STUDY OF GAS-ENGINE-DRIVEN AIR CONDITIONER FOR ANNUAL COOLING OPERATION

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ABSTRACT

Air conditioners which are used for cooling of computers or equipment for telecommunication must operate 24 hours a day throughout the year. This operation requires durability and efficiency as well as adaptability for heat cooling. To meet such needs, a refrigerant pump cycle is adopted that implements the refrigerant pump in the compression cycle and operates it instead of a compressor in low outdoor temperature. A new pump mechanism is being studied that is composed of a small compressor, tanks, and valves to fit for the refrigerant pump cycle. Simulation analysis shows that this system can contribute to energy saving. In addition, the system has proved suitable for the improved durability of gas engine-driven air-conditioners.

Key Words: ***annual cooling system, refrigerant pump, gas engine-driven air-conditioner***

1 INTRODUCTION

Due to the spread of IT equipments accompanying advances in computers and telecommunications in recent years, air conditioning loads for cooling IT equipment are increasing. This has led to the new trend of buildings designed for installation of multiple computers, equipment for telecommunications, and in addition, installation of facilities which support them, including security, backup power sources, and cooling of IT equipment. In such buildings, the equipment installed in the interior consumes electrical power in massive amounts, and measures to reduce power consumption and conserve energy are very important. In this paper, the author presents the results of his research of cooling systems aimed at resolving these problems by using gas cooling equipment.

2 REQUIREMENTS FOR ANNUAL COOLING OPERATIONS

There are two major types of air conditioning systems: the direct expansion system, and the chilled water circulation system. The latter presents the risk of damaging IT equipment in the event of water leakage from the pipes; thus, the former is preferable. The two major types of gas air conditioning systems are gas engine-driven air-conditioners (direct expansion system) and the absorption chiller. For the reasons noted above, we decided to select the former. Cooling of IT equipments also has other requirements, as follows.

a. Requirement for durability sufficient for operation for 24 hours a day throughout the year
b. Requirement for high efficiency because of the huge yearly load and the importance of reducing energy consumption
c. Requirements for higher air-flow rate and blowing temperature are greater than those of

conventional systems, because sensible heat accounts for almost the entire load generated indoors.

3 RESEARCH OF SYSTEMS ADAPTED TO YEAR-ROUND AIR CONDITIONING

The refrigerant pump system devised by T. Uekusa et al.[1)] would be effective for meeting these requirements. As shown in Fig.1, when the outside temperature is low, the compressor is shut down and the refrigerant pump is operated instead. With this system, refrigerant vapor from the indoor unit is cooled by the outdoor air in the heat exchanger installed outdoors. Because there is no need for motive power to compress the refrigerant vapor, the motive power requirement (of the refrigerant pump) is much lower than that of the compressor. Nevertheless, this system might be faced with problems related to the refrigerant pump, as follows.

a. Cavitation is liable to occur because of the volatility of the refrigerant.
b. When the indoor unit is higher than the outdoor one, the pump must have a head (lift) corresponding with this height differential; furthermore, a high head cannot be assured with a low-capacity pump.

The head needed for the pump shown in Fig. 2 is expressed by the following formula:

$$P = (\rho_L - \rho_G) gH + P_{Loss}$$

P: Required pump head
ρ_L: Refrigerant liquid density
ρ_G: Refrigerant vapor density
P_{Loss}: Pipe pressure loss

When the height differential between the indoor and outdoor units is 50 meters, the head would have to be at least 0.5 MPa, and this would make it difficult to select an appropriate refrigerant pump.

