

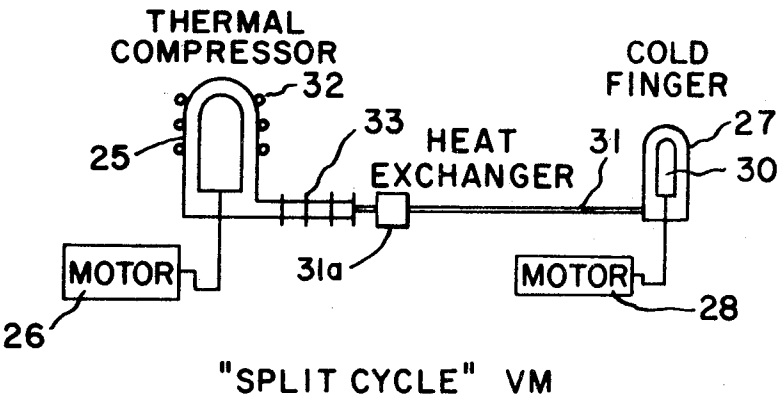
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			3,302,422 2/1967 Smith.....	62/6
			3,314,244 4/1967 Green.....	62/6
			3,379,026 4/1968 Cowans.....	62/6
[21]	Appl. No.	14,040	3,423,948 1/1969 Cowans.....	62/6
[22]	Filed	Feb. 25, 1970	3,431,746 3/1969 Webster.....	62/6
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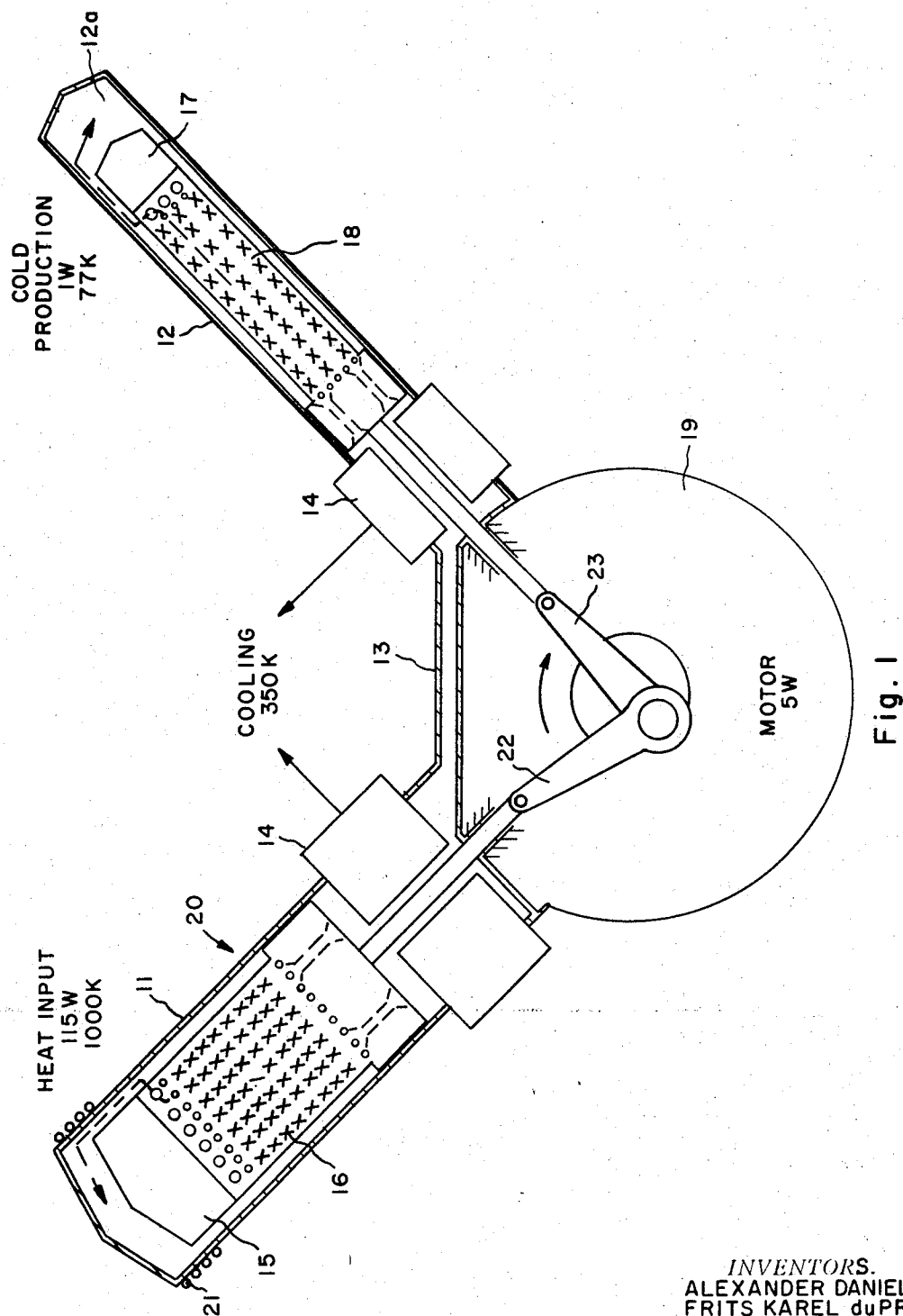
[54] THERMODYNAMIC REFRIGERATOR
12 Claims, 5 Drawing Figs.

