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3,467,842

OPEN MAGNETOHYDRODYNAMIC CYCLE AND METHOD
OF OPERATION OF MAGNETOHYDRODYNAMIC CYCLE

Filed June 29, 1967

2 Sheets-Sheet 1

fig.1

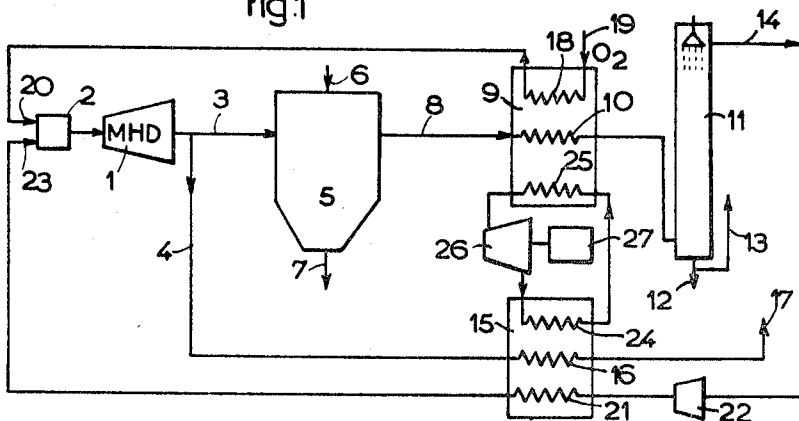


fig.2

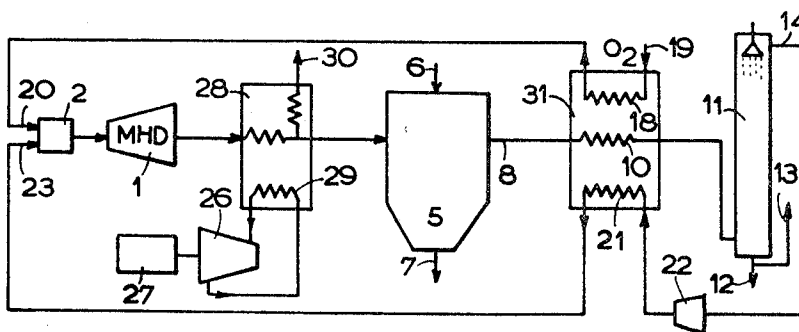
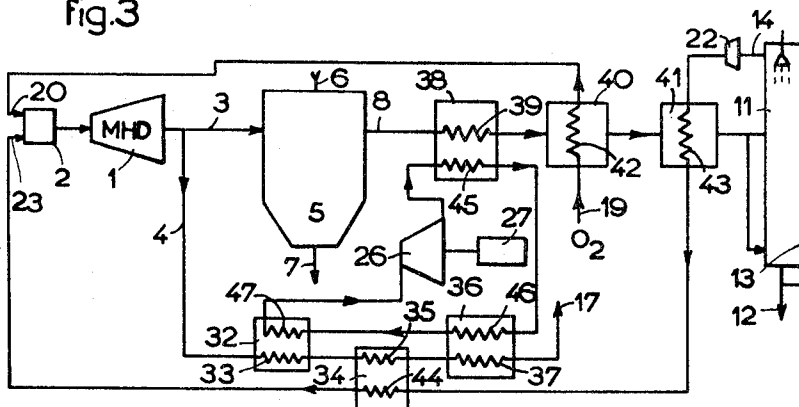


