RESEARCH ON NEW HEAT PUMP PROCESS

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***Abstract*—A new heat pump process has been developed at the Auroville Centre for Scientific Research (CSR). Its importance lies in its simplicity and in the fact that it works with a mechanical energy input theoretically nil. Only thermal energy is used. It can be solar and renewable. The working principle is presented, the thermodynamic cycle is defined, numerical calculations have been run and further changes are proposed.**

***Index Terms*—Counter flow heat exchanger, isentropic process, isochoric process, isobaric process, regenerator, vapor absorption cycle.**

I. INTRODUCTION

The heat pump invented at CSR in Auroville works with a mechanical energy input theoretically nil. A hot source provides the thermal energy necessary for its thermodynamic cycle. However, the process is different from a vapor absorption cycle as the state of the working fluid does not change.

For a closed system at constant volume, the mean concentration of molecules is constant. Therefore, a localized modification of the molecular concentration induces a variation in the concentration of the other gas molecules of the system. These variations can be induced by localized thermal energy exchange. It is therefore possible, at constant volume, to compress or expand a gas by using this principle [1].

The system we are describing optimizes the cyclic compression and expansion of a gaseous fluid by heat exchange. With a mechanical energy consumption theoretically nil, the fluid can reach a higher temperature than that of the hot source and a lower temperature than that of the cold sink. We will evaluate the magnitude of this effect in order to assess the importance of this process for future applications.

A. Description of figure 1

Figure 1 shows a piston which moves in a cylinder. It is displaced by a device which is not represented. It carries a gaseous fluid through a regenerator from compartment A to compartment B. One of the sides of the regenerator is kept at temperature Tc, the temperature of a cold sink. The other side is kept at temperature Th, the temperature of a hot source. The temperature and volume of a small cluster of molecules which passes through the regenerator from compartment A to compartment B increases. When it enters compartment B, it is at the same temperature (ideally) as that of the hot source and occupies a larger volume than it had when it left compartment A. Consequently, the volume of the other molecules of gas which are in compartment A and B decreases. This part of the gaseous fluid undergoes an adiabatic compression and the temperature rises. *There is an increase in the temperature and volume of a cluster of molecules when it is heated up while passing through the regenerator. It enters the hot compartment at the same temperature as the hot source before its volume decreases (since the other clusters increase in volume while passing through the regenerator). Its temperature continues to increase, by adiabatic compression, beyond the temperature of the hot source.* This temperature, higher than Th, is indicated by Th+. The temperature variations which occur in compartment A and B are the result of the work exchanged between the clusters of molecules passing through the regenerator (where their volume changes) and all the other molecules of gas. It is not the displacer piston which provides the energy of the compression (to displace the gaseous fluid, the displacer piston causes a pressure variation which is small). It is not a mechanical energy which makes the temperature increase beyond Th: it is the thermal exchange which provides this energy.

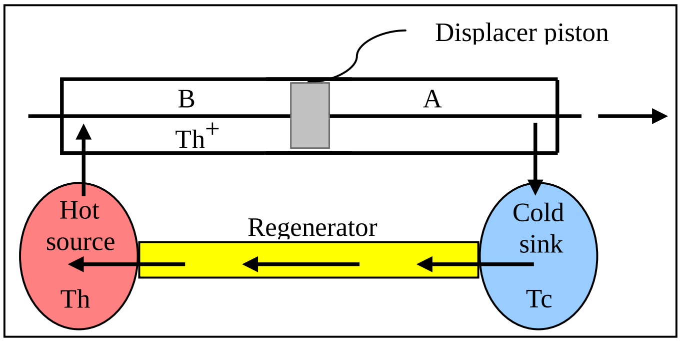

Fig. 1
Moving the gaseous fluid from the cold side to the hot side.

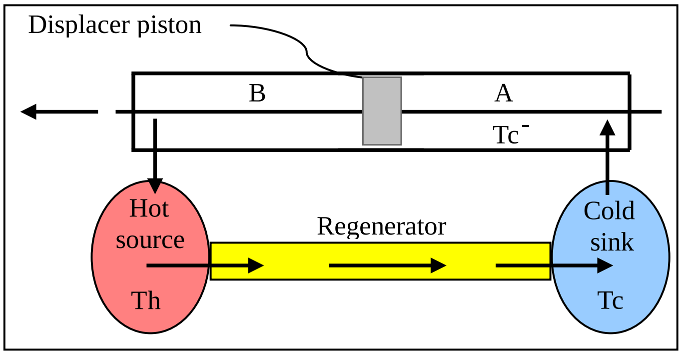

Fig. 2
Moving the gaseous fluid from the hot side to the cold side.

