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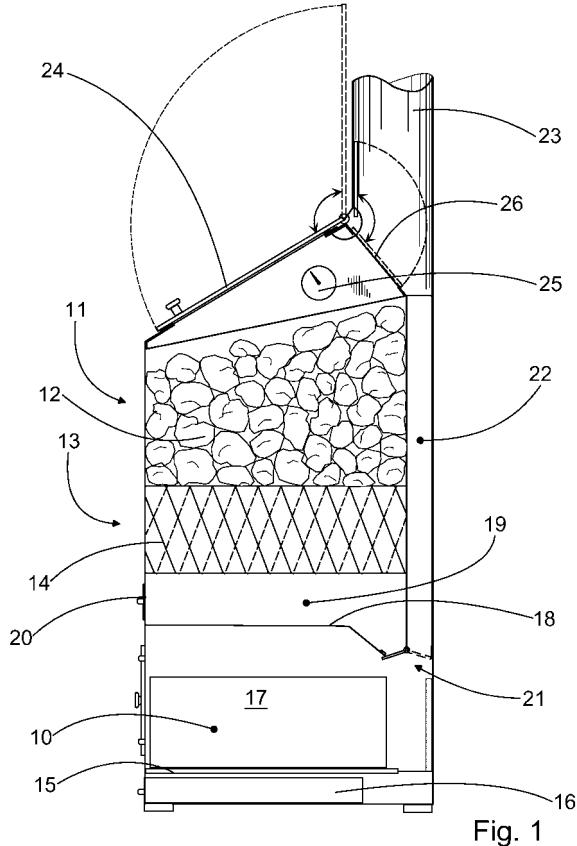
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### (54) Fireplace

(57) The invention relates to a fireplace, which includes a firebox (10) for burning a solid fuel and creating combustion gases. The fireplace also includes a heat store (11) for storing the heat of the combustion gases in the fireplace. The fireplace further includes a pre-heat store (13), which is fitted between the firebox (10) and the heat store (11) in the direction of flow of the combustion gases. The pre-heat store is formed of a metal honeycomb (14), the thermal storage capacity of which is greater than that of the heat store (11). The thermal efficiency of the fireplace is then improved, thus reducing carbon-dioxide emissions, as the amount of fuel required is reduced.



## Description

**[0001]** The present invention relates to a fireplace, which includes

- a firebox for burning a solid fuel and creating combustion gases, and
- a heat store for storing the heat of the combustion gases in the fireplace.

**[0002]** In wood-fired fireplaces, such as sauna stoves, open fireplaces, and closed stoves, poor thermal efficiency is a general problem. For example, in a continuously-heated sauna stove, the thermal energy released from the combustion of wood is transferred primarily by radiation from the walls of the firebox of the stove to the stove stones. In other words, the combustion gases first heat the walls of the firebox and are not in direct contact with the stones. Thus, the share of convection in the transfer of thermal energy is small, especially as the contact surface of the stove stones with the walls of the firebox are small and the thermal conductivity of the stove stones is low. Mainly for these reasons, the thermal efficiency of a continuously-heated is very low. The estimated efficiency is less than 20%.

**[0003]** There also exist so-called single-firing stoves, in which the efficiency of the thermal transfer is substantially better than in continuously-heated stoves. In single-firing stoves, the combustion gases travel among the stove stones, so that the gases are in direct contact with the stones. Thermal energy is then transferred to the stove stones with the aid of both convection and radiation. However, the thermal efficiency remains low for several different reasons, at an estimate of less than 40%. Firstly, the flow of combustion gases is distributed unevenly among the stove stones. Further, the surface area which will be in contact with the combustion gases is relatively small. The thermal conductivity of the stones is also poor. The thermal efficiency is further reduced by the manner of operation of a single-firing stove. The embers must be burned completely before beginning to use the sauna, to avoid carbon monoxide forming and spreading into the sauna room. As the embers die, the temperature of the combustion gases passing through the single-firing stove drops and at the same time the stove begins to cool. Corresponding problems also appear in other wood-fired fireplaces. In addition, the low thermal efficiency makes it necessary to use a great deal of excess fuel to heat the fireplace. Unnecessarily large amounts of carbon dioxide, carbon monoxide, and hydrocarbon emissions, as well as nitrogen oxide and particulate emissions are then passed into the air. In one known single-firing sauna stove, the manufacturer recommends using 10 - 20 kg of dry firewood for each firing.