fig.3



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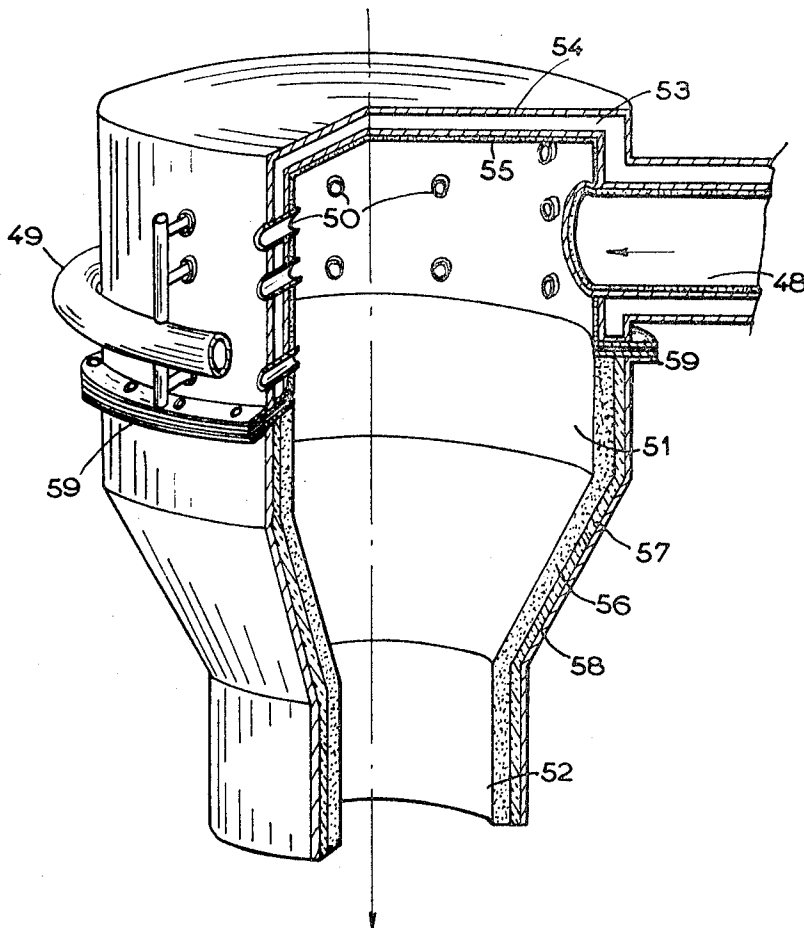
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fig. 4



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3,467,842

OPEN MAGNETOHYDRODYNAMIC CYCLE AND METHOD OF OPERATION OF MAGNETOHYDRODYNAMIC CYCLE

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10 Claims

ABSTRACT OF THE DISCLOSURE

A major fraction of gases from the magnetohydrodynamic nozzle is mixed in a chemical converter with a combustible substance to obtain an endothermic reaction, thus cooling the gases and avoiding the necessity of extensive use of high temperature materials.

The present invention relates to open magnetohydrodynamic cycles, and more particularly to a method of operating such an open magnetohydrodynamic cycle in which a fraction, preferably a major fraction, of the gases from the magnetohydrodynamic nozzle are recovered.

In open MHD cycles, reheating of the air, and recovery of the magnetohydrodynamic gases issuing from the nozzles causes severe technical problems given by the high temperatures, chemical attack and mechanical stability and resistance of materials available, and cause great difficulties in the design of heat exchange equipment. Present material limitations set a limit of about 2,000° K. for reheating of the gases; this, in turn, sets an overall limitation on the energy yield. In known apparatus hyperoxygenation of the combustion supporting substance increase the temperature, but in fact, cause a noticeable decrease of the energy yield.

In French Patent 1,401,387, assigned to the assignee of the present invention, apparatus is described which is designed to increase the overall energy yield which is actually outside of the MHD stage itself and operates at relatively lower temperatures. In accordance with this disclosure, a fraction of the gas from the MHD stage is mixed with a combustible substance which supplies an auxiliary combustion chamber arranged to reheat the combustion supporting medium, and eventually the combustible substance.

It is an object of the present invention to provide an MHD cycle in which the overall energy yield is improved.