[52]	U.S. Cl.....	62/6, 62/86
[51]	Int. Cl.....	F25b 9/00
[50]	Field of Search.....	62/6, 86

[56]	References Cited
	UNITED STATES PATENTS
1,275,507	8/1918 Vuilleumier..... 62/6

ABSTRACT: A cryogenic refrigeration apparatus operable in accordance with a thermodynamic cycle such as the Vuilleumier cycle, wherein the hot and cold chambers are physically separated, and the corresponding hot and cold displacers are driven reciprocally by separate motors. Proper pressure variations and phase difference between the motions of the displacers and the gas transported are maintained preferably by synchronizing the speeds of the different motors.

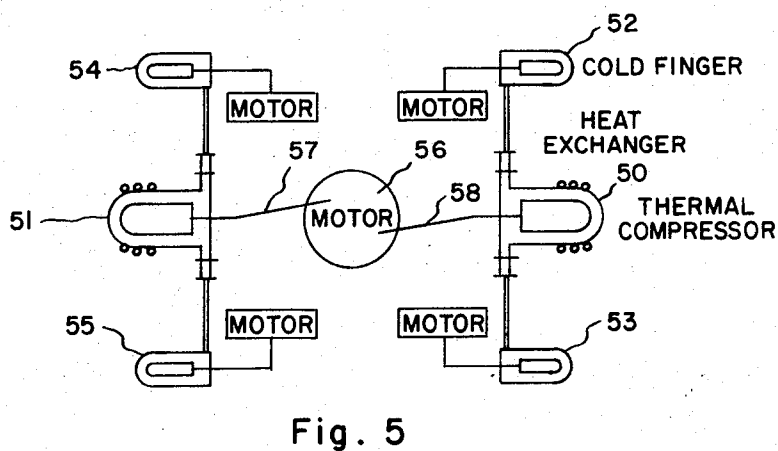
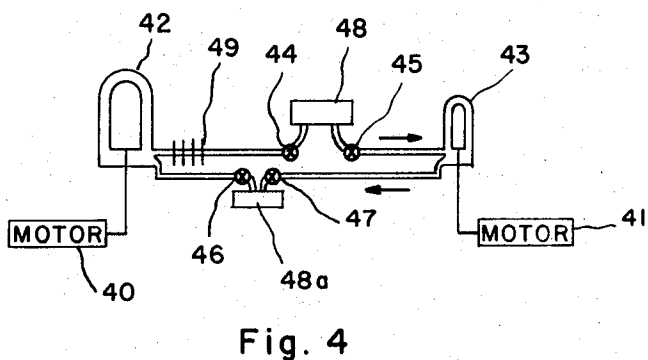
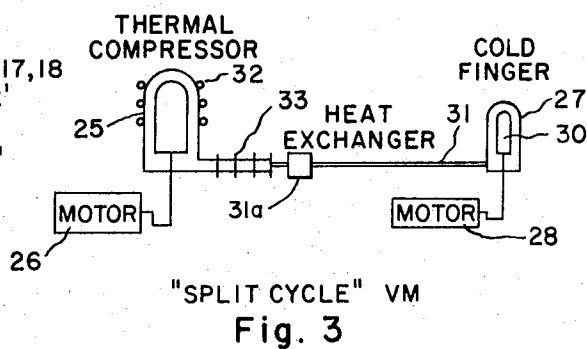
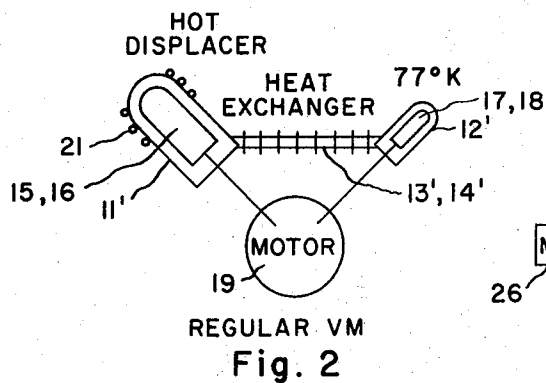




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THERMODYNAMIC REFRIGERATOR

BACKGROUND OF THE INVENTION

This invention is in the field of cyogenic refrigeration apparatus and thermodynamic cycles on which such apparatus operate, and particularly the field of refrigeration means operating on a cycle such as the Vuilleumier regenerative cycle as related to the idealized Stirling cycle.

In refrigeration apparatus operating on a Stirling regenerative cycle, there are typically five interconnected elements, namely a compression space, a cooler, a regenerator, a freezer, and an expansion space. In such devices the helium gas, working medium is first compressed in the compression space, then cooled in the cooler, and next flowed through a regenerator where additional heat from the gas is extracted and stored. Upon exiting the regenerator the gas flows into the expansion chamber where cold is produced and finally extracted by means of a freezer component. Subsequently, the gas is returned through the regenerator, where it reabsorbs the stored heat and flows again to the compression chamber to complete a cycle.