**[0004]** The invention is intended to create a new type of fireplace. The characteristic features of the present invention are stated in the accompanying Claims. In the fireplace according to the invention, a new type of heat

storing structure is used, by means of which heat is made available more efficiently than previous. In practice, the fireplace can be made hot more rapidly than previously by using less fuel. At the same time, emissions are substantially reduced.

**[0005]** In the following, the invention is examined in detail with reference to the accompanying drawings showing one embodiment of the invention, in which

- 5 10 Figure 1 shows a cross-section and side view of the fireplace according to the invention,
- 15 Figure 2 shows an angled front view of the fireplace according to the invention,
- 15 Figure 3 shows a top view of the front heat store according to the invention, and
- 10 Figure 4 shows a three-dimensional view of the front heat store according to the invention.

**[0006]** Figures 1 and 2 show the fireplace according

- 20 20 to the invention, using a single-firing sauna stove as an example. Generally, the fireplace includes a firebox 10, for burning a solid fuel and creating combustion gases. Firewood is usually used as the fuel. In addition, the fireplace includes a heat store 11 for storing the heat of the combustion gases in the fireplace. In a sauna-stove application, the heat store 11 is formed of stove stones 12. According to the invention, the fireplace further includes a pre-heat store 13, which is fitted between the firebox 10 and the heat store 11 in the direction of flow of the combustion gases. In addition, the pre-heat store is formed of a metal honeycomb 14, the heat-storage capacity of which is greater than that of the heat store 11. Thus, the thermal energy of the hot combustion gases is bound to the pre-heat store as efficiently as possible, 30 35 from where the heat is then released to the heat store. At the same time, the thermal efficiency improves substantially, thus reducing carbon-dioxide emissions, as the amount of fuel required is reduced. In other words, the energy contained in the fuel is exploited more efficiently than previously. Thus, more heat is obtained from the same amount of fuel. Alternatively, the same heat is obtained using a small amount of fuel than previously.

**[0007]** The example sauna stove is square and has dimensions of 450 mm x 450 mm. The height of the stove

- 45 to the upper surface of the stove stones is 800 mm. Beneath the firebox 10 is a grate 15, which is wide enough and long enough to provide a sufficient amount of oxygen for combustion. Beneath the grate 15 is an ash box 16. According to the invention, the volume of the firebox is 50 essentially as large or larger than the volume of the solid fuel required to charge the fireplace. Thus, the amount of firewood required to heat the fireplace will easily fit at one time into the firebox. In the example sauna stove, the firebox is 300-mm wide and high, and 450-mm deep.
- 55 In addition, at the edges of the firebox there are side plates 17 restricting the width of the combustion chamber, which prevent the firewood from spreading.

**[0008]** Air can flow from outside the side plates and

beneath the grate to under and to the side of the firewood. Air can also flow to above the firewood, to ensure the availability of the oxygen required for the combustion of the hydrocarbons vaporized from the firewood.

**[0009]** The spacious firebox permits efficient combustion of the fuel. In addition, the bottom surface area of the firebox 10 is preferably larger than the surface area of the heat store 11 and the pre-heat store 13. Thus, the combustion gases spread evenly while at the same time the pre-heat store heats throughout. In the example sauna stove, there is also a combustion chamber 19, delimited by a wall 18, between the firebox 10 and the pre-heat store 13 in the direction of flow of the combustion gases. The wall 18 guides the combustion gases into the combustion chamber 19, into which additional air can be led if necessary, guided by a slotted plate 20, in order to regulate the stove's internal air circulation.

**[0010]** In a single-firing sauna stove, the damper (not shown) is closed during sauna bathing. In order to allowing bathing to be started sooner, the stove includes shut-off means 21 for closing the flow connection from the firebox 10 to the combustion chamber 19. Thus, the flow connection from the firebox can be closed. In addition to this, the fireplace includes a bypass duct 22, starting from the firebox 10 and arranged to bypass the heat store 11 and the pre-heat store 13. Thus the embers can be burned completely, even after bathing has started. At the same time, unnecessary cooling of the heat store is avoided. In the embodiment shown in Figure 1, the bypass duct 22 is open, the shut-off means 21 being closed.

**[0011]** In the heating stage, the shut-off means 21 close the flow of combustion gases to the bypass duct 22 and allow the combustion gases to enter the pre-heat store 13 through the combustion chamber 19 and from there to the heat store 11 and through the upper flap 26 to the flue 23. The steam hatch 24 of the sauna stove is closed during the heating stage. Once there are only embers left in the firebox, the duct running through the stove is closed and at the same time the bypass duct from the firebox to the flue is opened. The embers can then burn completely with practically no cooling effect on heat store. At the same time, bathing can be started immediately, without the danger of carbon monoxide spreading into the sauna rooms. When the thermometer 25 shows that the sauna stove is in bathing condition, the shut-off means 21 are turned to the position, in which they close the flow of combustion gases to the combustion chamber 19 and at the same time open the flow to the bypass duct 22. The stove is now ready for bathing. Initially during bathing, the steam hatch 24 is opened and at the same time the upper flap 26 is closed, which prevents the flow of combustion gases to the flue 23. It takes about half an hour to heating the sauna stove to be ready for bathing.

