POWER GENERATION APPARATUS

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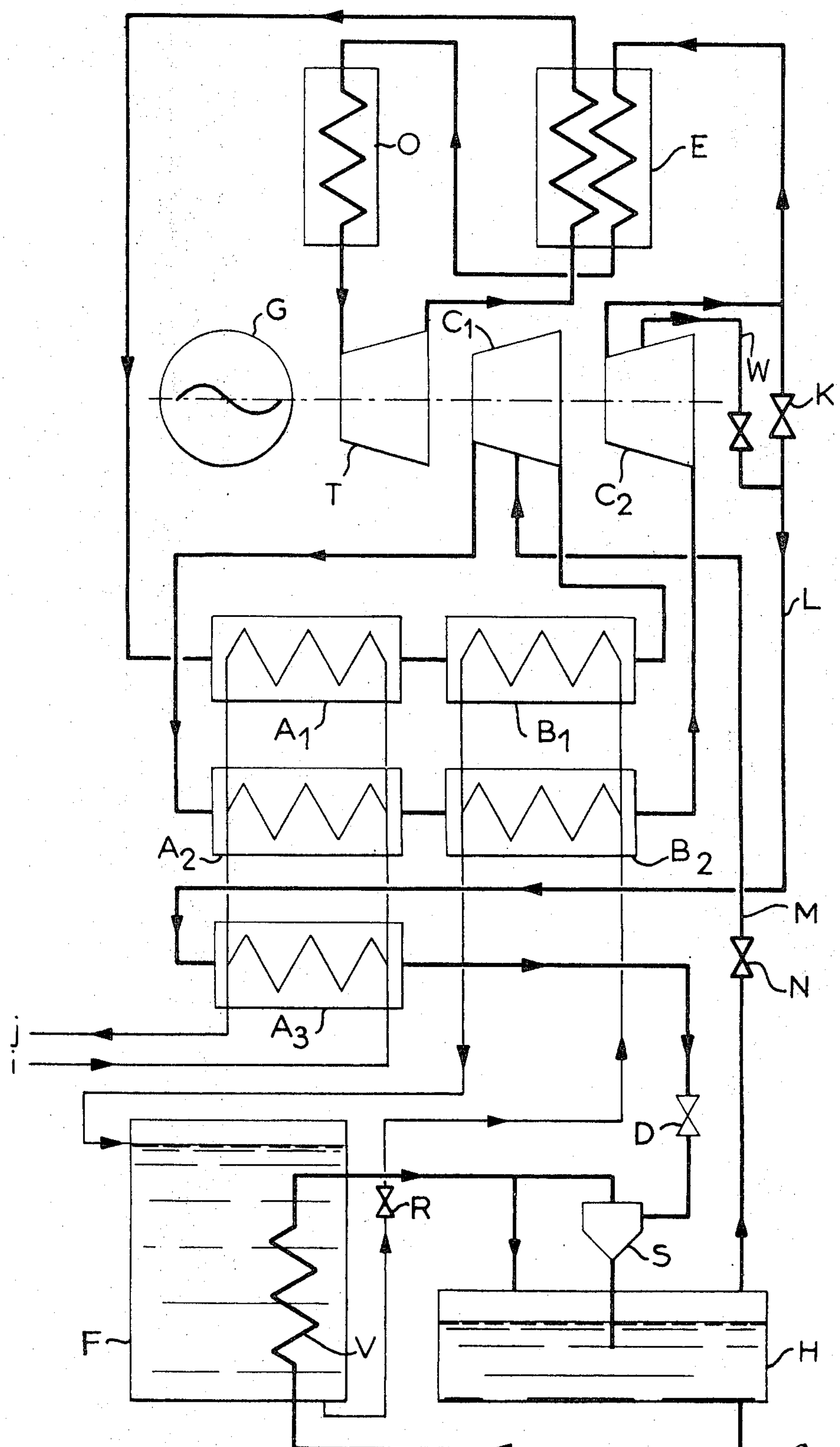

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POWER GENERATION APPARATUS

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ABSTRACT OF THE DISCLOSURE

Power generation apparatus employing a gas cycle includes networks for the working fluid, a cold-producing fluid and an intermediary fluid. These networks are arranged so that the cold-producing fluid may be recycled to cause progressive freezing of the intermediary fluid whereby this reserve of cold may be exploited to cool the working fluid at the cold source, during the periods of inactivity of the cold-producing fluid. It is thus possible to limit the operation of the cold-producing fluid to off-peak hours, at which time a store of frozen products is built up for use subsequently at times of demand.

