March 19, 1968 W. HANLEIN ET AL 3,374,371

METHOD AND HEAT EXCHANGER FOR PREHEATING THE COMBUSTION AIR OF MAGNETOHYDRODYNAMIC GENERATORS

Filed May 3, 1965 4 Sheets-Sheet 1

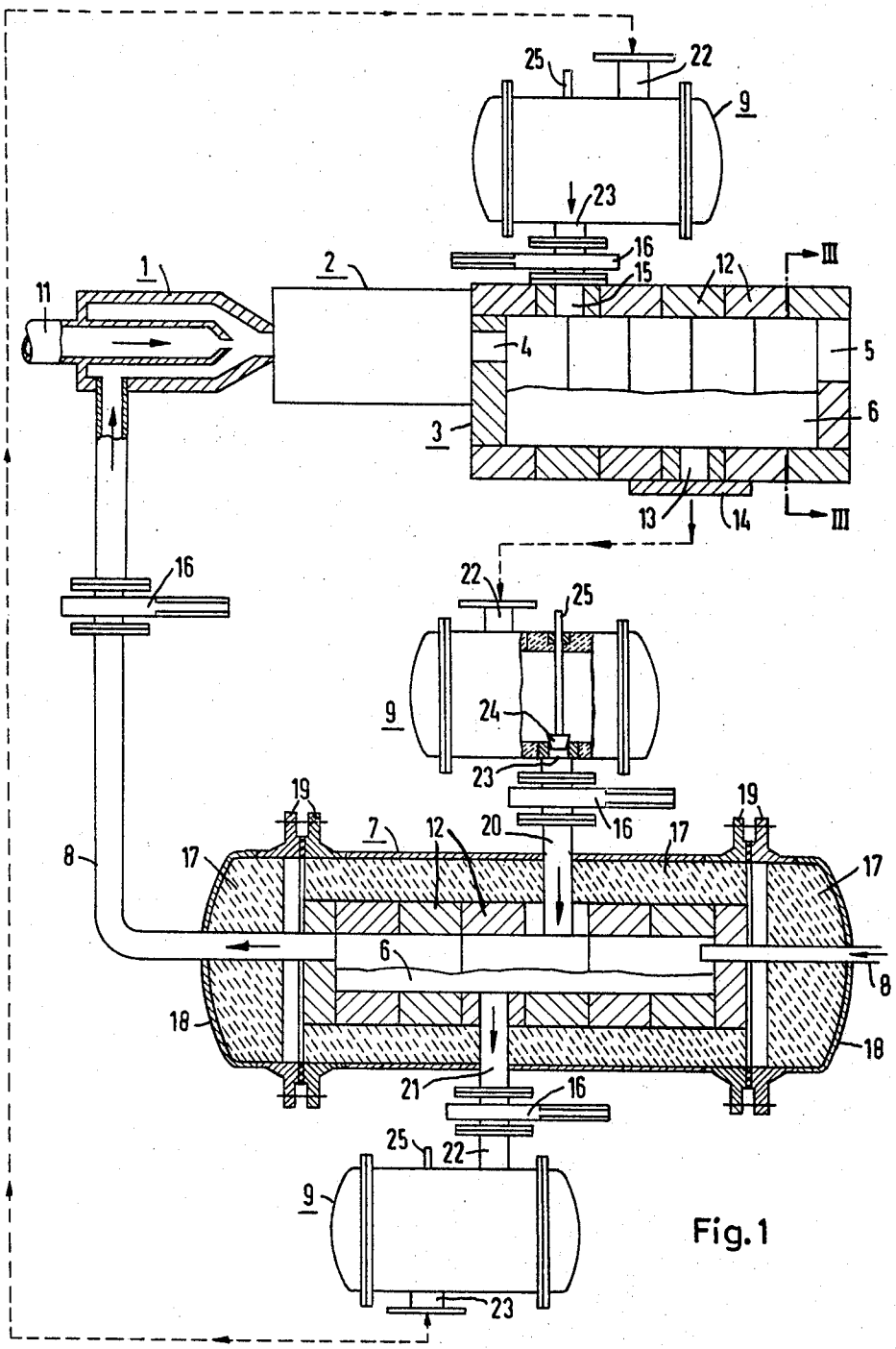


Fig. 1

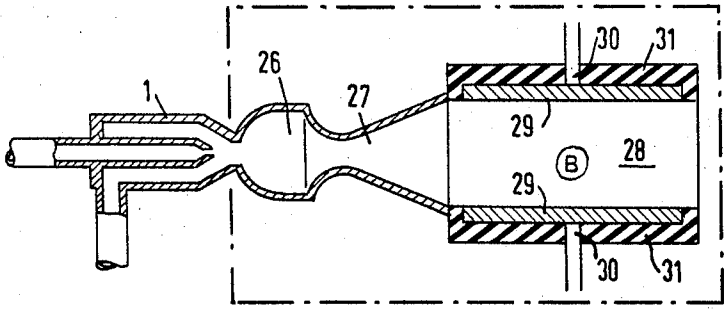