**[0012]** The structure of the honeycomb can vary in different embodiments. In any event, the honeycomb 14 is formed of several flow channels 27, thus clearly increasing the heat-transfer surface area. The flow channels preferably cross over each other, which makes the mixing

of the combustion gases more efficient and helps to improve the thermal efficiency. The fireplace according to the invention includes an efficient pre-heat store of small size. The pre-heat store is, for example, a honeycomb of corrugated steel or cast-iron sheets stacked on top of each other, or intertwined with each other, which is located immediately after the firebox. The honeycomb can be made of a heat-resistant steel sheet web, which is corrugated, for example, at an angle of 70 degrees relates to the longitudinal direction of the web. Generally, each flow channel 27 is delimited by one or more sheet-like profile pieces 28, to create a good ratio between the flow cross-sectional area and the heat-storing mass. Figure 3 shows part of four cast-iron profile pieces 28, which

10 delimit several flow channels 27. The honeycomb can also be made from web-shaped cast profile pieces. The profile pieces are set opposite each other, in such a way that the ridge corners of the corrugations run in opposite directions. This creates a structure, in which there is a set of channels that cross over each other. Thus, the flow of the combustion gases is efficient and the combustion gases are mixed effectively. Figure 4 shows two profile pieces 28 on top of each other, the ridge corners of which run in different directions.

15 **[0013]** If necessary, the profile pieces can be surfaced with, for example, an oxidizing catalyst. The honeycomb will then act as a catalyser, which will further significantly reduce the amount of toxic emissions, such as carbon monoxide and hydrocarbons.

20 **[0014]** In terms of operation of the fireplace according to the invention, it also important for the firebox to be designed correctly. The firebox should be large enough for the amount of wood needed for heating to fit into it at one time. It is also essential to ensure that a sufficient amount of oxygen for combustion is available in the combustion chamber, so that the hydrocarbons vaporized from the firewood can burn properly. This further raises the temperature of the combustion gases, which is essential in order to minimize the hydrocarbon and carbon-monoxide emissions. Due to the space restrictions imposed on sauna stoves, the delay time in the combustion chamber of the combustion gases is short, being in the order of 0,2 seconds. In this case, complete combustion requires a temperature of more than 800°C. To achieve 25 a sufficient temperature, the combustion chamber can, if necessary, be insulated on the inside with heat-resistant insulation, for example, a rock-wool insulation. The insulation also reduces the temperature of the outer surface of the fireplace.

30 **[0015]** Efficient combustion reduces hydrocarbon, carbon-monoxide, and particulate emissions. The fireplace according to the invention also reduces carbon-dioxide emissions by improving the thermal efficiency of the fireplace by means of a pre-heat store and bypass flow. Thus 35 substantially less firewood is needed to heat the fireplace. For example, in a sauna-stove application, clearly more rapid heating than previously is achieved as an additional advantage.

**[0016]** In the fireplace according to the invention, there is a pre-heat store of corrugated steel plates stacked on top of each other, or intertwined with each other, immediately after the firebox. However, before the pre-heat store, a sufficient combustion chamber is arranged. In the aforementioned set of channels, there is a free gas-passage connection between the flow channels. This permits the combustion gases to move laterally, if the pressure of the gas is unevenly distributed inside the pre-heat store. If there is a greater flow in some part of the honeycomb, then a greater back pressure will arise, which will automatically push the combustion gases to travel partly laterally. The flow, and at the same time also the temperature distribution, in the pre-heat store will then equalize. This will improve the efficiency of the pre-heat store and reduce the pressure loss caused by the honeycomb.

**[0017]** In the channels of the honeycombs there is typically a laminar flow. In that case, the flow velocity will be greatest in the centre of the flow channel and will diminish rapidly down to zero at the surface of the wall. A so-called stationary boundary layer, which forms an insulation reducing heat transfer, is also known. In the honeycomb according to the invention, the flow channels cross over each other and, due to this, each flow channel continually narrows and widens. This prevents a stationary boundary layer from forming and substantially improves the transfer of heat from the combustion gases to the pre-heat store.