SUBSTANCE OF THE PRESENT INVENTION

Briefly, in accordance with the present invention, by operating outside of the MHD stage proper, it is possible to increase the energy yield without operating at temperatures in excess of 1,350° K. and to obtain supply of the combustion chamber for the MHD nozzle and obtain therefrom an increased yield. A mixture of a major fraction of the gas obtained from the MHD nozzle, and a combustible substance is obtained in a chemical converter; further, a hyperoxygenated air is supplied to the combustion chamber for the MHD nozzle. The combination thus supplied has important effects. The hyperoxygenation, as utilized herein, is supplied not to increase the temperature level but rather to increase the energy which can be obtained from the MHD nozzle; further, it reduces or even entirely avoids dilution of gases from the nozzle by nitrogen from the air, and permits ready recovery of the thermo energy of the recycled gas without decrease of energy yield. The hyperoxygenation, if sufficient, further permits the introduction into the chemical

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converter (in which the fuel and the gas obtained from the MHD nozzle are mixed) of a quantity of gases including oxidizing elements (CO₂, H₂O) which are necessary to obtain on the one hand complete conversion of the combustible substance and of the other desirable operating temperatures, that is, temperatures in the neighborhood of 1,350° K., or less. The presence of nitrogen would otherwise result in an increase in temperature due to an excess of heat content if the necessary oxidizing gases were introduced into the chemical converter; or, an insufficient amount of oxidizing gases if desired temperatures only are to be obtained.

For a liquid combustible substance, complete conversion of carbon in a mixture of CO and H₂, results in an absorption of approximately 3,500 Kcal., for each kilogram of combustible substance. This amount of 3,500 represents the difference between the heat of combustion of the carbon monoxide, and hydrogen and the caloric value (in the order of 10,000 Kcal.) of the initial combustible material. This energy, stored in chemical form, does not require a heat exchanger and, if certain precautions are taken, is not affected by various treatment to which the gas can be subjected to, such as cooling, washing and cleaning, dilution, absorption of inert gases and the like.

The mass of the recycled gas is decreased by the amount of energy contained therein, which energy is converted into chemical form.

There thus results a noticeable increase of the overall yield of the MHD generator, in spite of energy which is absorbed during the hyperoxygenation.

The temperature levels of the recycled gases, after mixture with a combustible substance, enable the elimination of a substantial portion of the original gases from the MHD tube, in accordance with known methods. The treatment of the combustible substance in gaseous phase can readily be done for example by washing and furthermore permits the eventual elimination from the plasma of deleterious substances, such as sulphur compounds, so that the gases emitted from the MHD generator subsequently are devoid of such substances; the technical problems of the construction of combustion chambers and the MHD nozzles and the electrodes is thus simplified.

That portion of the gas which comes from the MHD nozzle which is not eventually recycled can be utilized as a heat source to generate steam, or it may be substantially cooled otherwise. It does not pose a problem of high temperatures and the consequent difficulties with construction materials.

The structure, organization and operation of the invention will now be described more specifically with reference to the accompanying drawings, in which:

FIGURE 1 illustrates, in schematic form, an MHD cycle in accordance with the invention; FIGURES 2 and 3 represent different embodiments of cycles in accordance with the invention; and FIGURE 4, in partly perspective, partly sectional view, illustrates a chemical converter useful in the cycle in accordance with the present invention.

Referring now to the drawings and more particularly to FIGURE 1:

An MHD nozzle 1 is supplied from a combustion chamber 2. The gases coming from the MHD chamber 1, at a temperature of about 2,400° K. are divided into two paths, 3 and 4. The gases along path 3 are led to a chemical converter 5, to be described in detail below, where they are mixed with a combustible substance supplied at 6.

The heat energy of the gas from the MHD nozzle 2, in the guide tube 3, is utilized to obtain endothermic reactions between the combustible substance admitted at 6 and the gases themselves, serving as oxidizing agents.

