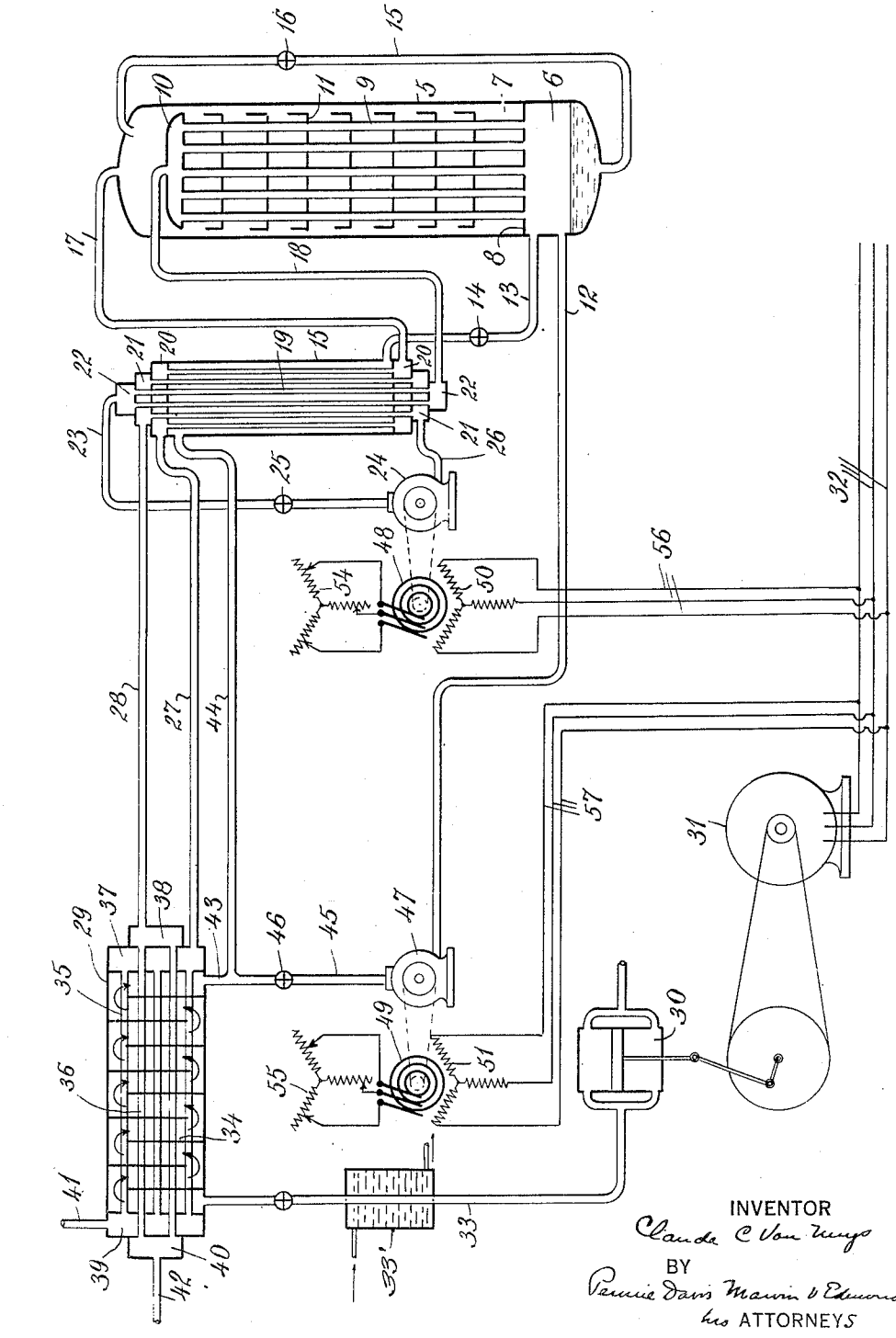
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REFRIGERATION

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REFRIGERATION.

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This invention relates to refrigeration involving the expansion of compressed gases with external work to produce low temperatures, and particularly to the useful recovery of a portion of the energy expended in compressing the gases before expansion. It has a special advantage when applied in connection with a turbine in which the gases are expanded though it may also be used with expanders of the reciprocating type.