**[0018]** The relative differences of different shapes of flow channel are depicted by the so-called Nusselt number (Nu). The Nusselt number can be used to depict the heat transfer of a surface relative to a situation, in which only thermal conduction occurs. For example, the Nusselt number for a square-shaped flow channel is about 3,0, when the flow velocity is 2 m/s. Correspondingly, the Nusselt number for a mixing flow channel according to the invention is about 12. In other words, heat is transferred to the heat store four times more efficiently, compared to a square-shaped flow channel.

**[0019]** The above example compares precisely structured structures, in which the flow distributions are relatively even. In a sauna-stove application, the size of the flow channels between the stove stones varies very greatly. The combustion gases then flow through the path of least resistance. In other words, the combustion gases flow through the largest openings. The flow resistance is proportional to the square of the hydraulic diameter of the opening, i.e. to the cross-sectional area of the opening. There is then little flow of the combustion gases through the smallest gaps, so that the transfer of heat to the stove stones is inefficient. At the same time, the stove stones heat unevenly.

**[0020]** From the point of view of heat transfer, the heat-transfer surface area is also an important factor. The transfer of heat is directly proportional to the heat-transfer surface area. In a plate-type structure, this surface area is large, compared, for example, to heat-storing stoves.

It can be typically 0,05 - 1,5 m<sup>2</sup> for each storage cubic decimetre. This is much more than in stove stones and the walls of heat-storing stoves, which are typically 0,005 - 0,05 m<sup>2</sup>/dm<sup>3</sup>.

**5** **[0021]** The thermal conductivity of the stones used in stoves is about 6,0 - 6,5 W/mK. The thermal conductivity of cast iron is about 40 - 45 W/mK. In other words, the thermal conductivity of cast iron is 6 - 7 times that of stone. As heat transfer takes place primarily with the aid of convection, the transfer of heat is proportional to the temperature difference of the gas and the heat-transfer surface. As heat transfers efficiently from the surface to the interior of the store material, the temperature difference remains as great as possible.

**10** **[0022]** As an example, the metal honeycomb described heats rapidly directly above a flow to a very high temperature of, for example, 700 degrees Celsius, thanks to its good heat-transfer properties. This is a great store of energy, through the specific thermal capacity of iron is relatively small, about 0,5 kJ/kgK. The heat can be utilized for the continuous heating during bathing of the stove stones above the pre-heat store in the stove. In open fireplaces, the heat is used to heat circulating air or the storage stones.

**15** **[0023]** One advantage of using a metal honeycomb pre-heat store is its ability to collect on its surface the soot arising during combustion, due to the mixing flow and thermophoresis. The soot adhering to the flow channels burns off, once the temperature of the surface reaches 600°C.

**20** **[0024]** The advantages of stones, bricks, or other ceramic heat-storage materials are a cheap price, a good heat-storage capacity (about 1 kJ/kgK), and, on the other hand, a relatively poor thermal conductivity and transfer ability compared to a metal construction. In the fireplace according to the invention, two different types of heat store are surprisingly combined, thus combining the advantages of both - the efficient heat-transfer ability of a metal pre-heat store and the large storage capacity and slow heat release of a ceramic heat store. The sauna stove according to the invention is also advantageously low, so that it also heats the lower parts of the sauna room.

**25** **[0025]** The amount of wood required to heat a sauna stove is, according to the accompanying calculation, as follows:

1. Cast-iron store (size 150 \* 450 \* 450 mm)

**30**

- volume = 1,5 dm x 4,5 dm x 4,5 dm = 30,4 dm<sup>3</sup>
- weight = 78 kg
- specific thermal capacity = 0,5 kJ/kgK
- stored energy 0 - 700°C (steam-creation range 100 - 700°C)
- $Q_{total} = 700 \times 0,5 \times 78 = 27,3 \text{ MJ}$
- energy available in the store for creating steam:

$$Q_{store} = 600 \times 0,5 \times 78 = 23,4 \text{ MJ}$$

## 2. Stove stones

- stone space =  $2,5 \text{ dm} \times 4,5 \text{ dm} \times 4,5 \text{ dm} = 50,6 \text{ dm}^3$
- weight by volume of steatite =  $2,98 \text{ kg/dm}^3$
- filling density = 50%
- amount of stone =  $0,5 \times 2,98 \times 50,6 = 75 \text{ kg}$
- specific thermal capacity =  $1 \text{ kJ/kgK}$
- heating of the stove stones 0 - 300°C
- stored energy =  $300 \times 1 \times 75 = 22,5 \text{ MJ}$
- energy available in the stove stones for creating steam:

