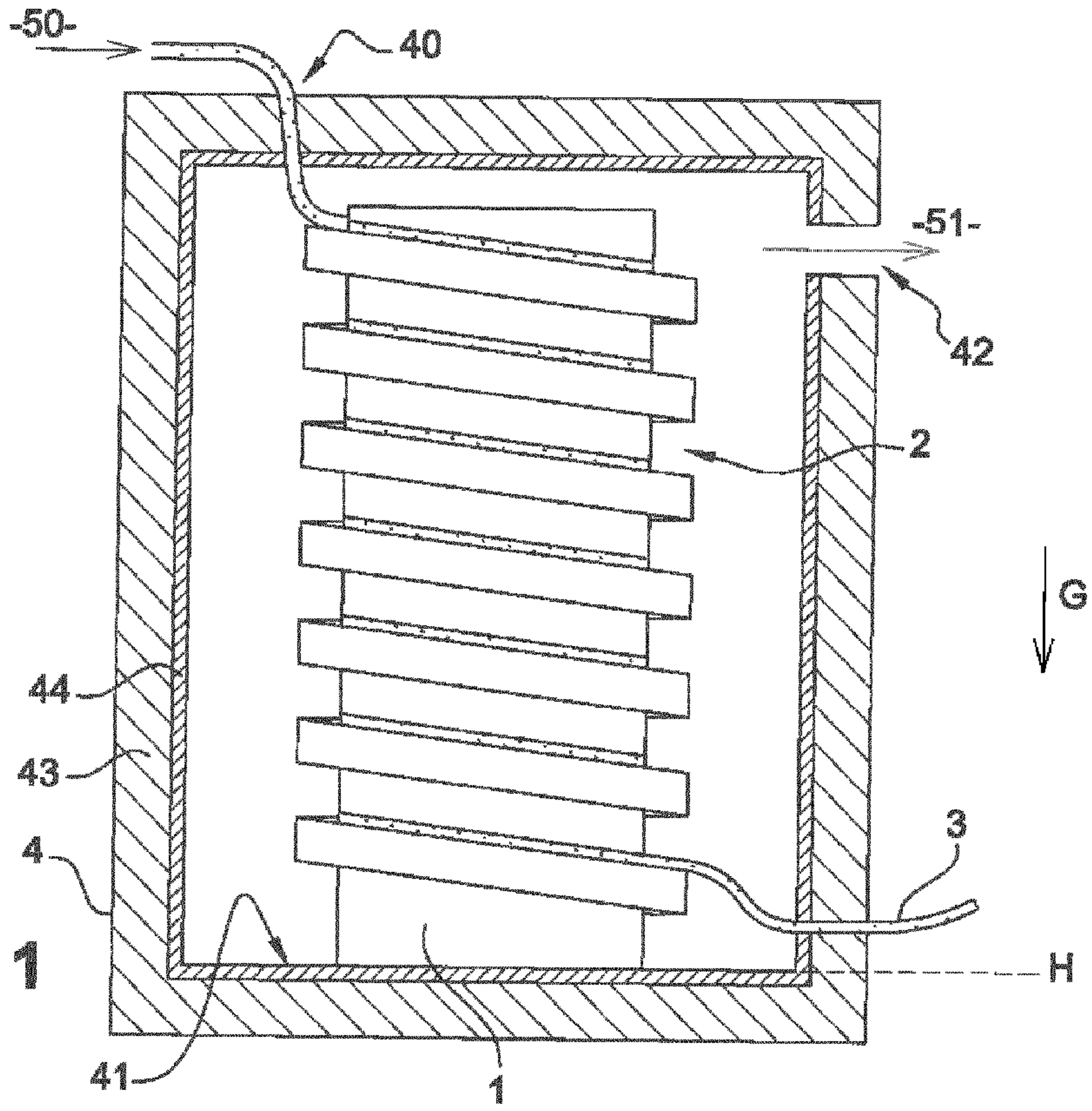

Fig. 1