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Carbon dioxide and water vapor within the gases from the MHD nozzle transform hydrocarbons of the combustible substance into carbon monoxide, and hydrogen, with the absorption of heat. In the apparatus, the caloric energy of the gas from tube 3, obtained from the MHD nozzle 1, at a temperature of about 2,400° K. is converted partly into chemical form, partly into heat energy and partly into losses to the walls. The endothermic reaction of conversion causes absorption of energy of approximately 35 percent of the total energy content of the combustible substance introduced into the chemical converter. This energy may thus be recycled without necessity of heat exchanges, because it is obtained directly by mixing in the converter.

The speed of the gas from the MHD nozzle can be utilized to improve and speed up the mixture of oxidizing gases and combustible substance, particularly by obtaining a rapid rotation of the gaseous masses. The temperature within the chemical converter 5 is approximately between 1,200° K. to 1,350° K. Seed, primarily in the form of carbonates, or potassium sulfate, respectively, is thus in liquid form and may be recovered to a great part from the bottom of the chemical converter, as seen at 7, in accordance with processes well known and utilized, for example, in the cellulose industry. Separation of the gaseous current into its liquid components is further improved by the rotation to which the gaseous masses in the apparatus 5 are subjected.

The gas leaving the converter 5 at 8, which is principally composed of carbon monoxide and hydrogen, with an excess of carbon dioxide and water vapor, are led to a heat recovery and heat exchanger apparatus 9. In a passage 10 within heat exchanger 9, the temperature is decreased to the region of about 500° K. Thereafter the gases are led to a scrubber or washing tower 11. External regeneration of the cleaning substance permits extraction of the remainder of the seed at 12, in solution; and at 13 carbon dioxide and water vapor absorbed during the washing step. The mixture of carbon monoxide, and hydrogen is taken out of the washing tower 11 at 14, at a temperature of about 300° K., for further utilization as combustible substance in the combustion chamber 2.

The portion of the gas following the path 4 is led through a heat recovery and heat exchanger apparatus 15, through a passage 16, and exhausted at 17 in a smokestack.

Heat exchangers and heat recuperators 9 and/or 15 are utilized to preheat a oxygen enriched air supplied through a tube 19, led through the heat exchanger through tubes 18 and supplying the combustion chamber 2 for the MHD nozzle 1 at an inlet 20. The temperature to which the substance admitted at 19 is raised can be about 900° K. Recuperators 15 and/or 9 are utilized to preheat the substances from the washing tower 11 at its exit 14 to a temperature of from 1,200° K. to about 1,300° K., in a heat exchanger tube 21. The gases are further, preferably, compressed in a single or multi-stage compressor 22. The main drive of the compressor is not shown, and may be obtained directly from gas turbines or from other prime mover. The combustible substance is introduced into the combustion chamber 2 to 23.

Heat exchanger tubes 24, 25 further utilized in heat exchangers 15 and 9 respectively, are elements of a water boiler to supply a conventional turbine 26, driving a conventional alternator 27. The conventional steam-turbine-generator arrangement is not shown in detail since it is well known, and the steam for the drive of the turbine is a by-product when practicing the present invention.

FIGURE 2 shows a modification of the cycle in accordance with FIGURE 1, in which all of the gas coming from the MHD nozzle 1 is taken to the chemical converter 5. The temperature is preferably preliminarily decreased to a range of about 2,000° K. in the heat exchanger 28, which further includes boiler tubes 29 for a conventional

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turbine 26 with a generator 27. A portion of the gas may be taken off by a chimney 30, after supplementary cooling. Heat exchangers 9 and 15 of FIGURE 1 can then be replaced by a single heat exchanger 31, utilized to preheat at the same time oxygen admitted at 19 as well as combustion substance obtained from the chemical converter 5.