In existing liquefaction systems such as are employed in the separation of the constituents of the atmosphere for commercial purposes, expansion engines are used. It has been proposed to directly connect the expansion engine with the main compressor and thus to utilize the energy recovered. The suggestion is wholly impracticable because it would require the expansion engine to operate at invariable speed whereas the volume and pressure of the working fluid vary in different phases of the operation. This requires a variation of the speed of the expander to maintain efficiency, particularly in the case of turbine expansion since the turbine is efficient only when operated at a definite speed with any given conditions of pressure and volume of the working fluid. Consequently the energy is usually employed in operating a direct current generator, and the current produced is dissipated through a resistance of the grid type and is a total loss.

The installation of systems of greater capacity than those now in use will depend to a large extent upon the possibility of recovering a portion of the energy derived from expansion in an economically useful form. Limitations of speed of the expanding means must be avoided, and preferably the energy should be recovered as electric current of the kind which is utilized in driving the motor for the compressor.

It is the object of the invention to provide for the conversion of the energy derived from expansion and to automatically deliver the electrical energy recovered to the power line and to permit adjustment of the converter from time to time depending upon the existing conditions so that expansion at maximum efficiency is continually assured.

Other objects and advantages of the invention will be apparent as it is better understood by reference to the following specification and accompanying drawing which illustrates diagrammatically the application of the invention to a liquefaction system.

It is assumed that the motor which drives the compressor will be operated with alternating current of the kind usually supplied by power lines. An ordinary alternating current synchronous generator could be connected to the expansion engine or turbine, but the speed of operation of such a generator is necessarily invariable. There is no advantage, therefore, over the proposal to connect the expander directly to the compressor. The difficulty is entirely avoided, however, by the use of an induction generator with a wound rotor and a variable external resistance connected therewith. Such a generator has the advantage that the speed and the amount of energy transformed may be varied independently within certain limits by varying the resistance of the rotor circuit. The operation of the generator may be regulated, therefore, depending upon the conditions of pressure and volume of working fluid in the liquefaction system to permit operation of the expansion engine and particularly of a turbine at maximum efficiency. Thus, if the conditions of pressure and volume of working fluid require the operation of the turbine at a certain definite and previously ascertained speed, the resistance connected to the rotor circuit of the generator will be adjusted correspondingly to permit operation of the turbine and generator at that speed while generating current which has the characteristics of the power line current and can be delivered directly to the power line.

The induction generator has another advantage inasmuch as it operates interchangeably as a generator or motor depending upon whether mechanical or electrical energy is delivered thereto. Consequently, as long as the expansion engine or turbine delivers energy to the generator, power will flow therefrom to the power line. If the expansion engine or turbine fails for any reason to deliver energy to the generator the latter will act as a motor drawing current from the power line and driving the expansion engine or turbine until the normal condition is again resumed. The generator acts thus as a balance wheel to maintain the engine or turbine in operation at its speed of maximum efficiency under the conditions which are assumed to exist regardless of any temporary

alterations of these conditions. Any permanent change in conditions is met by an adjustment of the resistance of the rotor circuit which automatically changes the speed of operation of the generator and of the expansion engine or turbine to which it is connected.

In carrying out the invention the expansion engine or turbine is preferably directly connected to the induction generator which is electrically connected in a shunt circuit from the power line feeding the main driving motor for the compressor. The variable resistance of the induction generator rotor is conveniently arranged so that it may be varied at will with the changes of conditions of pressure and volume of the working fluid. By suitable regulation of the generator the recovery of energy at maximum efficiency is assured and the recovered energy is delivered directly to the power line and utilized. The saving in energy is at once apparent as a reduction of the total energy consumed in compressing the gases prior to expansion thereof.

In the following more detailed description of the invention it is assumed to be applied to a liquefaction system whereby the constituents of gaseous mixtures may be separated. It has, however, a broader application to refrigeration where low temperatures are attained by the expansion of a working fluid in an engine or turbine. The simple type of liquefaction apparatus is described merely that the invention may be clearly explained.