BACKGROUND OF THE INVENTION

This invention relates to power generation apparatus employing a gas cycle, more particularly, the invention relates to such apparatus characterised by the provision of a refrigerating machine intended to reduce the cold source temperature. Such apparatus, in consequence of this reduction in temperature, is apt to yield a power complement greater than the power absorbed by the refrigerating machine.

In their U.S. patent application No. 788,887, filed Jan. 3, 1969, the applicants have described, in apparatus of this kind, the application of an intermediary fluid performing the heat transfer between the cold-producing fluid of the refrigerating machine on the one hand and the working fluid of the gas cycle on the other hand.

The main object of the invention is to provide apparatus which is operable at a constant or nearly constant power output, despite the variations of distribution grid demands.

According to the invention power generation apparatus employing a gas cycle comprises a network for circulation of working fluid with a compressor, a heat source and a turbine, a network for circulation of cold-producing fluid with means of performing compression, cooling, decompression and vapourisation, and a network for circulation of intermediary fluid with a tank arranged to contain this fluid in solid-liquid phase balance and means of causing a heat exchange with the working fluid on the one hand and with the cold-producing fluid on the other hand. Such an arrangement renders it possible to recycle the cold-producing fluid to cause progressive freezing of the intermediary fluid, and to exploit this reserve of cold to cool the working fluid at the cold source, during the periods of inactivity of the refrigerating machine.

The intermediary fluid kept in a solid-liquid phase balance in point of fact represents an accumulator of frozen products. In power stations affected by load fluctuations, apparatus according to the invention render it possible to limit the operation of the refrigerating machine to off-peak hours, the frozen products stored being available subsequently at times of demand and especially at peak periods.

The present invention thus provides a particularly convenient method for accumulation of surplus power, given that the storage of frozen products is easier, less expensive and considerably more compact than accumulating a reserve of water under load. An expedient of this nature is thus most useful in the case of apparatus operating under a narrow range of output variation only to meet considerable power demand fluctuations, or in the case of apparatus of which the thermal efficiency decreases appreciably with the load on the turbine.

The invention also includes a process for application of the power generation apparatus described above, in which process a variable quantity of the power generated by the gas turbine is diverted to increase the cold reserve of the tank, and varying withdrawals are made from this reserve to cool the working fluid prior to compression.

BRIEF DESCRIPTION OF THE DRAWING

The figure by way of example shows diagrammatically a form of power generating apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The apparatus selected and illustrated operates in a closed cycle employing one decompression—which may moreover advantageously be performed in several units—and two compressions with intermediate cooling. With reference to the drawing, a turbine T drives a load G and two compressors C1, C2. The turbine T is co-ordinated with a heat source O, for example a nuclear reactor, and with a regenerator E, the working fluid being carbon dioxide gas, for example.

Two coolers A1, A2 employing cold water circulation, are situated in the ducts of working fluid supplying the compressors C1, C2, respectively. These coolers A1, A2 and also a third cooler A3, are supplied in parallel by a cold water circuit having an inlet at *i* and an outlet at *j*.

The apparatus also includes two coolers B1, B2 employing circulation of cold-producing fluid. These coolers B1, B2 are positioned upstream of the compressors C1, C2 and are arranged to be swept by the flows of working fluid issuing from the coolers A1, A2 respectively. The coolers B1, B2 are installed in a closed circuit with a tank F feeding them in parallel with cooling fluid through an adjustable flow valve R.