$$Q_{\text{stone}} = 200 \times 1 \times 75 = 15 \text{ MJ}$$

## 3. Energy available for use in creating steam:

- $Q_{\text{steam}} = 23,4 \text{ MJ} + 15 \text{ MJ} = 38,4 \text{ MJ}$

## 4. Energy required to heat the stove:

- $Q_{\text{heating}} = 27,3 \text{ MJ} + 22,5 \text{ MJ} = 49,8 \text{ MJ}$

## 5. Amount of wood required for heating

- thermal value of wood about  $19 \text{ MJ/kg}$
- thermal efficiency about 70%
- amount of wood =  $49,8 \text{ MJ} / (0,7 \times 19 \text{ MJ/kg}) = 3,7 \text{ kg of dry wood}$

## 6. Stove's water-evaporation capacity

- specific thermal capacity of water =  $4,2 \text{ kJ/kgK}$
- water's heat of evaporation =  $2260 \text{ kJ/kg}$
- energy required to heat water 10 - 100°C and for evaporation =  $90^\circ\text{C} \times 4,2 \text{ kJ/kgK} + 2260 \text{ kJ/kg} = 2638 \text{ kJ/kg}$
- loss = consumption of energy for other than water evaporation = 20%
- stove's evaporation i.e. steam generating capacity =  $0,8 \times 38400 / 2638 \text{ kJ/kg} = 11,5 \text{ kg water}$

**[0026]** On the bases of the above calculation, a firebox-full (3,7 kg) of dry wood can heat the stove to bathing condition. In addition, 11,5 litres of water can be used to make steam. The sauna room will be ready for bathing in about half an hour, whereas in known single-firing sauna stoves the heating will take from one to two hours. In addition, only one-fifth of the firewood required for known stoves will be used. Rapid combustion can be ensured by using pieces of firewood that are smaller and drier than usual. The size of the firewood can be, for example,  $4 \times 4 \times 35 \text{ cm}^3$ , in which case the combustion surface area of the firewood will be large. The temperature of the flame will then be high, which will further promote the complete combustion of the combustion gases.

**[0027]** A new type of moveable combustion box, which is formed of a grate equipped with sides, can be used as

an alternative to a traditional firebox. The combustion box is pulled out of the stove's firebox along slider rails and the firewood and kindling are loaded into the combustion box. After this, the firewood is lit and the combustion box is pushed back into place. Ignition can be performed simultaneously from the side and the top. The lower part of the combustion box acts as a grate, in which there are transverse fins next to vertical supports, thanks to which a sufficient gap remains between the surface of the grate and the wood to ensure good air circulation. In a sauna-stove embodiment, the stove stones forming the heat store are laid on top of the pre-heat store. After the heating stage, the lower metal pre-heat store will be considerably hotter than the upper heat store. When bathing, this will mean a soft discharge of steam, because the stove stones forming the heat store will not be too hot. On the other hand, the stove stones will remain suitably warm for a long time, because the stove stones cooled by the water will receive additional energy from the hot metal pre-heat store.

## Claims

25 1. Fireplace, which includes

- a firebox (10) for burning a solid fuel and creating combustion gases, and
- a heat store (11) for storing the heat of the combustion gases in the fireplace,

30 **characterized in that** the fireplace further includes a pre-heat store (13), which is fitted between the firebox (10) and the heat store (11) in the direction of flow of the combustion gases, and which is formed of a metal honeycomb (14), the thermal storage capacity of which is greater than that of the heat store (11), so that the thermal efficiency of the fireplace is improved, thus reducing carbon-dioxide emissions, as the amount of fuel required is reduced.

35 2. Fireplace according to Claim 1, **characterized in that** the honeycomb (14) is formed of several flow channels (27), which cross over each other.

40 3. Fireplace according to Claim 2, **characterized in that** each flow channel (27) is delimited by one or more sheet-like profile pieces (28).

45 4. Fireplace according to Claim 3, **characterized in that** there is a catalysing surfacing in the profile pieces (28).

50 5. Fireplace according to any of Claims 1 - 4, **characterized in that** the bottom surface area of the firebox (10) is greater than the surface area of the heat store (11) and the pre-heat store (13).