B. Description of figure 2

Figure 2 shows a piston which carries a gaseous fluid from compartment B to compartment A through a regenerator. When a small cluster of molecules enters compartment A it is at the same temperature (ideally) as the cold sink and occupies a smaller volume than the one it had when it left compartment B. Consequently, the volume of the other molecules of gas which are in compartment A and B increases. This part of the gaseous fluid undergoes an adiabatic expansion. This expansion is followed by a drop in temperature. The gas which entered compartment A at the same temperature as the cold sink will reach, by adiabatic expansion, a lower temperature than the one of the cold sink. *The temperature and volume of a cluster of molecules decreases while passing through the regenerator. It enters the cold compartment at the same temperature as the cold sink before its volume increases (since the following clusters decrease in volume while passing through the regenerator). Its temperature continues to decrease, by adiabatic expansion, below the temperature of the cold sink.* This temperature, lower than Tc, is indicated by Tc-.

The temperature variations occurring in compartment A and B come from the work exchanged between the molecule clusters passing through the regenerator (where their volume changes) and all the other gas molecules present.

II. THERMODYNAMIC CYCLE AND METHOD

The thermodynamic cycle has been defined and a simplified calculation method has been used in order to estimate the evolution of the pressure and temperature of the gas.

A. The system

- closed system, number of molecules n = const.
- rigid container, total volume Vt = const.
- ideal gas
- The volume of the regenerator Vr is regarded as very small in comparison to Vt: Vr ≈ 0
- The displacer piston divides Vt into two compartments A and B of variable volumes Va and Vb. Since Vr is insignificant, we have: Va + Vb = Vt = const.
- The energetic input of the displacer piston is supposed to be nil: w ≈ 0. The pressure in compartment A is equal to the one in compartment B: Pa = Pb.
- Compartments A, B and piston: adiabatic
- The regenerator is supposed to be perfect.

B. The thermodynamic cycle and the calculation method

Clusters of n_c molecules follow each other while passing through the regenerator. There, their volume and temperature is altered by thermal exchanges. Since the total volume is constant, a variation in volume (for a cluster of n_c molecules) localized inside the regenerator is compensated by a volume variation which is equal and opposite and involves all the other molecules of gas. Depending on whether the molecule cluster passing through the regenerator is heated up or cooled down the gas inside the compartments A and B undergoes an adiabatic compression or an adiabatic expansion. It goes through variations of volume, pressure and temperature. In order to quantify these variations, we have simplified the problem by using the method described hereafter.

A cluster of n_c gas molecules passes through the regenerator. Its volume variation is equal to dV_{n_c}. If n_c is small compared to the total number of n molecules, then dV_{n_c} is small compared to Vt. The smaller dV_{n_c} is compared to Vt the more the pressure variation is reduced. With a very small n_c, dV_{n_c} can be calculated with a pressure considered as constant. The calculation of dV_{n_c} is more precise if n_c is small compared to n.

The thermodynamic cycle has been defined for a cluster of n_c molecules passing from compartment A to compartment B then from B to A:

1-isobaric heat addition. 2-adiabatic compression (until complete filling of the hot compartment). 3-adiabatic expansion. 4-isobaric heat rejection. 5-adiabatic expansion (until complete filling of the cold compartment). 6-adiabatic compression.

Calculation of the volume variation at constant pressure for n_c molecules passing through the heat exchanger with:

$$PV = nRT \qquad (1)$$

Calculation of the pressure variation by adiabatic compression of the molecules inside compartments A and B with:

$$\frac{PV}{T} = \text{const.} \qquad (2)$$

$$PV^k = \text{const.} \qquad (3)$$

Calculation of the temperature variations resulting from the adiabatic compression with:

$$T2=T1(P2/P1)^{\frac{k-1}{k}} \quad (4)$$

The calculation of the change of temperature differs depending on whether a compartment is filled up or emptied. In fact, when a compartment is emptied, its temperature follows the pressure variations, but when a compartment is filled up, the gas entering the compartment is at a different temperature than the gas already in the compartment. The gas entering in the hot compartment is at a temperature Th and cools down the gas which is at a higher temperature than Th (with which it mixes). The same phenomenon occurs in the cold compartment: the gas entering this compartment is at the temperature of the cold sink Tc and limits the temperature drop below Tc.

III. RESULTS

Figure 3 and 4 show the change of temperature in the hot compartment and the cold compartment for the values Tc=300k and Th=800k, with k=Cp/Cv=1.67 for an ideal gas. The system has reached steady-state. These are theoretical maximums, calculated without dead volume.