Referring to the drawing, 5 indicates a column having compartments 6 and 7 separated by a partition 8. A plurality of tubes 9 are supported in the compartment 7 and communicate at one end with the compartment 6 and at the other end with a head 10. A plurality of trays 11 are disposed in the compartment 7 to collect the liquid produced as hereinafter described.

The compressed gaseous mixture enters the compartment 6 through a pipe 12 and passes upwardly through the tubes 9 in indirect contact with the liquid in the trays 11. The resulting heat-interchange causes a partial liquefaction of the gaseous mixture in the tubes and the liquid thus formed flows downwardly through the tubes into the compartment 6. In accordance with the well-established principles of "backward return" in selective liquefaction, the liquid entering the compartment 6 from the tubes 9 is enriched in the more readily condensable constituent thereof while a residual gas consisting principally of the less condensable constituent escapes to the head 10 and thence through a pipe 18.

Additional liquid to make up for heat losses in the column is supplied to the compartment 6 through a pipe 13 which is controlled by a valve 14 from a liquefier 15. The liquids combining in the compartment 6 are delivered therefrom to a pipe 15′ and pressure-reducing valve 16 to the top of the column 5. The liquid fills the trays 11 and flows downwardly through the column. As a result of the heat-interchange between the liquid and the gaseous mixture in the tubes 9, a portion of the liquid is vaporized and rises through the column from which it escapes through a pipe 17.

The gases delivered through the pipes 17 and 18 are utilized in the liquefier 15 to secure by heat-interchange the liquefaction of a portion of the incoming gaseous mixture, the liquid formed being delivered through the pipe 13 as hereinbefore described. The liquefier consists preferably of a shell with a plurality of tubes 19 extending therethrough and communicating with compartments 20, 21 and 22 at opposite ends thereof. The pipes 17 and 18 communicate with the compartments 20 and 22 at one end of the liquefier so that the gases pass through the communicating tubes and are delivered to the corresponding chambers 20 and 22 at the opposite end of the liquefier. From the chamber 22 the gases are delivered through a pipe 23 to an expansion engine or turbine 24 under control of a valve 25. After expansion the gases pass through a pipe 26 to the chamber 21 at one end of the liquefier and thence through the communicating tubes 19 to the corresponding chamber 21 at the opposite end of the liquefier. From the chambers 20 and 21 the gases which are still at relatively low temperature are delivered through pipes 27 and 28 to an exchanger 29 which is utilized to heat the incoming gaseous mixture.

The mixture is compressed in a compressor or blower 30 which is driven preferably by an electric motor 31. The motor is supplied with electrical energy usually of the three phase alternating type through a power line 32. The compressed gaseous mixture passes from the compressor 30 through a pipe 33 and water cooler 33′ to the exchanger 29 where it passes about baffles 34 in contact with tubes 35 and 36 through which the gases are delivered from chambers 37 and 38. These chambers are connected to the pipes 27 and 28. The tubes 35 and 36 communicate with chambers 39 and 40 at the opposite end of the exchanger having outlets 41 and 42 through which the gases are discharged to the atmosphere or delivered to suitable receptacles therefor.

In passing through the exchanger the incoming compressed gas is cooled by heat-interchange with the outgoing constituents from the column and in its relatively cold condition is delivered to a pipe 43. A branch pipe 44 delivers a portion of the cold gas under its initial pressure to the liquefier where it is liquefied by indirect contact with the cold gases in the tubes 19, and it is finally delivered through a pipe 13 to the chamber 6 of the column. The balance of the gas passes through

a pipe 45 controlled by a valve 46 to an expansion engine or turbine 47 where it is expanded with external work. The cold gas from the engine or turbine is delivered through the pipe 12 as hereinbefore described to the chamber 6 of the column.