Fig. 2

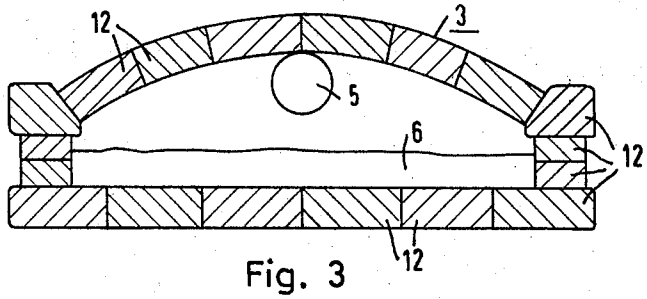


Fig. 3

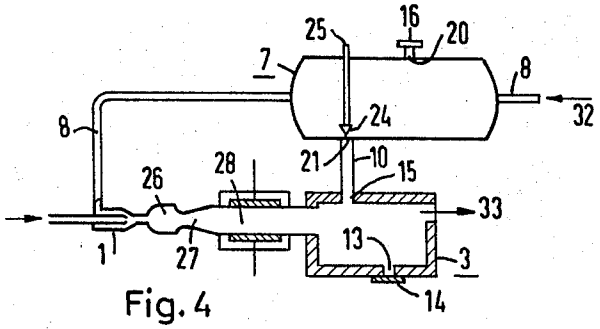


Fig. 4

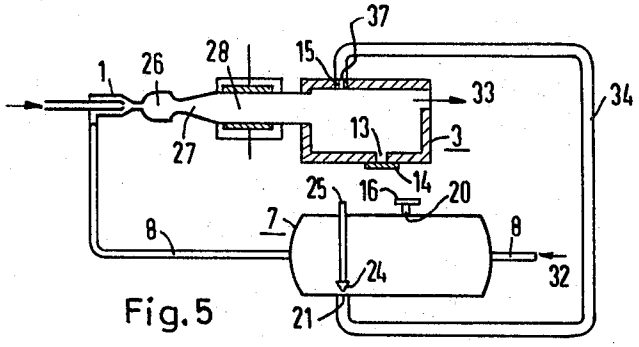


Fig. 5

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Filed May 3, 1965 4 Sheets-Sheet 3