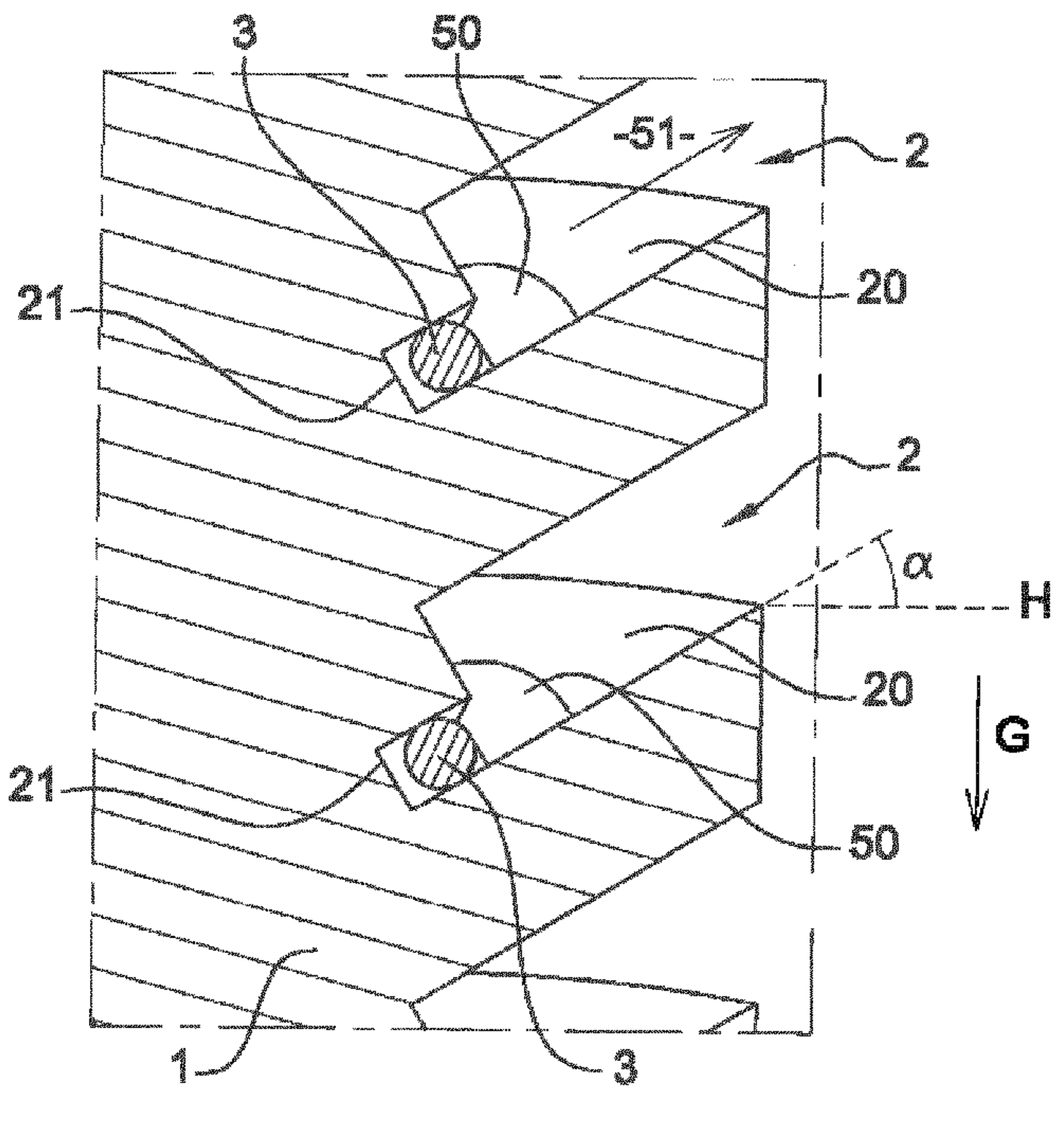

Fig. 2