The tank F may contain a cold-producing agent such as a brine in the liquid state or in a state of liquid-solid phase balance. A nest of tubes V, which at least in this example is immersed in the tank, is arranged in a closed circuit with a vessel H containing a liquefied cold-producing fluid. Also, at least in this example, this gas is carbon dioxide gas drawn from the outlet of the compressor C2 by means of a duct L branching from the duct supplying the turbine T through the regenerator E and the reactor O. The duct L is controlled by a valve K and the gas flowing therein is ducted to the vessel H after having undergone a condensation in the cooler A3, a throughflow decompression in a valve D, and a separation of the phases in a separator S. Moreover, a duct M controlled by a valve N connects the vessel H to an intermediate intake stage of the compressor C1.

The operation of the ducts L and M thus assures, successively, that the compression, condensation and decompression of the cold-producing fluid is kept in phase balance in the vessel H.

The working fluid evolves, for example, between pressures of the order of 15 to 60 bars, and the vessel H may be under a saturation pressure of approximately 25 bars, or under a lower pressure.

Two methods of operation of this apparatus, corresponding to two load conditions, will now be described.

(I) Operation at off-peak periods

The valves K and N are open for operation of the ducts L and M during periods of low demand. The valve R is closed partially or completely. The gas fed to the turbine T leaves it after decompression and returns to the compressor C1 after having circulated in the regenerator E and after being cooled in A1, and if appropriate in B1. This partially compressed gas is mixed with gas drawn from the vessel H and fed to the intermediate intake point of the compressor C1. The mixture issuing from C1 is cooled in A2 and, if appropriate in B2, and undergoes a second compression in C2. At the outlet of C2, the greater part of the flow is recycled to the turbine T through the regenerator E and the reactor O, the remainder returning to the vessel H after condensation in A3, decompression in D and phase separation in S. The liquefied gas fed to the vessel H is vapourised again in the nest of tubes V whilst cooling the brine contained in the tank F and whilst freezing the same gradually. The frozen products generated in the compression (C1), condensation (A3) and decompression (D) circuits, are thus stored in the vessel F.

(II) Operation during demand and peak periods

The valves K and N are closed. The reserve of carbon dioxide gas of the vessel H ceases to be operative, thus reducing the work of the compressors and increasing the available turbine power. The valve R is open, and the two coolers B1, B2 operating at full rate, cause maximum cooling of the working fluid prior to its infeed into compressors C1 and C2, thus increasing the output of the apparatus. This cooling action corresponds to an infeed of heat to the tank F, with progressive melting of the frozen part of its contents, and without increase in the temperature of its liquid phase circulating in the coolers B1, B2.

The apparatus is appropriate for various other methods of operation applicable by appropriate adjustment of the valves R, K and M. The valve R may thus be opened as far as need be during off-peak periods, to keep the output of the plant at an appropriate value, whilst forming a reserve of ice in the tank F which is sufficient for the following period of demand.

According to another mode of operation, applicable for example in the case in which the reserve of ice is exhausted, the vessel H remains in operation during demand periods, and the carbon dioxide gas liquefied by the compressors serves the purpose of cooling the working fluid sweeping the exchangers B1, B2 whilst acting through the fluid contained in the tank F but without forming ice in the latter.

The apparatus described hereinabove thus offers the possibility of accumulating power during off-peak periods for release during demand periods, without modifying the rate of operation of the heat source, the means employed to form this reserve of power consisting of diverting a part of the mechanical work produced during off-peak periods to freeze a fluid, and of exploiting the ice thus formed to lower the temperature of the working fluid at the cold source, during demand periods.

In a particular case, it is found that 40 kgs. of ice renders it possible to accumulate 1 kwh., whereas in hydraulic accumulators, the storage of 1 kwh. requires 1,000 litres of water to be stored under a head of approximately 460 metres. The storage of power in the form of ice thus renders it possible to effect a considerable reduction in size and in investment and exploitation costs, whilst providing an appreciably higher output than in existing power storage apparatus.