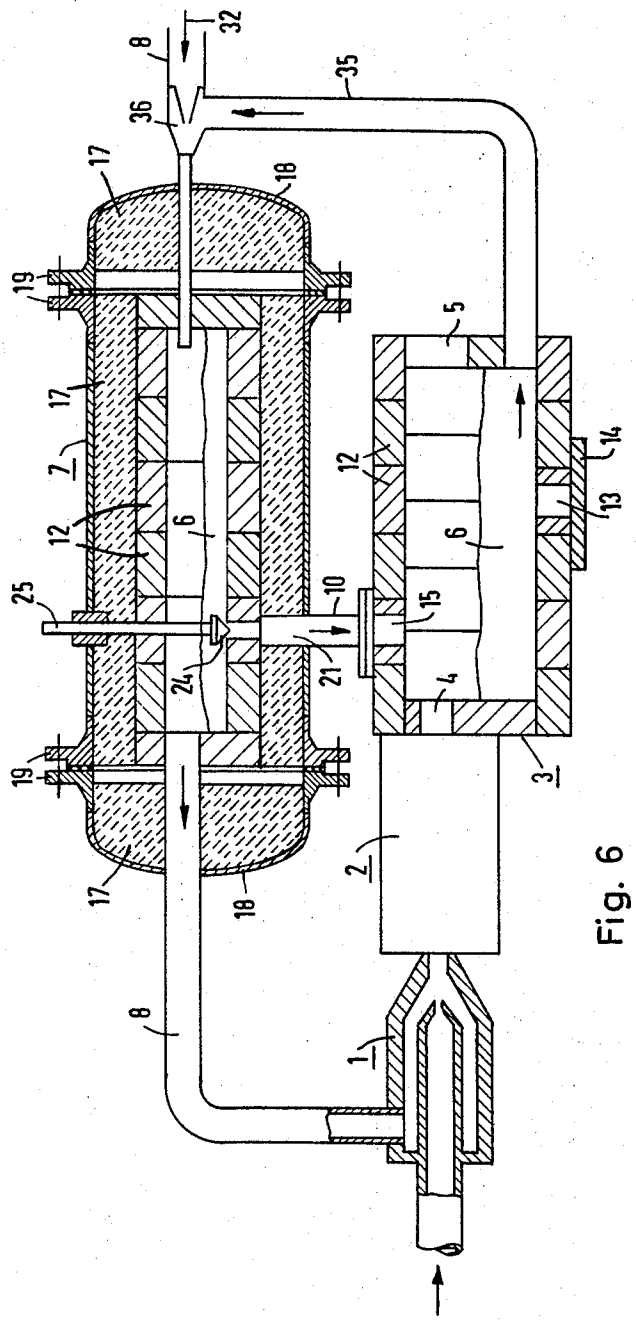


Fig. 6

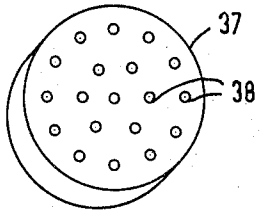

37
38

Fig. 7

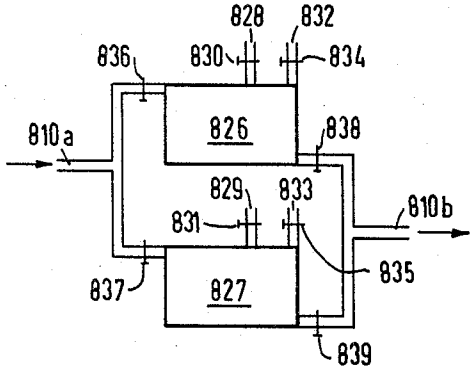

828
832
836
830
834
826
838
810a
829
833
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810b
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837
827
839

Fig. 8

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3,374,371

METHOD AND HEAT EXCHANGER FOR PREHEATING THE COMBUSTION AIR OF MAGNETOHYDRODYNAMIC GENERATORS

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8 Claims. (Cl. 310—11)

ABSTRACT OF THE DISCLOSURE

The combination in an MHD generator, having combustion-air supply means and a waste-gas outlet, of a heat exchanger plant including a first container and a second container, both containing molten liquid heat transfer material when in operation, the first container being connected to the waste gas outlet and forming a path for gas in heat-exchanging contact with the surface level of the molten material in the first container, the second container being connected in the combustion-air supply means and forming a supply path for air above and in heat-exchanging contact with the surface level of the molten material in the second container, the second container having a pressure-resistant jacket and, in operation, having a higher internal pressure than the first container, both containers having material charging and discharging means for transferring material from the second container to the first container, the material charging and discharging means including in each of the two containers an outlet below the level and an inlet above the level.

Our invention relates to a method and to heat exchanges for preheating the combustion air of magneto-hydrodynamic (MHD) generators, operating with rapidly flowing flame or flue gases from fuels burnt with air. As a rule, the hot gases thus supplied to MHD generators are provided with an addition of readily ionizable substances, such as salts of the alkali metals, to serve as seed materials, whereby the working gas in the generator assumes plasma properties. By employing a magnetic field perpendicularly to the flow direction of the plasma, an electric voltage is generated between electrodes spaced from each other in a direction perpendicular to the flow direction of the plasma and perpendicular to the direction of the magnetic field. The electrodes are then available to furnish utilizable electric power.

To afford an economical operation of MHD generators operating with flame gases, it is desirable to burn the fuels, for example oils or pulverized coal, not with pure oxygen but with atmospheric air. This requires preheating the air to temperatures above 1500° C., preferably above 2000° C.