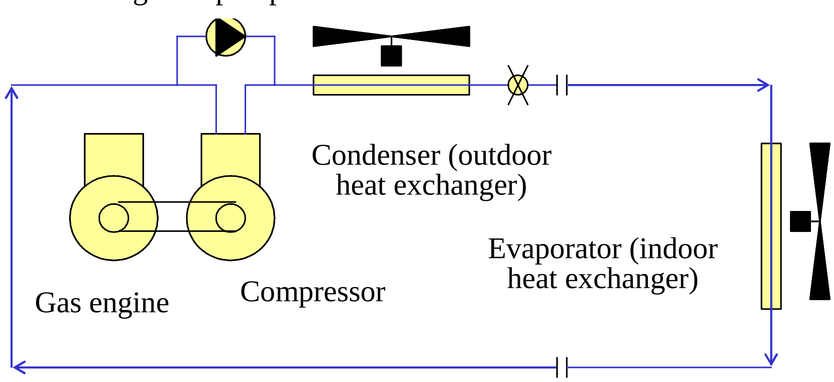


Fig. 1. Air conditioning system based on a refrigerant pump.

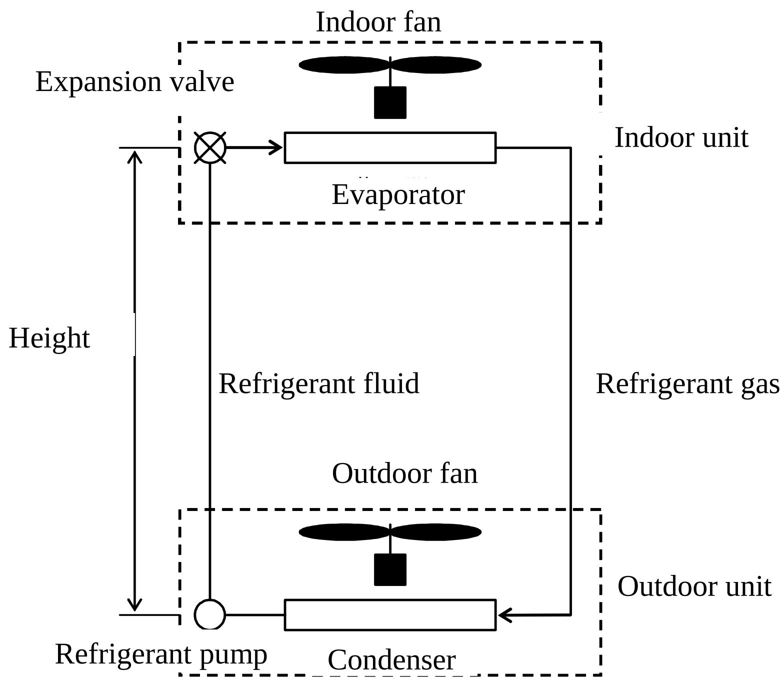


Fig. 2 Diagram when the indoor unit is higher than the outdoor unit.

With the attachment of an appropriate pump, the refrigerant pump cycle would offer an extremely high benefit for gas engine-driven air conditioning systems for cooling IT equipments. The reasons are described below:

a. It would make it possible to stop the engine during operation of the refrigerant pump, and this would greatly increase durability of the system.
b. The operation would have a high efficiency because of the low level of power consumption
c. The higher air-flow rate to attain sensible-heat air conditioning would make it possible to raise the evaporation temperature. So, the refrigerant pump system will work even when the outdoor temperature is not very low. This, in turn, would lengthen the duration of refrigerant pump cycle operation.

4 NEW REFRIGERANT PUMP SYSYTEM (GDP)

4.1 Principle of New Refrigerant Pump Cycle

We have been researching the development of a new pump mechanism for the refrigerant pump cycle. Instead of a mechanical pump, we implemented a small compressor in the refrigeration cycle to perform suction and discharge of the refrigerant liquid by the pressure difference it creates. We called this kind of pump a “gas-driven pump” (GDP). Its mechanism is as shown in Fig. 3.

The major components of the pump are the compressor, two tanks (T1 and T2), four stop valves (SV1 - SV4), and four check valves (CV1 - CV4). Each of the two tanks is equipped with two stop valves and two check valves. On each tank, one of the stop valves is connected to the compressor discharge line, and the other, to the compressor suction line. In the same way, one of the check valves is connected to the GDP suction line, and the other, to the GDP discharge line, in the direction of easy flow. The following is a description of the GDP mechanism, beginning with (1) as the starting point.