The invention is not limited in any way to the specific details of the embodiment described above. For example, the valve D of the drawing may be replaced by an auxiliary decompression turbine.

Also, the cold-producing fluid and the working fluid may differ from each other and may be compressed either separately or in one and the same compressor, according to the arrangements described in U.S. patent application No. 788,894, filed Jan. 3, 1969, filed in the applicants' name for "Apparatus for Generation of Energy in a Closed Gas Cycle."

Furthermore, the pipe L may be fed by an intermediate tap-off point W of the compressor C2, thereby rendering it possible to select the most suitable pressures for the working cycle and the refrigeration cycle independently of each other.

We claim:

1. Power generation apparatus employing a gas cycle, comprising a network for circulation of working fluid with a compressor, a heat source and a turbine, a network for circulation of cold-producing fluid with means of performing compression, cooling, decompression and vapourisation, and a network for circulation of intermediary fluid and a tank arranged to contain this fluid in solid-liquid phase balance and means of causing a heat exchange with the working fluid on the one hand and with the cold-producing fluid on the other hand.

2. Apparatus according to claim **1**, in which the cold-producing fluid and the working fluid are of the same nature.

3. Apparatus according to claim **1**, in which the cold-producing fluid and the working fluid are placed in circulation through one and the same compressor.

4. Apparatus according to claim **1**, in which the network of cold-producing fluid comprises means of controlling the flow rate placed in circulation in the said network.

5. Apparatus according to claim **1**, in which the network of the cold-producing fluid comprises a vessel arranged to contain the same in gas-liquid phase balance.

6. Apparatus according to claim **3**, in which cold-producing fluid is fed to an intermediate intake stage of the compressor.

7. Apparatus according to claim **3**, in which at least a part of the cold-producing fluid is delivered to an intermediate delivery stage of the compressor.

8. Apparatus according to claim **3**, in which the compressor comprises several units arranged in series in the path of the fluid to be compressed, with two coolers arranged in series in one fluid feed pipe to each unit, and one being fed with a fluid at atmospheric temperature and the other with intermediary fluid.

9. Apparatus according to claim **1**, in which said last-defined means includes first and second separate liquid-cooled heat-exchange devices in series relation with said working-fluid network and with said cold-producing network, respectively.

10. Apparatus according to claim **9**, in which a single liquid coolant circulation system serves both said heat-exchange devices.

11. Apparatus according to claim **10**, in which said single circulation system includes a water supply.

12. Apparatus according to claim **9**, in which said last-defined means further includes a third intermediary-fluid-cooled heat-exchange device in said working-fluid network.

13. Apparatus according to claim **12**, in which said third device is between said first heat-exchange device and the inlet to said compressor.

14. Apparatus according to claim **9**, in which said last-defined means further includes a third intermediary-fluid-cooled heat-exchange device in said cold-producing network.

15. The method of operating a gas-turbine power-generating plant in which a network for circulation of working fluid includes a compressor, a heat source and the gas turbine, and in which a circulating liquid-cooling system with a storage tank is connected in heat-exchange relation with the working fluid prior to compression, which method comprises diverting a quantity of the power generated by the gas turbine to refrigerate liquid coolant in the tank, and varying the flow of liquid coolant in heat-exchange relation with the working fluid.

16. The method of claim 15, in which the liquid coolant is refrigerated by first refrigerating a cold-producing fluid, storing a supply of the cold-producing fluid, and withdrawing cold-producing fluid from the supply to cool liquid in the storage tank.

17. The method of claim 16, further comprising withdrawal of cold-producing fluid from the supply to additionally cool the working fluid prior to compression.

18. The method of claim 15, wherein in periods of greater load demand the power diversion for refrigeration is reduced and the liquid-coolant flow in heat-exchange relation with the working fluid is increased.

19. The method of claim 15, wherein the power diversion for refrigeration is in intermittent periods in accordance with the tank content of frozen coolant.

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