6. Fireplace according to any of Claims 1 - 5, characterized in that there is a combustion chamber (19) delimited by a wall (18) between the firebox (10) and the pre-heat store (13) in the direction of flow of the combustion gases. 5

7. Fireplace according to Claim 6, characterized in that the fireplace includes shut-off means (21) for closing the flow connection from the firebox (10) to the combustion chamber (19). 10

8. Fireplace according to Claim 7, characterized in that the fireplace includes a bypass-flow channel (22), which is open when the shut-off means (21) are closed, starting from the firebox (10) and arranged to bypass both the heat store (11) and the pre-heat store (13). 15

9. Fireplace according to any of Claims 1 - 8, characterized in that the volume of the firebox (10) is essentially as large as, or larger than the volume of solid fuel required to charge the fireplace. 20

10. Fireplace according to any of Claims 1 - 9, characterized in that the fireplace is a sauna stove, in which the stove stones (12) forming the heat store (11) are laid on top of the pre-heat store (13). 25

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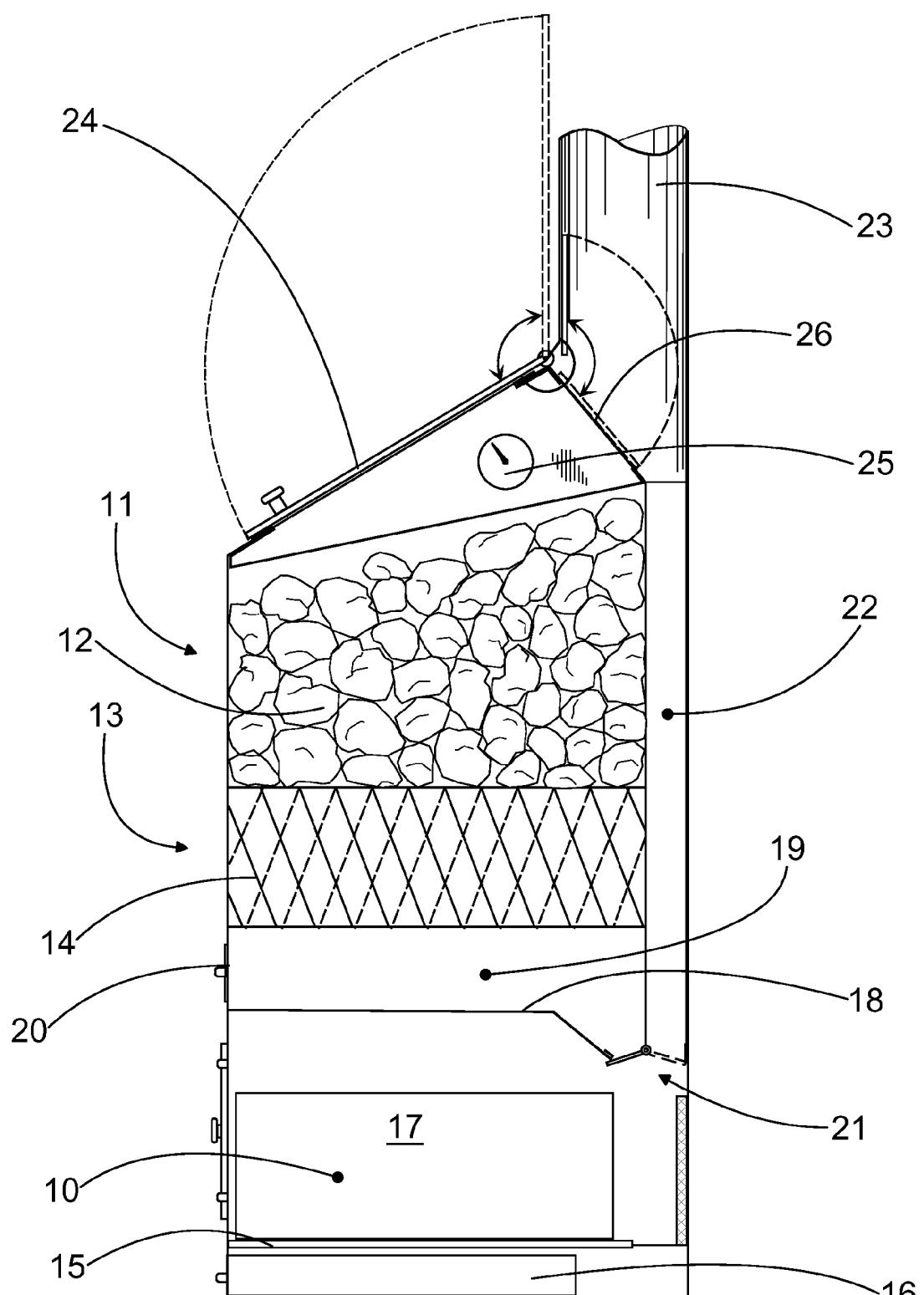