FIGURE 3 illustrates a further embodiment of the invention, in which cooling of the gas obtained from the MHD nozzle 1 is done in several stages. The gas following path 4 is led, in succession, to a boiler 32, through a passage 33, through a heat exchanger 34 having a passage 35 and a further boiler 36 having a passage 37 before being exhausted through a chimney or smokestack at 17. The gas following path 3, which would be approximately 80 percent of the total amount of gases obtained from the MHD nozzle 1 is mixed in chemical converter 5 with combustible substance at 6, leaving at a temperature of about 1,350° K. to be led in succession to a boiler 38, through a passage 39, and to heat exchangers 40, 41. Heat exchanger 40 is utilized to preheat slightly hyperoxygenated air applied at 19. The combustion gas obtained from the washing tower 11 at outlet 14, after being compressed, is slowly reheated to about 900° K. in passage 43 of heat exchanger 41; and then led through tube 44 of heat exchanger 34 for a rapid increase to a temperature of about 1,373° K. The conventional turbine-generator set 26, 27 is supplied with steam from lines 45, 46 and 47 obtained from boiler tubes in boilers 38, 36 and 32, respectively.

FIGURE 4 is an example of a chemical converter having a vertical axis. The oxidizing gases from the MHD nozzle 1 are applied by a channel 48. They enter at a high speed, for example, in the order of about 50 meters per second. The direction of tube 48 is not radial, but rather tangential, so that the gases within the converter 5 will have a rapid rotational movement. Combustible supporting substance, for example, as a liquid, is applied through tube 49 and distributed by injection nozzles 50, located around the circumference of the converter, so as to be atomized or pulverized in recirculating zone, for example, the vortex such that droplets of liquid of combustible substance are rapidly heated, evaporated, and at least partially decomposed by contact with the gas at a somewhat moderate temperature, and in a zone of the converter where the conversion reactions are not too rapid. Only towards the end of that recirculating zone will be combustible substance subjected to attack by oxidizing gases. By that time, due to the great speed of rotation, the best mixing conditions will have been achieved, and the temperature (since rather hot gases will still be present) and the oxidation conditions (since the input gases are still at elevated temperatures and contain carbon dioxide and water vapor) will be an optimum.

The amount of gas entering at tube 48 and the amount of substance supplied through inlet 49 readily permits determination of the reaction temperatures, for example, to set it between 1,000 and 1,100° C., of the reactions within reaction chamber 51. The reaction of oxidation of carbon, and decomposition of molecules of the combustible substance are endothermic. Thus, the temperature of the oxidizing gases decreases rapidly and the converter, over practically its entire volume, will be at a temperature similar to the exit temperature of the converted gases. The converted gases leave by a central orifice 52 at the lower end of the converter.

The rapid rotational movement of the gas in the converter improves the separation of the compositions which constitute the input gases applied through tube 48, which may be liquid. Melting temperatures of potassium carbonate and potassium sulfate are actually below the temperatures of the gases in the converter. Original material introduced through tube 48 and not converted can also be removed through the base of the converter.

The upper region of the converter is preferably cooled by a water jacket 53, having an outer metallic cover 54;

the interior can be lined by a refractory layer 55, for example, alumina, having a thickness of about 50 mm., for example. The lower part of the converter need not be specially cooled. The envelope may simply be insulated by an internal refractory layer 56 of alumina, and insulated with brick work 57; an external metallic cover 58 is provided. The upper and lower portions are connected by means of flanges 59.

The following table gives comparative results of recovery of energies relative to one kg. of combustible substance, evaluated in Kcalories, in three cases:

Cycle 1.—Direct cycle, utilizing as combustible substance slightly hyperoxygenated air (O_2+3N_2), reheated to 2,000° K. with heat obtained from the gases from the MHD nozzle;

Cycle 2.—Chemical conversion cycle in accordance with the present invention, utilizing slightly hyperoxygenated gas (O_2+3N_2) and reheat of the conversion gas and the combustion substance to about 1,370° K.;

Cycle 3.—Chemical conversion cycle in accordance with the invention, utilizing 95 percent pure oxygen, reheated to 900° K., and further reheat of the conversion gas to about 1,373° K.