Although ideally three elements (compression space, regenerator, and expansion space) are sufficient to explain the operation of such cycles, in most practical machines, the cooler and freezer elements have been added in order to effect adequate heat transfer between the gas in the compression and expansion spaces and the surroundings; the cooler and freezer elements thus compensate for the poor thermal contact and heat transfer capability between the working gas and the two cylinders. In the Stirling cycle apparatus as thus described, there is established variable volume compression and expansion spaces having different average temperatures, with a motor provided to drive the displacers in a suitable phase relationship, whereby the gas is successively compressed and expanded.

The Vuilleumier cycle differs from the Stirling cycle primarily in its means for establishing pressure variations in the gas for compression and expansion. In known Vuilleumier cycle refrigerators, there are within a single housing, two chambers and a connecting duct, a displacer piston reciprocally movable in each chamber, and a single electric motor with a dual connecting rods for driving the two displacers at exactly the same speed and in a 90° or other phase difference. Heat is added into one chamber with a higher gas pressure resulting in the working space, thus establishing a thermal compressor in substitute for the mechanical compressor of the Stirling cycle. In this Vuilleumier device the heated and compressed gas flows from the hot space through regenerator material in the corresponding displacer, through the connecting duct which includes heat exchanger means to transfer heat to the ambient, then through a second regenerator in the cold chamber displacer, with cold finally produced in the remote space of the nonheated cylinder.