The hot waste gases issuing from the generator channel in which, as a rule, the above-mentioned electrodes are located, are available for thus preheating the combustion air. However, the heretofore available heat exchangers do not permit operating at the required high temperatures. For example, recuperators, operating on the counter-flow principle, can be built in practice for operation at rated temperatures of no more than about 800° C., due to the sensitive heat-exchanging partitions.

It is an object of our invention to find a way of continuously heating the combustion air of MHD generators to temperatures above 1500° C. with the aid of the waste gas heat issuing from the MHD generators.

According to the invention, we preheat the combustion air for an MHD generator by heat exchange with the waste gas heat of the MHD generator through the medium of a molten-liquid heat-transfer medium in such a manner that the heat exchange takes place at the surface of a mass liquified by melting, preferably a mass consisting of glasses or the like vitreous materials, metal oxides or metals. The gaseous media are thus placed directly in heat-exchanging contact with the surface or surface level of the molten mass, no partitioning wall structure being placed between the melt and the gaseous substances.

For performing the method according to the invention, we preferably provide a heat exchanger which comprises a first container inserted into the gas flow from the MHD generator and constituting a vessel similar to that of a glass melting pot or trough as used in glass manufacture, and the heat exchanger further comprises a second container which is interposed into the air supply to the MHD generator and supplied with molten material from the first container.

According to another feature of our invention, the flame waste gases and the combustion air are passed through a single container subdivided into two flow spaces by a partition which extends down to slightly below the surface level of the molten material. The heat exchange then takes place directly above the melt at the surface level of the molten material in the respective two chambers.

Heat exchangers thus operating in accordance with the invention afford utilizing the available experience made with Siemens-Martin furnaces and glass-melting furnaces, and thus constitute rugged plants of reliable performance.

Also utilizable to the benefit of the method and apparatus according to the invention are the experiences gained in the glass manufacturing industry with regenerative pot furnaces. Such regenerative furnaces are equipped with flue shafts in which the burnt gases from the furnace pass through firebrick checker-work cells which are thus heated to a high temperature. Thereafter the direction of the draft through the cells is reversed by dampers so that the combustion air passes through the heated cells, this alternating operation being periodically repeated. The principle of regenerative heating in this manner is not suitable for producing a continuous plasma jet as required for the operation of MHD generators, but when employing a heat exchange according to the invention at the surface level of a molten mass instead of at a firebrick checker structure, an analogous regenerative principle becomes applicable.

For further explaining the invention, various embodiments of heat exchangers according to the invention will be described by way of example with reference to the accompanying drawings in which:

FIG. 1 shows schematically and mainly in section an MHD plant equipped with such a heat exchanger.

FIG. 2 illustrates schematically the MHD generator of the plant shown in FIG. 1.

FIG. 3 is a cross section along the plane denoted by line III—III in FIG. 1.

FIGS. 4 and 5 show diagrammatically and in simplified form embodiments of further heat exchangers according to the invention.

FIG. 6 shows schematically and mainly in section still another MHD plant according to the invention with an internal circulation of the heat exchanging medium.

FIG. 7 illustrates schematically a ceramic screen plate constituting a detail of the heat exchanger according to FIG. 5.

FIG. 8 is a schematic diagram of a pressure lock applicable with heat exchanger plants according to FIGS. 4 and 5.

Referring to FIG. 1, there is shown at 1 a plasma burner 1 of the concentric nozzle type for producing a hot flame whose combustion gases pass through an MHD generator 2 separately illustrated in FIG. 2 and described

further below. The flame gases leaving the MHD generator 2 then pass through a container 3 which has inlet and outlet openings 4, 5 and is designed in the manner of a glass melting trough of the type used in pot furnaces or tank furnaces. The container 3 is provided at 6 with materials which are solid at normal room temperature and are heated and molten by the hot flame gases. The materials consist of glasses or similar vitreous substances, metal oxides, slag or metal. The material, in molten-liquid condition, is transferred to a second heat-insulated container 7 which is interposed into a supply line 8 through which the combustion air is supplied to the burner 1.