(1) 0) T1 is empty of refrigerant fluid, and T2 is full of it.
1) SV1 is open, SV2 is closed, SV3 is closed, and SV4 is open.
2) T1 is connected to the suction side of the compressor through SV1, and its pressure falls. This results in suction of the refrigerant fluid into T1 through the GDP suction line and CV2.
3) T2 is connected to the discharge side of the compressor through SV4, and its pressure rises. This results in discharge of the refrigerant fluid stored in T2 into the discharge line of the GDP through CV3.

(2) 1) There is no change in the action of the SVs.
2) The liquid level of T1 rises due to suction of refrigerant fluid through the GDP suction line and CV2.
3) The liquid level of T2 falls due to the discharge of refrigerant fluid through CV3 and the GDP discharge line.

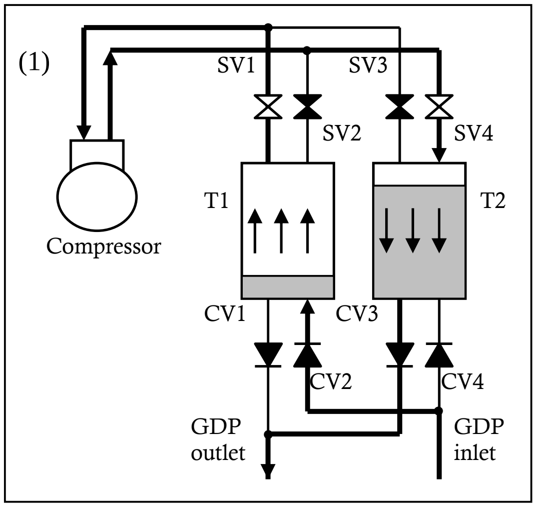
(3) 1) There is no change in the action of the SVs.
2) T1 becomes full.
3) T2 becomes empty.

(4) 1) SV1 closes, SV2 opens, SV3 opens, and SV4 closes.
2) T1 is connected to the discharge side of the compressor through SV2, and its pressure rises. This results in discharge of the refrigerant fluid stored in it into the discharge line of the GDP through CV1.
3) T2 is connected to the suction side of the compressor through SV3, and its pressure falls. This results in suction of the refrigerant fluid into T2 through the GDP suction line and CV4.

(5) 1) There is no change in the action of the SVs.
2) The liquid level of T1 falls due to the discharge of refrigerant fluid through the GDP discharge line and CV1.
3) The liquid level of T2 rises due to the suction of refrigerant fluid through CV4 and the GDP suction line.

(6) 1) There is no change in the action of the SVs.
2) T1 becomes empty.
3) T2 becomes full.

Processes (1) - (6) above are repeated.



T1, T2: Refrigerant tanks, SV1, SV2, SV3, SV4: Stop valves,
CV1, CV2, CV3, CV4: Check valves