The pressure variations in the cold volume of this Vuilleumier device are produced by the motion of the hot displacer in the following way. If the hot displacer is "down," much of the helium is in the hot area, the average helium temperature will be high, and the pressure will be high everywhere in the working space. On the other hand, if the displacer is "up," very little of the helium is in the hot area, the average helium temperature will be low, and the pressure will be low. Therefore, as long as the hot displacer moves up and down in the correct phase relationship to the motion of the cold displacer, the required pressure and volume variations are produced in the cold expansion space, and cold is produced according to the equation of $Q = \oint p dV$; this equation defines cold production per period in the various thermodynamic cycles, with the same cold produced in a given expansion volume no matter how the pressure variation is produced.

A further characteristic of the Vuilleumier refrigerator is that the power required to drive the displacers may be small, since the only forces on the displacers are those due to the pressure drop of the helium flowing through them and to the

mechanical friction. Furthermore, since there is a heat input at the hot chamber, and at the cold finger where an object is cooled, it follows that the heat rejection to the ambient equals the sum of these amounts, plus the small amount of heat equal to the motor input.

The above equation for cold production should be considered with respect to conditions on which it is based, namely the cold production during one cycle in a volume into which (and out of which) a gas can flow only via an ideal regenerator. This is the situation encountered in both the idealized Stirling and Vuilleumier regenerative cycles, with these cycles differing only in the way they produce the periodic pressure variations, since the cold-volume variations are always due to a sinusoidal motion of a displacer piston. One of the unique features of the Vuilleumier refrigerator is that its constant volume process with no mechanical compression, results in low bearing loads, long mechanical life, and quiet operation; also such construction is compact and has minimized dead space, as shown in the drawings.

Known Vuilleumier cycle refrigerators are constructed generally as described above, with the stated features and advantages; however, such apparatus has a number of major limitations and disadvantages. Since both hot and cold displacers are contained within a single housing, it is inherent in the apparatus design that the heat source applied to the hot chamber is in close proximity to the cold chamber. In situations where the source of heat is available only at a point remote from the place where cold production is to be provided, a long heat pipe would be required to bring the heat to the hot chamber, with corresponding expense and complications; in such cases, the Vuilleumier cycle refrigerator would not be desirable. Furthermore, there are now various situations calling for cold production in a given location, with the dissipation of any heat into this area being intolerable. Thus the presence, near the cold production area, of the heat source, or the hot chamber, or even a heat pipe would render prior Vuilleumier refrigerators impractical.

Another limitation in these devices concerns the cyclic pressure variations of the gas caused by movement of the displacers with a proper phase difference. To achieve this phase relationship while cycling the hot and cold displacers at the same speed, known devices use a single motor with dual connecting rods. Since it has been established that the cold displacer must be reciprocated relatively slowly to minimize flow losses therein, a consequence is an equally slow-running hot displacer and resulting design inflexibility.

SUMMARY OF THE INVENTION

The present invention is an improvement of the Vuilleumier cycle refrigerator apparatus which overcomes the various structural and functional limitations described above in the prior art. To accomplish these improvements the basic structure of a typical known Vuilleumier refrigerator has been so significantly altered that the hot and cold cylinders are physically separated, with an independent electric motor drive means for each. With this new arrangement the hot and cold displacers can be operated by motors having synchronized speeds or different speeds; and both the hot chamber and the heat source may be located quite remote from the area of cold production. Where the new apparatus has motors operable at different speeds, the hot and cold chambers interconnected by tubes, include valves synchronized with each displacer, whereby the desired pressure variations in the gas are obtained. Also connected between the hot and cold sides can be an adsorber to remove contaminants of the flowing gas stream. In a further embodiment, a single thermal compressor formed by a hot-side cylinder, displacer, and electric motor, may cooperate with a plurality of remote cold fingers. In each of the above embodiments the cold and hot chambers and their associated displacers and drive means are designed to be physically separated and independent of each other, except for interconnecting duct means.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a prior art Vuilleumier cycle refrigeration apparatus.