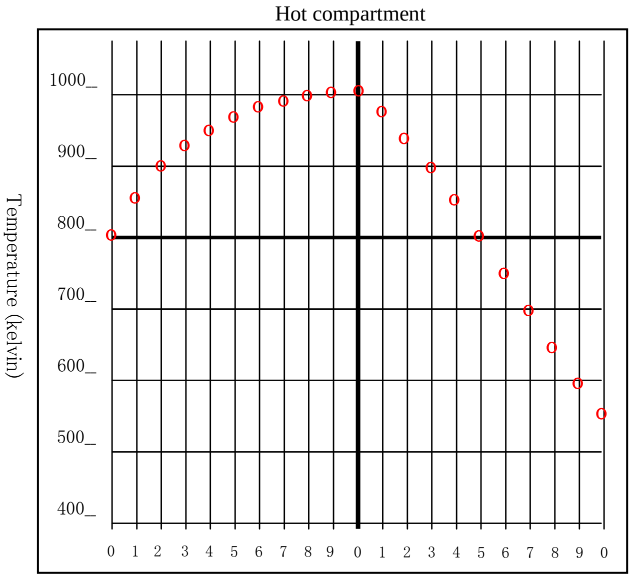

Fig. 3
Filling, then emptying the hot compartment

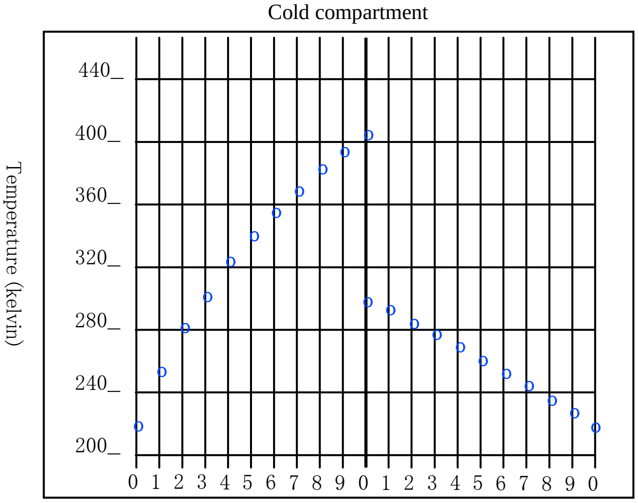

Fig. 4
Draining, then filling the cold compartment

During the filling of the hot compartment (cf figure 3), the temperature of the gas increases from 800 to 1,000k. During the draining, the temperature drops from 1,000 to 550k. The gas reaches the maximum temperature of 1,000k when the hot compartment is full and reaches the minimal temperature of 550k when it is empty. The amplitude of the increase is lower than the amplitude of the drop. The gaseous fluid enters the hot compartment at the temperature of the hot source Th and comes out at a variable temperature.

During the filling of the cold compartment (cf figure 4), the temperature drops from 300 to 220k. The gas reaches the minimum temperature of 220k when the cold compartment is full and it reaches the maximum temperature 410k when it is empty. The amplitude of the drop is lower than the amplitude of the increase. The gaseous fluid enters the cold compartment at the temperature of the cold sink Tc and leaves it at a variable temperature.

IV. DISCUSSION

In the hot compartment, there is a cyclic variation of the gas temperature above and below the temperature of the hot source. In the cold compartment, there is a cyclic variation of the gas temperature above and below the temperature of the cold sink. Starting from a primary deltaT (between Th and Tc) without spending mechanical energy, two secondary deltaT appear by cycles, one on the cold side and one on the hot side. Considering the route of the gas (cf figure 2), we can state that during the draining of the hot compartment, heat is given to the hot source (when the gas is exiting at a higher temperature than Th) and heat is taken from the hot source (when the gas is exiting at a lower temperature than Th). Considering the route of the gas (cf figure 1), we can state that during the draining of the cold compartment, heat is taken from the cold sink (when the gas is exiting at a lower temperature than Tc) and heat is given to the cold sink (when the gas is exiting at a higher temperature than Tc). So, heat is given to the hot source and heat is taken from the hot source and heat is taken from the cold sink and heat is given to the cold sink. Potentially then, we have four thermal fluxes which appear and disappear in cycles, two on the hot side and two on the cold side of the device.

Figure 5 shows how it is possible to use these temperature variations on the cold side. Three conduits C1, C2 and C3 are used for the filling and the draining of compartment A. A distributor dispatches the gas through these conduits according to the flow of the gas (filling or draining) and according to its temperature. The conduit C3 can be used to drain compartment A when the temperature of the gas is higher than Tc. The conduit C3 is a heat exchanger which can release heat (Q_{out}). The conduit C1 is used to empty compartment B when the gas is at a lower temperature than Tc. The conduit C1 is a heat exchanger which can absorb heat (Q_{in}). The conduit C2 is used to fill up the compartment at the temperature of the cold sink. The conduit C2 can also be used for draining compartment A when the gas is at a temperature close to Tc. The heat which migrates through the regenerator from the hot side to the cold side (when the working fluid moves in this direction), is absorbed (ideally) by the cold sink before the working fluid passes through conduit C2. Figure 5 shows a heat pump in working condition (a device to operate the displacer is not shown).