The air flowing through the container 7 in contact with the surface level of the molten material is heated to a temperature of 1500° to 2000° C. and reaches the burner 1 at a corresponding high temperature. A second line 11 feeds fuel to the burner 1, for example diesel oil, which burns with the hot air. To permit using compressed air, for example at a pressure of 20 to 30 atmospheres, the container 7 is given a pressure-resistant and correspondingly sealed design.

The container 3 for melting the heat transferring material may be composed of firebrick or may be lined with fire clay or the like refractory mass and may be held together by tensioning anchors of iron or steel, such anchors not being illustrated.

The bottom of container 3 has an outlet opening 13 below the surface level of the molten material. The outlet 13 is normally closed by a valve member here constituted by a slider 14 covered with fire clay. Located in the top portion of the container 3 and hence above the surface level of the molten material, is an inlet 15 through which cooled heat-transfer material is supplied into the container from the second container 7. The inlet is closed by a valve member 16 consisting, for example, of a water-cooled slider of steel. As shown in FIG. 3, the container 3 is preferably given an arcuate roof of fire-brick masonry.

The container 7 is preferably cylindrical. Its interior design is similar to that of the container 3. An inner lining of firebrick is preferably surrounded by a masonry layer 17 of so-called light firebrick. "Light firebrick" consists of porous bricks or blocks of fire clay. To permit passing compressed air to the burner 1, the container 7 is enveloped by a pressure-resistant jacket of steel closed at both ends by cover portions 18 attached by means of flanges 19.

The container 7 is supplied with molten liquid material through an inlet opening 20 closed by a valve 16 corresponding to the valve 16 of container 3. An outlet opening 21 at the bottom of container 7, also closed by a valve 16 of the same design, permits discharging the cooled heat-transfer material.

The transfer of material between the two containers 3 and 7 may be effected with the aid of auxiliary containers 9 similar to those employed in foundry techniques, various types of ladles used in such techniques being also applicable. Three such containers 9 are shown in FIG. 1. Each of these containers may comprise a steel jacket lined with fireclay and be equipped with an inlet 22 and an outlet 23. The outlet 23 may be provided with a conical closure head 24 of oxidation-protected molybdenum which can be lifted and lowered from the outside with the aid of a linking rod 25. To afford filling the container 7 in opposition to the pressure obtaining therein, air under super-atmospheric pressure may be applied to the inlet 22 of the transfer container 9 during filling operation. The containers 9 are to be moved from container 3 to container 7, or vice versa, and connected with the respective inlets and outlets of the containers as shown.

The MHD generator, shown schematically in FIG. 2, comprises the above-mentioned burner 1, a combustion chamber 26, an accelerating nozzle 27 of the Venturi type, and a generator channel 28. Respective electrodes 29 are mounted in channel 28 on opposite sides and are connected with conductors 30 passing to the outside through an insulating cover 31 of the channel. A magnetic field is applied perpendicularly to the plane of illustration, the field-producing means not being illustrated. Heat exchangers according to the invention are suitable not only for this particular type of MHD generator, but also for any other types of generators operating with burner or flame gases.

In the modified embodiment shown in FIG. 4, the container 3, traversed by the combustion gases, is mounted beneath the pressure container 7, and the inlet 15 of container 3 communicates with the outlet 21 of container 7 through a tubular conduit 10. Several respective inlets and outlets may be provided and interconnected in this manner to facilitate cleaning the containers and expediting the first charging-up of the containers. The valve for closing the outlet 21 is shown to consist of a conical closure body 24. Compressed air is forced through the air conduit 8 and container 7 in the direction of the arrow 32. The waste gases escape from container 3 in the direction of the arrow 33. When the closure body 24 is lifted, the over-pressure in container 7 and the effect of gravity cause the cooled but still molten material, such as glass, to drain from container 7 into container 3 where it is heated to a more thinly liquid condition. The return of the material from container 3 back to the pressure container 7 may be effected with the aid of transfer containers 9 as described above with reference to FIG. 1.

In the plant shown in FIG. 5, the container 3 traversed by the combustion gases is mounted above the pressure container 7 and one of the inlets 15 of container 3 is connected by a conduit 34 with an outlet 21 of the pressure container 7. Compressed air is forced into the air supply pipe 8 in the direction of the arrow 32. The spent gases leave the container 3 in the direction of the arrow 33. When the conical closure 24 of the valve in container 7 is lifted to the open position, the pressure of container 7 forces the cooled but still molten material through the conduit 34. With a suitable design of the inlet opening 15, such as by the provision of a screen or sieve insert, the material then drips into the container 3. For this purpose, a perforated disc member 37 of ceramic material is inserted into the inlet opening 15. The member 37 is separately shown in FIG. 7 on larger scale. The pores or sieve openings are denoted by 38.