FIG. 2 is a schematic view of apparatus similar to that of FIG. 1.

FIG. 3 is a schematic view of the new split-cycle refrigerator.

FIG. 4 is a further embodiment of the new invention in FIG. 3.

FIG. 5 is a further embodiment of the invention in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

As shown in FIG. 1, the prior art Vuilleumier cycle refrigerator has a hot chamber 11, a cold finger 12, and a connecting duct 13 and cooler 14. FIG. 2 is similar with hot and cold sides 11' and 12' and a combination duct and cooler 13' and 14'. Within each hot chamber is displacer 15 and its internal regenerator 16, and within each cold finger is its displacer and regenerator 17 and 18. A single electric motor 19 drives the two displacers in FIGS. 1 and 2 at the same speed, in a 90° phase relationship. The apparatus thus described are closed systems, each within a single housing 20. Disposed about a portion of the hot cylinders 11, 11' is shown a heat exchanger 21 for transferring heat from an external source into the hot chamber and heating the gas therein.

As shown in FIG. 1 the cyclic gas flow pattern is as follows. After the gas is heated in chamber 11 with a resulting pressure increase, it flows through regenerator 16 to heat exchangers 14 where it is cooled, then through regenerator 18 to expansion space 12a with resulting cold production. A freezer element not shown would be used to transfer the cold to a device or area to be refrigerated and the gas then returns to complete the cycle.

Motor 19 has two connecting rods 22 and 23 for driving the hot and cold displacers respectively at the same speed, and at a 90° phase difference which might be varied as required. In the device disclosed cold production of 1 watt at 77° K. would be achieved with a heat input of 115 watts at 1,000° K., 5 watt motor, and intermediate cooling at 350° K.

The first shown embodiment of the new invention in FIG. 3 has a thermal compressor 25 and its motor 26, and a separate cold finger 27 with its motor 28. While the motors are physically separated, they are operated at the same speed, so that the reciprocal movements of the thermal compressor displacer 29 and the cold finger displacer 30 will also be identical, but at a suitable phase difference. One preferable method for attaining synchronized operation of the motors with a selected phase difference would be to use electronic control means.

Interconnecting the hot and cold sides 25 and 27 is a single duct 31; with this arrangement the gas will be cyclically moved between the hot and cold sides with the desired pressure variations, with no requirement for valves to control the gas flow. Also present is heat exchanger 32, either separate or part of duct 31, for transferring heat from an external source into the hot chamber 25 and a second heat exchanger 33 for removing certain heat of compression before the gas is expanded in the cold finger. Any heat rejection associated with the thermal compressor and its associated motor, and any vibrations from these elements may be isolated from the cold finger, and also may be spaced quite remotely. It is also possible to replace the thermal compressor 25 with a different, mechanical compressor, and still retain the other structural features described above.

A variation of the embodiment of FIG. 3 is shown in FIG. 4 where motors 40 and 41 for the thermal compressor 42 and the cold finger 43 respectively are run at different speeds, preferably with the cold finger displacer at a low speed to minimize flow losses and the hot displacer at a relatively higher speed as determined by design considerations. When the motors are run at different speeds, the desired cyclic gas pressure variations will be obtained by synchronizing valves 44, 45, 46 and 47 with the displacer movements. These valves

are associated with pressure chamber 48 wherein the higher pressure gas is stored and cyclically released to the cold finger and a low-pressure chamber 48a. Heat exchanger 49 provides cooling for the gas subsequent to its heating and pressure stage in the hot chamber 42.