Fig. 1

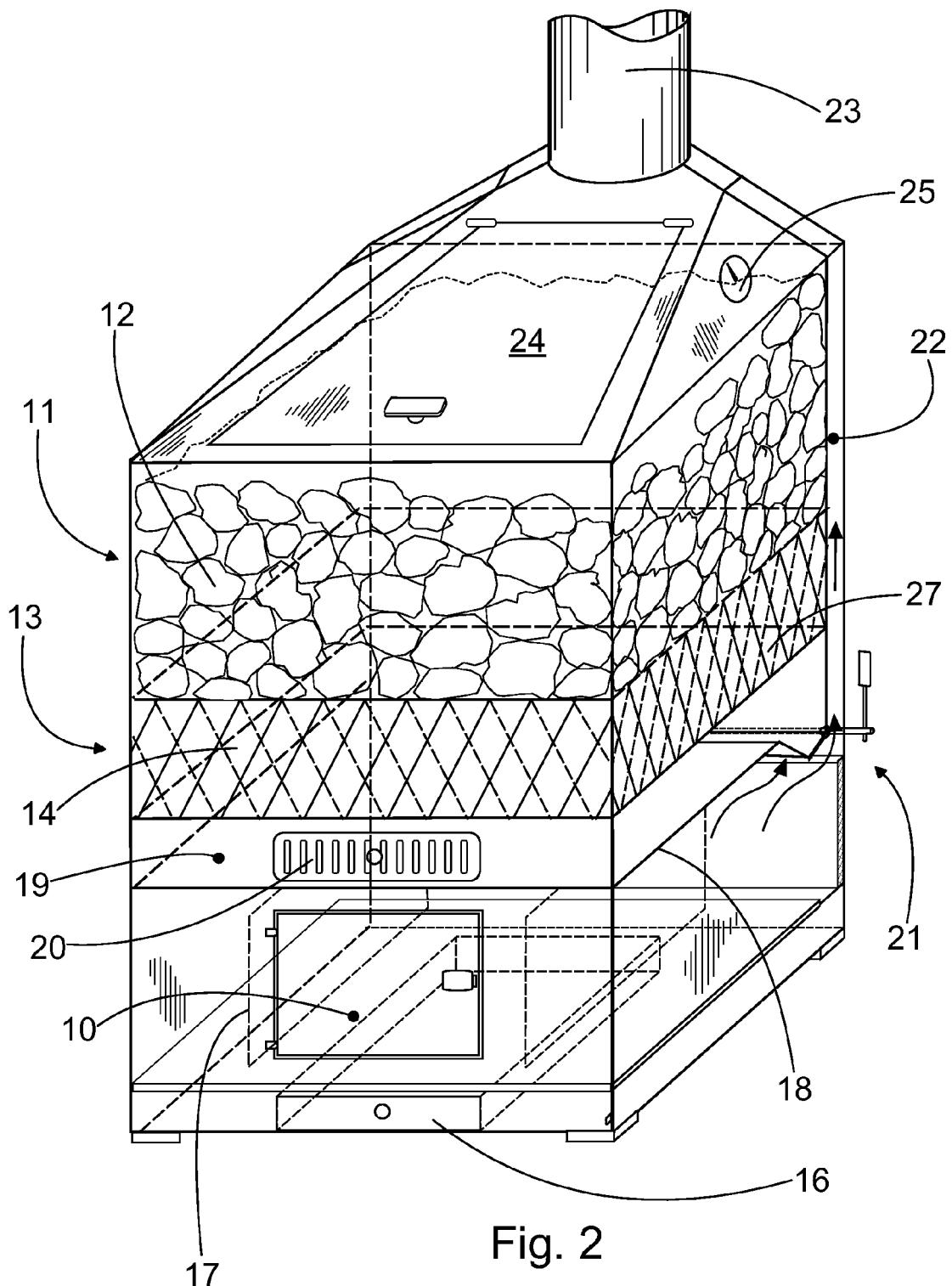


Fig. 2

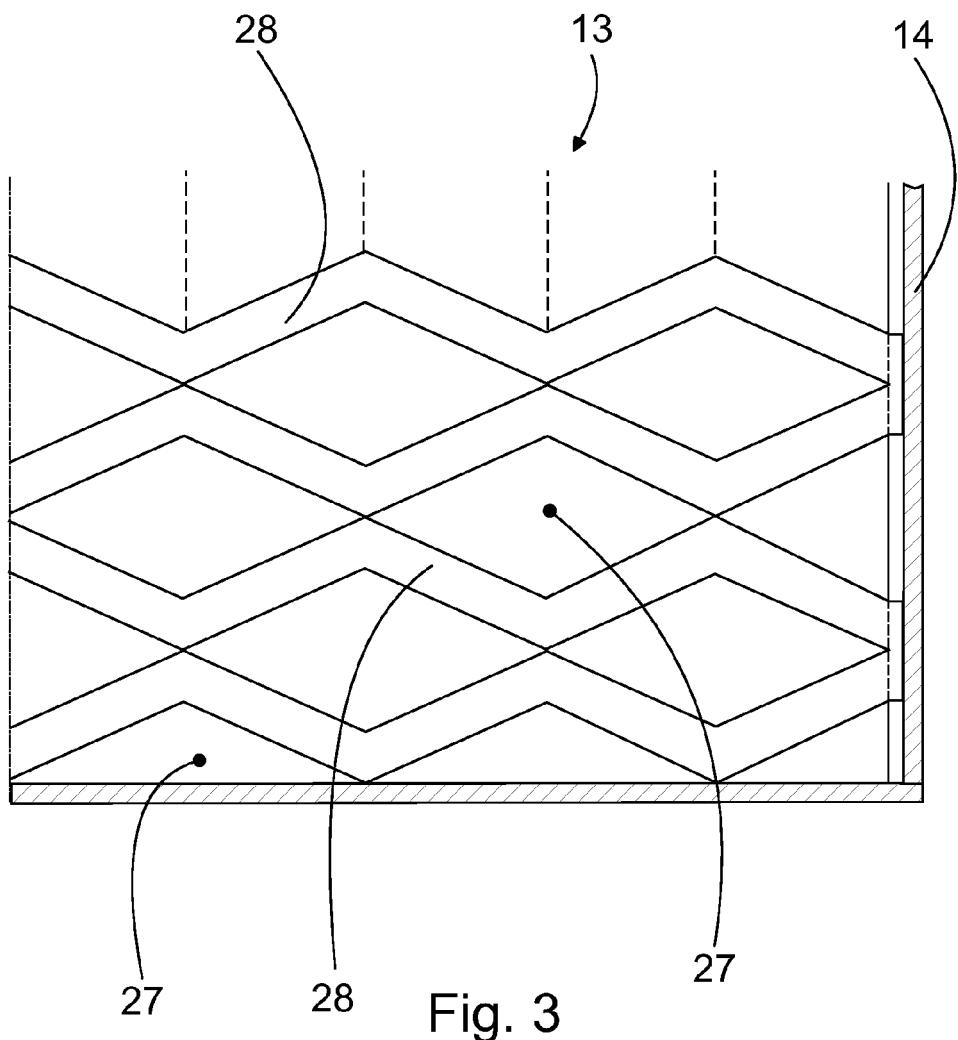