It has been believed that the temperature of the gases from the MHD nozzle are substantially constant at about 2,400° K. The recoverable energy from the MHD nozzle is the portion directly transformed into electricity and the energy which is lost to wall losses. This last energy is usually utilized to heat water for a conventional steam turbine-generator assembly. It is not separately considered herein because, as a first approximation, it may be considered to be the same for all three cases.

The combination of the chemical conversion which permits elimination of heat exchangers operating at high temperatures, and of extremely strong hyperoxygenation is most efficient with respect to energy yield, and makes combined MHD-steam generator equipments commercially feasible, since the costly high temperature heat exchangers which are further difficult to maintain, can be eliminated; further, consumption of combustible substance is reduced.

Energy balance (Kcal.)	Cycle 1	Cycle 2	Cycle 3
Caloric content of combustible substance	9,450	9,450	9,450
Entrance energy to MHD nozzle	14,980	17,933	15,175
Output energy from MHD nozzle (2400° K.)	11,830	14,050	7,950
Energy recoverable in MHD nozzle	3,150	3,883	7,225
Energy recoverable in conventional power station	6,300	5,567	2,225
Preheat for substance to be burned	5,530 (2,000° K.)	3,430 (1,100° C.)	490 (900° K.)
Reheat for combustible material	0	1,663 (1,100° C.)	1,848 (1,100° C.)
Chemical energy recovered	0	3,390	3,390
Total energy recycled	5,530	8,483	5,728
Energy of separation of oxygen	160	160	780
Gas to be compressed (kg.)	11.8	15.25	7.35

A noticeable decrease in the energy output of the conventional steam turbine generator equipment in a combined unit will be obtained. The price of conventional steam generator-turbine-alternator assemblies is approximately proportional to the power capability,

whereas the costs of MHD installations decrease relatively with an increase in power output; thus, by increasing the relative power output from the MHD portion of the combined unit, a total economic advantage is obtained.

I claim:

1. Method of operating an open magnetohydrodynamic cycle comprising the steps of recovering a major fraction of gas from the magnetohydrodynamic nozzle; and supplying the combustion chamber of the magnetohydrodynamic nozzle by

(a) a mixture of a combustible substance and said major fraction of the gas recovered from said magnetohydrodynamic nozzle, and

(b) a hyperoxygenated combustion supporting substance.

2. Method as claimed in claim 1 including the step of mixing said mixture of a combustible substance and said major fraction of gas recovered from said magnetohydrodynamic nozzle in a chemical converter.

3. Method as claimed in claim 2 including the step of preheating said hyperoxygenated combustion supporting substance by gases obtained from said chemical converter.

4. Method as claimed in claim 2 including the step of supplying a steam boiler with gases obtained from said chemical converter to supply heat thereto.

5. Method as claimed in claim 2 including the step of water cleaning the mixture of a combustible substance and said major fraction of gas recovered from said magnetohydrodynamic nozzle; and the further step of further preheating said cleaned mixture.

6. Method as claimed in claim 2 including the step of passing said major fraction of gas recovered from the magnetohydrodynamic nozzle to a heat exchanger; and then passing said gas into said chemical converter.

7. Method as claimed in claim 6 including the step of passing water through said heat exchanger to generate steam.

8. Method as claimed in claim 1 including the step of subjecting said mixture of a combustible substance and said major fraction of gas recovered from said MHD nozzle to an endothermic reaction to convert heat energy into chemical energy whereby the temperature of said mixture and gases will decrease.

9. Method as claimed in claim 2 including the step of introducing said major fraction of gases recovered from said MHD nozzle into a cylindrical reaction chamber in a tangential direction to obtain rapid circular movement of said gases, having a vortex.

10. Method as claimed in claim 2 including the step of preheating said hyperoxygenated combustion substance by gases obtained from said magnetohydrodynamic nozzle.

References Cited

UNITED STATES PATENTS

3,214,615 10/1965 Way ----- 310-11

DAVID X. SLINNEY, Primary Examiner