The re-filling of the heated melt from container 3 into container 7 may be effected with the aid of the above-mentioned transfer containers 9. However, the outlet opening 13 of container 3 may also be connected with the inlet opening 20 of container 7 for the purpose of transferring the re-heated and more highly liquid melt into the pressure container, provided care is taken to seal the pressure of container 7 from the lower pressure in container 3.

An internal circulation of the molten medium, generally of the kind just mentioned, is also embodied in the heat exchanger according to FIG. 6. The containers 3 and 7 are connected with each other in the same manner as in FIG. 4. The container 7 is designed as a pressure container. The container 3, traversed by the combustion gases, is connected by a conduit 35 with an injector nozzle 36 which is interposed in the line 8 for supplying the combustion air and is located on the fresh-air side ahead of the container 7. Air is supplied through the injector nozzle under considerable pressure, for example 10 to 20 atmospheres. As a result, the nozzle 36 inducts molten material through conduit 35 from container 3 and blows this material in the form of drops into the container 7. The conduit 35 is jacketed with heat-insulating material. If this conduit has great length, it may be additionally heated to prevent excessive cooling of the molten material.

The droplets of material thus blown into the pressure container 7 have a very large surface-to-volume ratio so that an especially intensive transfer of heat to the air is secured. Analogously, the presence of the heat-transfer

material in form of drops within the container 3 would promote the heating and melting of this material under the effect of the combustion gases. For that reason, the heat-transfer material may be given a composition tending to facilitate the formation of drops. Ordinary glass compositions, such as used for window panes, is well suitable for this purpose.

As mentioned above, the use of transfer containers as shown at 9 in FIG. 1 may be avoided by effecting the transfer with the aid of pressure locks. Such a pressure lock is schematically illustrated in FIG. 8 and will be described with reference to the embodiments shown in FIGS. 4 and 5. In a plant according to FIG. 4, the conduit 810*b* (FIG. 8) is to be connected with the inlet 16 of the high-pressure container 7 and the conduit 810*a* with the outlet 13 of the low-pressure container 3. In a plant according to FIG. 5, the conduit 810*b* is likewise to be connected with the inlet 16 and the conduit 810*a* with the outlet 13. The operation of the pressure lock according to FIG. 8 is as follows.

Assume that the storage vessel 827 contains highly heated and thinly liquid melt and thus is in condition for operation, and that the storage vessel 826 is to be filled. The valves 832 and 833 shown in FIG. 8 are to be connected to a supply of gas under higher pressure than obtaining in the fresh-air supply line (8 in FIGS. 4, 5). For transferring the molten material, the closure valves 837, 831, 838, 834 are to be closed and the valves 839, 835, 836, 830 to be opened. It will be understood that each of these valves is preferably formed of a slider such as the slider 16 described above with reference to FIG. 1. With the lock system in this condition, the melt flows through the conduit 810*a* into the storage vessel 826, the air escaping through the conduit 838. Simultaneously the storage vessel 827 is being emptied by pressure gas supplied through the line 833, and the melt is pressed into the container 7 interposed in the fresh-air supply line 8 (FIGS. 4, 5) to serve as heat-exchange medium. When the vessel 827 is emptied, the operation can be reversed. The lock device thus permits pumping the melt from a vessel of lower pressure into a vessel of higher pressure or in opposition to gravity. When employing such pressure locks, which may also have a different design, a continuous refilling operation can be achieved.

Heat exchangers for performing the method of the invention may be modified in a variety of ways to meet any particular requirements or desiderata. For example, in the plant shown in FIG. 6, the transfer from the pressure container 7 through the conduit 10 may be facilitated by giving the bottom of the pressure container 7 a funnel-shaped inner configuration. Upon a study of this disclosure such and other variations, as regards design, shape and arrangement of components, will be obvious to those skilled in the art. The invention, therefore, can be given embodiments other than particularly illustrated and described herein, without departing from the essential features of the invention and within the scope of the claims annexed hereto.