Fig. 3

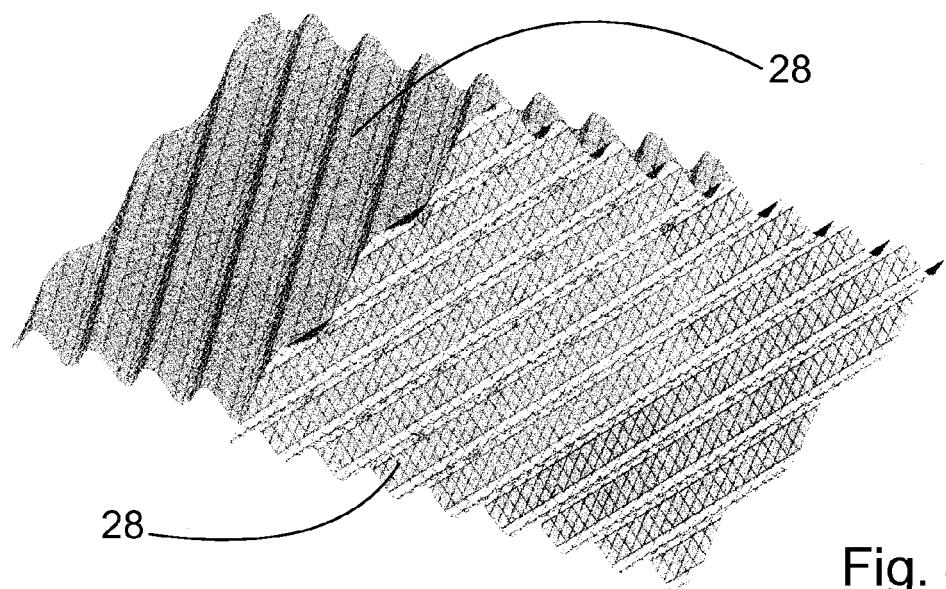


Fig. 4