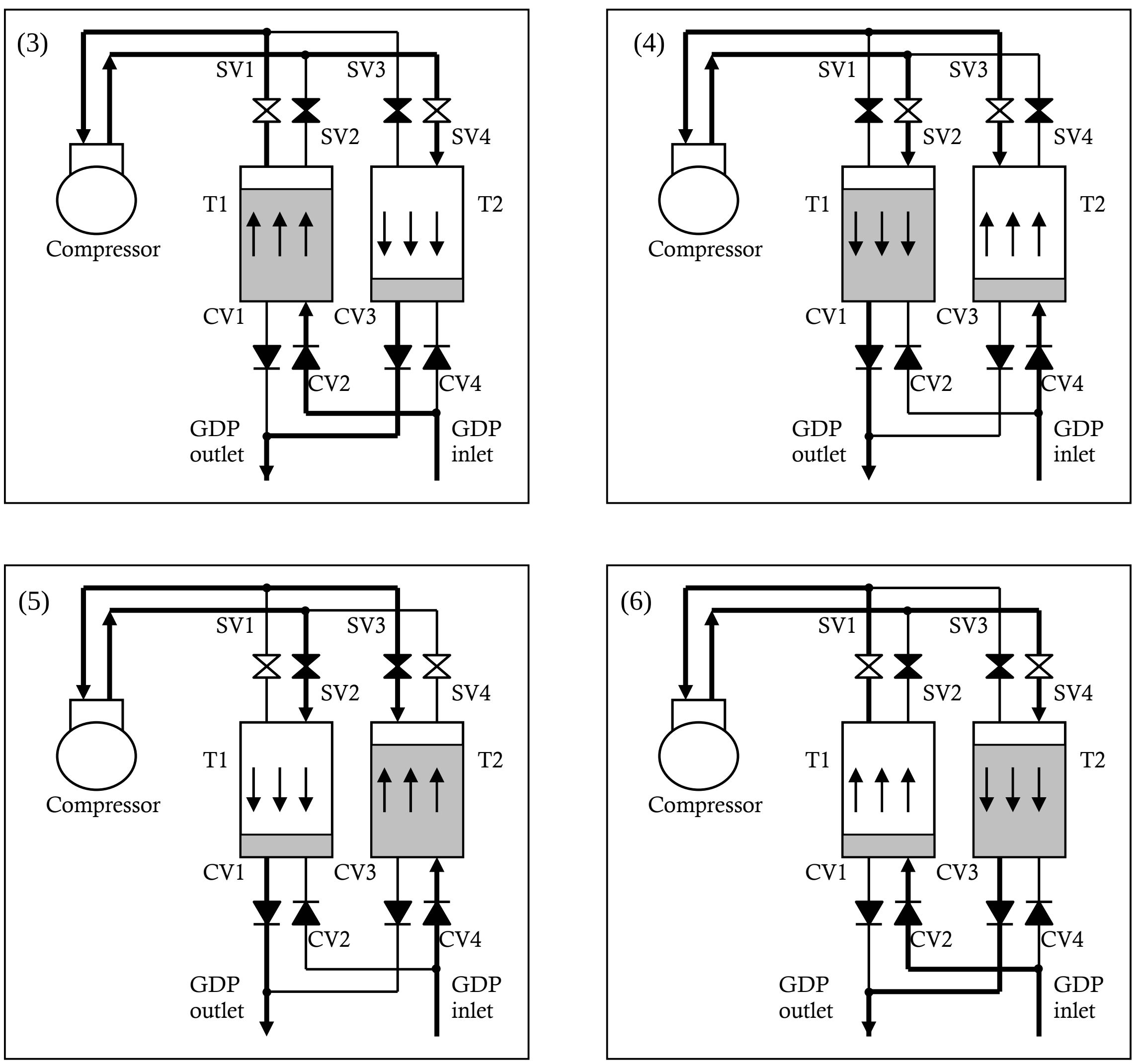


Fig. 3 GDP mechanism.

4.2 Analysis of the System Applying a GDP

This section presents the procedure and results of simulation of a system applying a GDP. The GDP discharges the refrigerant fluid stored in the tank by means of the compressor-discharged gas. The rate of discharge from the compressor is theoretically equal to the volumetric flow rate of the refrigerant liquid circulating through the indoor and outdoor heat exchangers. Therefore, the theoretical requisite rate of compressor circulation may be obtained by the following formula:

$$G_{theory} = (\rho_G / \rho_L) \times G_{main}$$

where $G_{theory}[kg/s]$: Theoretical mass flow rate of refrigerant circulating through the compressor

$G_{main}[kg/s]$: Mass flow rate of refrigerant circulation through the indoor unit

$\rho_L [kg/m^3]$: Density of refrigerant liquid discharged from the tank

$\rho_G [kg/m^3]$: Density of refrigerant vapor discharged from the compressor

However, part of the refrigerant is evaporated by the fall in pressure in the tank connected to the compressor inlet. As a result, compressor circulation rate actually required is larger than the theoretical motive power, as shown in the following formula.

$$G_{actual} = G_{theory} + G_{evap} = a \times G_{theory}$$

where $G_{actual}[kg/s]$: Actual mass flow rate of refrigerant circulating through the compressor

$G_{evap}[kg/s]$: Mass flow rate of refrigerant evaporating in the refrigerant tank