As the result of the operation under properly regulated conditions liquid enriched in oxygen, for example, accumulates in the chamber 6 and is delivered through the pipe 15 and expansion valve 16 to the upper part of the column. It descends through the trays 11 therein and is vaporized by heat-interchange with the gas in the tubes 9. The vapor escaping through the pipe 17 is the gaseous mixture enriched in one of the constituents, for example, oxygen, which is one of the products of the operation. A residual gas consisting of substantially pure nitrogen, for example, will be delivered to the head 10 and will escape through the pipe 18. By the application of a suitable rectifying column and liquid reflux a further purification may be obtained, but for many purposes and particularly in the production of oxygenated blasts for metallurgical and other furnaces and for industrial operations generally, the method described has the distinct advantage of simplicity and economy.

The engines or turbines 24 and 47 are connected either directly or through belts or other driving means to induction generators 48 and 49 having field windings 50 and 51. The rotor circuits of the generators are connected through brushes 52 and 53 to variable resistances 54 and 55. Suitable means for varying the resistances are provided as is usual in such apparatus. The field windings are connected by conductors 56 and 57 in parallel with the power lines 32. The generators are designed to deliver current having the same characteristics as that of the power lines 32, and consequently the application of power to the generators will result in the delivery of current to the power lines and the current will be utilized in the motor 31.

As hereinbefore indicated, the system is particularly advantageous in connection with the use of turbines for expansion since turbines operate most efficiently only within a limited range of speed for any given pressure and volume of gas. The provision of variable resistance in the rotors of the generators permits the regulation of the generators to produce current of the desired characteristic at a speed of operation which is determined by the most effective speed of the turbines. Consequently the pressure and volume of the gas being known, the turbine can be operated at the most efficient speed and the energy delivered thereby can be converted directly into current which is reused in driving the compressor. Leaving out of account the losses due to mechanical and electrical inefficiency, therefore, the energy required to operate the system is limited to the requirement for separation of the gaseous constituents plus the losses resulting from heat-leakage. The generators act, moreover, to maintain the system in its normally efficient operating condition during any temporary failure of the pressure and volume of the expanding gases because at such times the generators will act as motors drawing current from the power line and driving the turbines at their proper speed for efficient operation. If the unusual condition continues a new adjustment must be made, but if it is only temporary the resumption of normal conditions results in the generation of current which is returned to the power line. This condition assures maximum efficiency of the system.

The invention depends upon and comprehends the utilization of electric generators capable of producing current of predetermined characteristics under variable speed conditions so that the energy recovered can be transformed and utilized directly and without unusual loss in the system. While it would be desirable in a liquefaction system to limit the input of energy to that required for the separation of the constituents and for losses unavoidable in the system, practical considerations require the application of a considerable additional quantity of energy. The recovery of a portion of the energy input is accomplished most effectively in the manner hereinbefore described.

Various changes may be made in the form and arrangement of the parts, it being understood that no attempt has been made to illustrate and describe herein details of liquefaction systems which are known to those skilled in the art.

I claim:

1. A method of refrigeration, which comprises compressing a gas with expenditure of electrical power from an external source, cooling and expanding the gas to recover energy therefrom, thereby further reducing the temperature of the gas, converting the recovered energy into electrical power having the same characteristics as the power which is utilized in compressing the gas, supplementing the external power with the power thus developed, and regulating the rate and degree of expansion by adjusting the conversion to produce the desired electrical current while expansion is conducted at maximum efficiency under given conditions of pressure and volume of the gas.

2. A method of refrigeration, which comprises compressing a gas with expenditure of electrical power from an external source, cooling and expanding the gas to recover energy therefrom, thereby further reducing the temperature of the gas, converting the recovered energy into electrical power having the same characteristics as the power which is

utilized in compressing the gas, regulating the rate and degree of expansion by adjusting the conversion to produce the desired electrical current while expansion is conducted at maximum efficiency under given conditions of pressure and volume of the gas and utilizing the recovered electrical power to automatically supplement the external source of power in compressing the gas.

3. A method of refrigeration, which comprises compressing a gas with expenditure of electrical power from an external source, cooling and expanding the gas to recover energy therefrom, utilizing the energy to generate electrical power having the same characteristics as the power which is utilized in compressing the gas, flexibly associating the two power sources to supplement each other, and regulating the rate of expansion by adjusting electric variables to permit expansion at maximum efficiency under given conditions of pressure and volume of the gas.

In testimony whereof I affix my signature.

CLAUDE C. VAN NUYS.