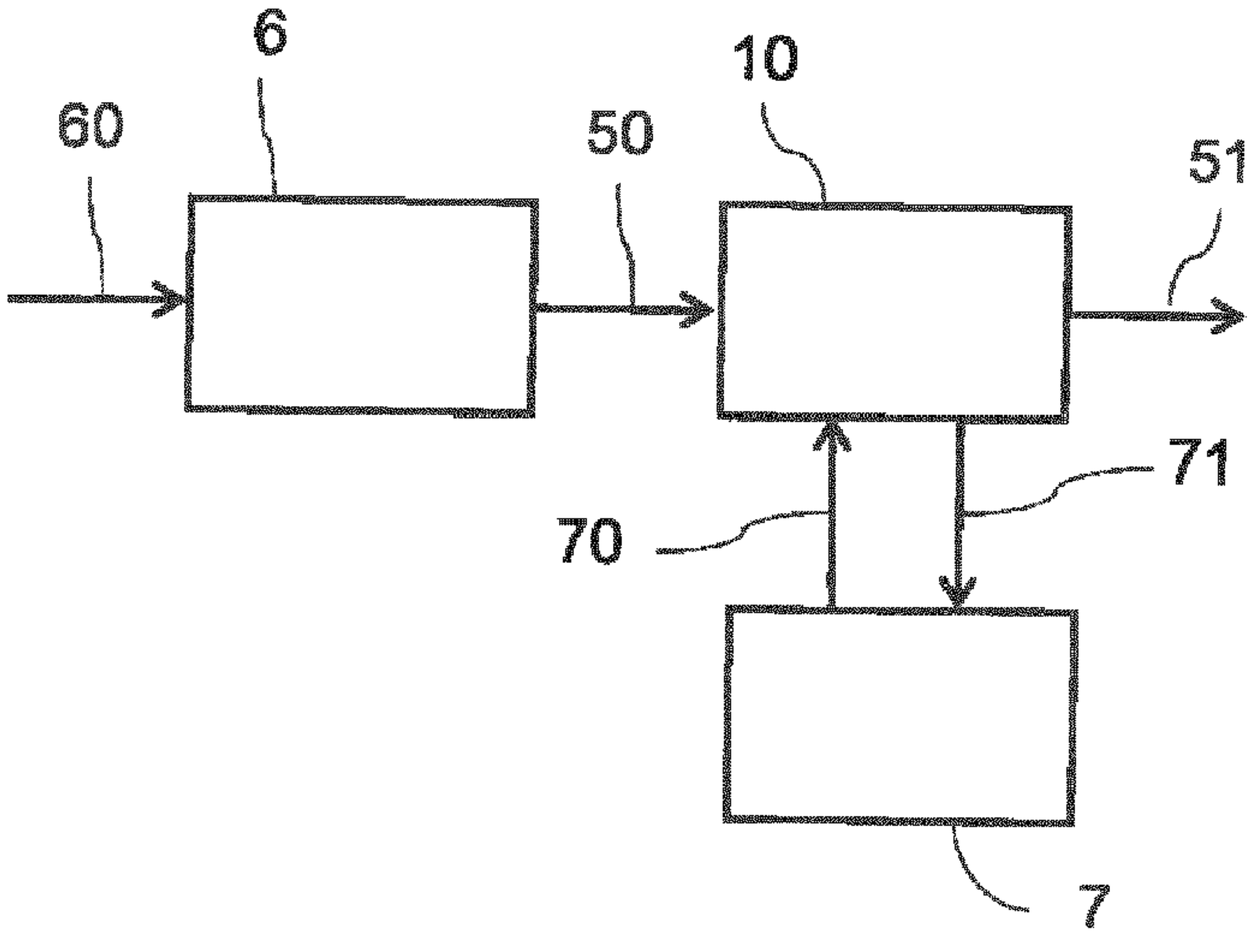

Fig. 3