$a = 1 + G_{evap} / G_{theory}$ ¥

The work load applied to refrigerant may be calculated by applying the following hypothesis. First, inlet and outlet pressure of the compressor may be expressed by the following formulas:

$$P_{CPin} = P_{GDPin} - dP_1$$

$$P_{CPo} = P_{GDPo} - dP_2$$

where

P_{CPi} : Compressor suction pressure

P_{CPo} : Compressor discharge pressure

P_{GDPin} : GDP inlet pressure

P_{GDPo} : GDP outlet pressure

dP_1 : Pressure difference between P_{CPin} and P_{GDPin}

dP_2 : Pressure difference between P_{CPo} and P_{GDPo}

The following formula is derived when the requisite GDP head is dPo.

$$P_{GDPo} = P_{GDPin} + dPo$$

Compression efficiency is defined as a_{CP} to take account of loss in the compressor.

We performed a simulation to calculate required power for the compressor in the case of utilization of the GDP under the conditions described below.

Refrigerant: R410A

GDP inlet pressure: 1.$06MPa$ (Saturation pressure at 9 degree of Celsius)
$dPo = 0.5MPa$
$dP_1 = 0.1MPa$
$dP_2 = 0.2MPa$
$a = 2.0$
$a_{CP}=0.7$

Table 1 shows the result of the simulation. It is proved that the refrigerant pump cycle can reduce electric consumption to about 20% of conventional compression cycle.

Table 1. Comparison between conventional compression cycle and refrigerant pump cycle

	Compression cycle	Refrigerant pump cycle
Compressor inlet pressure	1.05 MPa	0.95 MPa
Compressor outlet pressure	1.55 MPa	1.75 MPa
Refrigerant flow rate through the compressor (Compression cycle=100)	100	11.5
Work of compressor (Compression cycle=100)	100	18.5

4.3 GDP Issues

Based on the results of research thus far, GDPs are thought to have the issues noted below. Tasks for the future consist of fabrication of a prototype, confirmation of the issues, study of methods of resolving them, and improvement of the prototype.

a. Some amount of work is always given by the compressor to the refrigerant vapor circulating through the GDP, and there is a need for a mechanism to cool the refrigerant.
b. The pressure inside the refrigerant tank is reduced while the tank is connected with the compressor inlet, and part of the refrigerant liquid stored in the tank consequently evaporates. This results in an increase of the amount of refilling with refrigerant vapor in the GDP, and necessitates discharge of the vapor within the GDP into the main circuit at a proper interval.
c. Lubricating oil may become mixed into the compressor discharged gas. Such admixture may cause a shortage of lubricating oil stored in the compressor due to the lack of a circuit to return oil to the compressor.

4.4 Solution to the Issues

Some methods are researched to solve these issues. The cycle to solve the issues is now in research, described below and in Fig. 4. To solve issue a, compressor discharged gas from CP2 is cooled by the ambient air through HX2 (air-refrigerant heat exchanger) with the result that refrigerant temperature may not increase excessively.

To solve issue b, BV2 and BV4 opens tentatively when the compressor (CP2) discharged pressure increases considerably. Part of the compressor-discharged gas will be transferred to the HXo (Outdoor heat exchanger) and will condense there. Therefore, refrigerant in the refrigerant pump cycle can be partly purged, and the pressure will decrease.

Finally, to solve issue c, sometimes CP1 should be operated, and the conventional compression cycle works so that lubricating oil will be stored in the OS1 (Oil Separator). After that, BV2 opens and lubricating oil will be transferred to CP2 through CT5, BV2, and CT4. When this process is completed, the system will be back to the refrigerant pump cycle mode.