The temperature of the gaseous fluid which passes through C1 increases as compartment A is emptied. The secondary deltaT between C1 and C3 is therefore not the theoretical maximum that we have calculated. Moreover, with a dead volume of 5% and taking into account the various losses, we have estimated that the secondary deltaT efficient between C1 and C3 would only reach, at best, about 35% of the theoretical maximum. This means that with Tc=300K, Th=800k and k=1.67, C1 and C3 could reach, in the real world, temperatures of 270 and 330k. However, it is possible to increase the secondary deltaT:

1- by using C2 for draining gas (when it is at a temperature close to Tc).
2- By increasing the temperature of the hot source.
3- By associating two heat pumps in series (cf. figure 6).

It is also possible to replace the regenerator by a double counter flow heat exchanger (cf.figure 7).

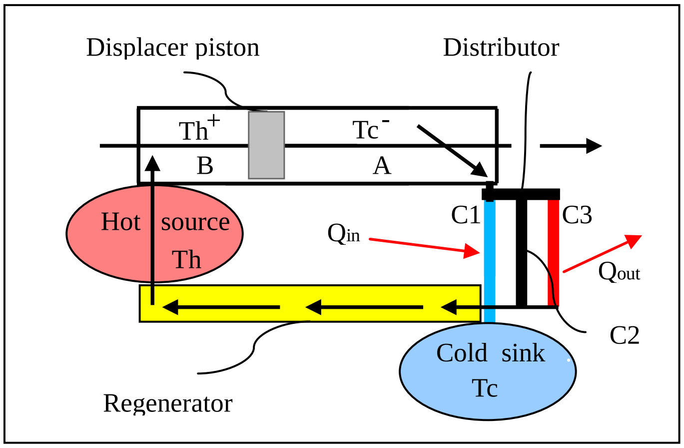

Fig. 5
Heat pump in working condition.

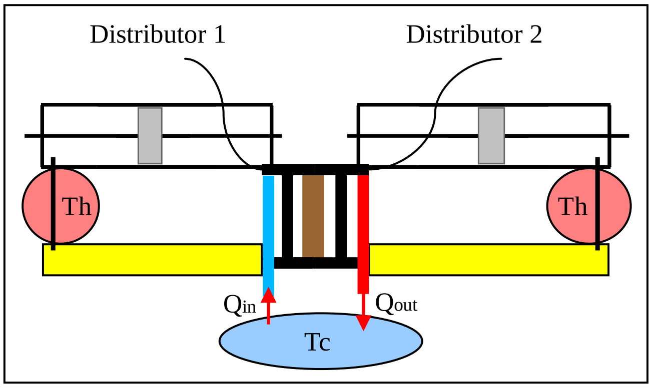

Fig. 6
Heat pumps in series.

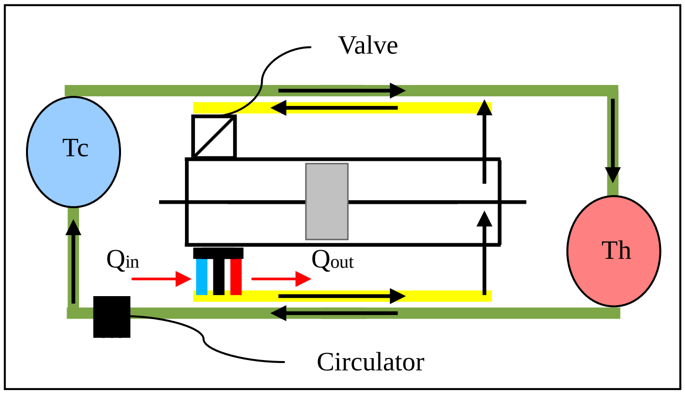

Fig. 7
Heat pump with double counter flow heat exchanger.

V. CONCLUSION

A device has been presented which uses the thermal energy of a hot source. Without spending mechanical energy, it can reach a temperature higher than the one of the hot source and a temperature lower than the one of the cold sink. Four thermal fluxes appear and disappear in cycles and can be used to warm or to cool. What has still to be seen is the efficiency of this heat pump and the amount of thermal energy which migrates from the hot source to the cold sink through the regenerator or the double counter flow heat exchanger. A detailed heat balance will answer these questions.

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