A still further embodiment of the present invention is shown in FIG. 5 where there are two thermal compressors 50 and 51 driven by a single motor 42. Connected to each compressor is a pair of cold fingers 53, 54 and 55, 56. Since each of the four cold fingers has its own electric motor, interdependent of, but synchronized with the compression drive means 52, there will be cold production by the cold fingers at a plurality of locations, all remote from the heat source and from the thermal compressors, without a need for valves.

In any of the above embodiments an adsorber, 31a may be added in the connecting duct 31 of FIG. 3 between the hot and cold sides, for removing contaminants in the gas as it flows cyclically. From the point of view of flexibility in use, these and other embodiments may utilize various heat sources, including electrical heat, propane, and isotopes.

What is claimed is:

1. Thermodynamic apparatus operable in accordance with the Vuilleumier regenerative cycle with a heat source comprising:

- a. a thermal compressor formed of a hot chamber defining therein a heating space, a hot displacer reciprocally movable in the hot chamber, first drive means connected to the hot displacer for driving same, and first heat exchange means for transferring heat from said heat source into said heating space,
- b. a cold finger formed of a cold chamber defining therein a gas expansion space and being physically separated from the hot chamber, a cold displacer reciprocally movable in the cold chamber, and second drive means being connected to the cold displacer for driving same and being independent of the first drive means, the expansion space having a lower average temperature than the heating space average temperature.
- c. duct means interconnecting the hot and cold chambers, with a working medium flowable cyclically through the duct between said spaces,
- d. second heat exchange means associated with the duct for cooling same by transferring heat from the medium flowing therethrough to ambient, and
- e. a regenerator associated with each displacer through which the working medium flows.

2. Apparatus as defined in claim 1 wherein the hot and cold chambers are formed by cylinders having corresponding bores in which the displacers are reciprocated.

3. Apparatus as defined in claim 1 wherein the drive means are electric motors which are synchronized to attain the same speeds and a selected phase difference.

4. Apparatus as defined in claim 1 wherein the first and second drive means are electric motors, the first drive means is operated at a higher speed than the second, the apparatus further comprising valve means synchronized with the drive means for controlling the gas flow and pressure variations of said gas.

5. Apparatus as defined in claim 1 further comprising a second cold finger and second duct means interconnecting the second cold finger with the thermal compressor.

6. Apparatus as defined in claim 1 comprising a second thermal compressor, and auxiliary drive means interconnecting the first drive means and the second compressor, the first and auxiliary drive means being opposed and balanced to minimize vibration.

7. Apparatus as defined in claim 1, further comprising valve means for controlling communication of each of said chambers with said duct means, operation of the valves being synchronized with the two drive means to provide the desired phase difference between the displacer motion and the pressure variation.

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8. Apparatus as defined in claim 1 further comprising an adsorber connected between said chambers for removing contaminants from the gas flowing through the adsorber.

9. Apparatus as defined in claim 1 wherein each regenerator is disposed within a displacer.

10. Apparatus operable in accordance with a thermodynamic regenerative cycle such as the Vuilleumier and Stirling cycles, and with a heat source comprising:

- a. compression means including a compression chamber defining therein a compression space, a piston reciprocally movable in the chamber, and first drive means connected to the piston for driving same,
- b. a cold finger formed of a cold chamber defining therein an expansion space and being physically separated from the compression chamber, a cold displacer reciprocally movable in the cold chamber, and second drive means being connected to the cold displacer for driving same and being independent of the first drive means, the ex-

pansion space having a lower average temperature than the heating space average temperature,

c. means for synchronizing the speed of the two drive means at a selected phase difference,

d. duct means interconnecting the compression and cold chambers, with a working medium flowable cyclically through the duct between said spaces,

e. second heat exchange means associated with the duct for cooling same by transferring heat from the medium flowing therethrough to ambient, and

f. a regenerator associated with the displacer through which the working medium flows.

11. Apparatus as defined in claim 10 wherein said drive means are electric motors.

12. Apparatus as defined in claim 10 wherein the regenerator is disposed within the displacer.

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