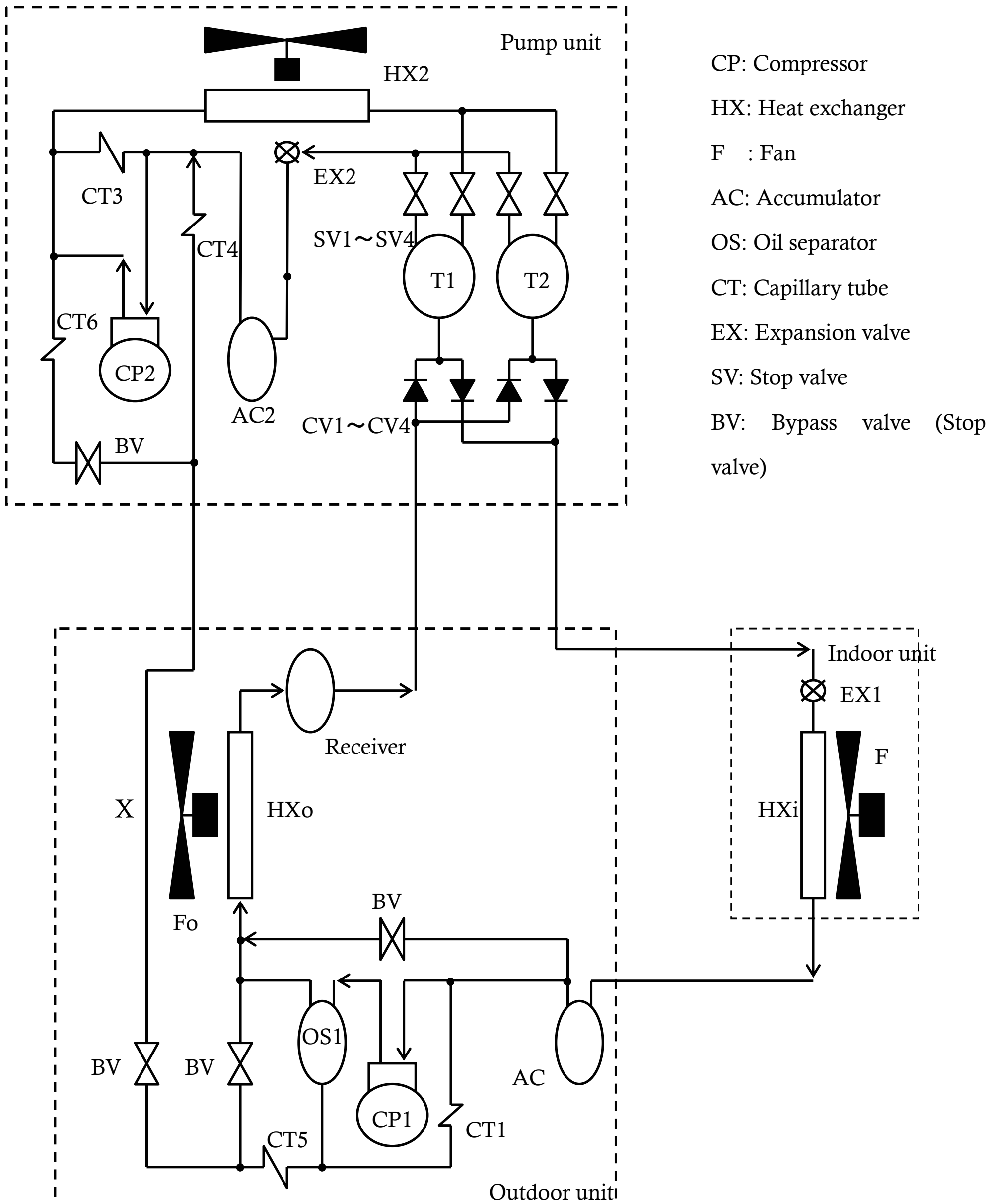


Fig. 4. Schematic diagram of an air-conditioner with GDP.

4 CONCLUSIONS

a. We researched a system that applies a gas engine air conditioner and is intended for rooms with telecommunication equipments or computers.
b. We devised a GDP for realizing a refrigerant pump system adapted to year-round air conditioning.
c. We estimated the performance in the event of GDP application and ascertained that a high-efficiency operation would be possible.
d. We identified the GDP issues.
e. The issues and solutions to develop GDP are researched.
f. Tasks for the future are fabrication of a prototype and resolution of the issues.

REFERENCES

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