As liquid medium to be used in the heat exchanger the metals, iron, nickel, chromium, manganese, niobium and the alloys thereof, which are not easily oxidizable, may serve for example.

While, in the foregoing description of the illustrated embodiments, reference is made to the use of molten glass as heat transfer medium, various other materials that are solid at normal room temperature and liquid at the available generator waste-gas temperatures, may be employed in the same manner. Particularly suitable, for example, are high-melting and sufficiently oxidation-resistant metals such as iron, chromium, manganese, niobium and alloys of these metals. Also applicable are slags and oxides, such as silicon dioxide, aluminum oxide (alumina), mixtures of silicon dioxide and alumina, or boron oxide, with alkalies and earth alkalies, these oxidic materials being preferably used in compositions exhibiting vitreous character in the temperature range utilized for heat exchange.

We claim:

1. With an MHD generator having combustion-air supply means and a waste gas outlet, the combination of a heat exchanger plant comprising a first container and a second container which both contain molten liquid heat transfer material when in operation, said first container being connected to said waste gas outlet and forming a path for gas in heat-exchanging contact with the surface level of the molten material in said first container, said second container being connected in said combustion air supply means and forming a supply path for air above and in heat-exchanging contact with the surface level of the molten material in said second container, said two containers having material charging and discharging means for transferring material from said second container to said first container, said material charging and discharging means comprising in each of said two containers an outlet below said level and an inlet above said level, each of said two containers having two mutually aligned openings located above said level on opposite container sides for the passage of gas and air respectively through said containers.

2. In an MHD generator plant according to claim 1, said first container being situated above said second container, and conduit means through which said inlet of said first container communicates with said outlet of said second container for transferring said molten material from said second container to said upper, first container.

3. In an MHD generator plant according to claim 1, said first container being situated below said second container, and conduit means through which said inlet of said first container communicates with said outlet of said second container for transferring said molten material from said second container to said lower, first container.

4. In an MHD generator plant according to claim 1, said inlet of at least one of said containers comprising a perforated diaphragm member for supplying the molten material in droplet form.

5. In an MHD generator plant according to claim 1, said inlets and outlets comprising respective closure valves each having a water-cooled shut-off slider.

6. With an MHD generator having combustion-air supply means and a waste gas outlet, the combination of a heat exchanger plant comprising a first container and a second container which both contain molten liquid heat transfer material when in operation, said first container being connected to said waste gas outlet and forming a path for gas in heat-exchanging contact with the surface level of the molten material in said first container, said second container being connected in said combustion air supply means and forming a supply path for air above and in heat-exchanging contact with the surface level of the molten material in said second container, said two containers having material charging and discharging means for transferring material from said second container to said first container, said material charging and discharging means comprising in each of said two containers an outlet below said level and an inlet above said level, said first container being situated below said second container, and conduit means through which said inlet of said first container communicates with said outlet of said second container for transferring said molten material from said second container to said lower, first container, and further comprising an air injection nozzle interposed in said combustion-air supply means flow-wise ahead of said second container and having a suction chamber, and suction conduit means connecting said suction chamber with said outlet of said first container, whereby said nozzle causes heated molten material from said first container to be injected with the combustion air into said second container.

7. In an MHD generator plant according to claim 6, comprising a compressed-air supply conduit connected

with said nozzle and having ahead of said nozzle a pressure of 10 to 20 atmospheres.

8. With an MHD generator having combustion-air supply means and a waste gas outlet, the combination of a heat exchanger plant comprising a first container and a second container which both contain molten liquid heat transfer material when in operation, said first container being connected to said waste gas outlet and forming a path for gas in heat-exchanging contact with the surface level of the molten material in said first container, said second container being connected in said combustion-air supply means and forming a supply path for air above and in heat-exchanging contact with the surface level of the molten material in said second container, said two containers having material charging and discharging means for transferring material from said second container to said first container, said material charging and discharging means comprising in each of said two containers an outlet below said level and an inlet above said level, said inlets and outlets comprising respective tubular ducts, a conical closure member seated on each of said ducts and liftable therefrom for opening the duct, and a closure control rod actuable from the outside for lifting and lowering said closure member.

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DAVID X. SLINEY, *Primary Examiner.*