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DEVELOPMENT OF AIR REFRIGERATION SYSTEM "Pascal Air"

MACHIDA A.(*), **BOONE J.** (**)
(*) Mayekawa MFG. CO., LTD, Technology Laboratory
Head Office 2-13-1, Botan, Koto-ku, Tokyo 135-8482, Japan
(**) Mayekawa MFG NV/SA Europe,
Leuvensesteenweg 605, Zaventem, 1930, Belgium,
jan.boone@mayekawa.eu

1. INTRODUCTION

About 20 years ago it has become evident that fluorocarbon refrigerants being used in food, fishery, agriculture, beverage and dairy industries for industrial freezing/cooling are having a significant impact on global warming and ozone depletion, but drastic measures have not been taken yet. Particular measures for the field of ultra-low temperatures below -50°C are overdue. At present mainly HFC23/HCFC22 vapour compression binary refrigeration systems are used, but according to the terms of the Montreal Protocol, HCFC22 is a regulated substance and its use in new equipment was prohibited by 2010 and will be totally phased out by 2020. HFC23 has an Ozone Depletion Potential ODP of 0 but its large Global Warming Potential GWP of 11700 and the fact that HFC23 is a byproduct formed during the manufacture of HCFC22 indicate that after the abolition of HCFC22, HFC23 will be difficult to obtain.

In this context, a refrigeration system "Pascal Air", was developed using the ultimate natural refrigerant "air", targeting the field of ultra-low temperature. This paper provides an introduction to the principle and characteristics as well as an introduction example in the field of an air refrigeration system "Pascal Air".

2. PRINCIPLES OF AIR REFRIGERATION SYSTEMS

Air is the most familiar gas for us, its Ozone Depletion Potential ODP and Global Warming Potential GWP are both 0 and by being neither toxic nor flammable, it is referred to as the ultimate natural refrigerant. However, its critical temperature of -140.7℃ is low, and when air is used in a higher temperature range, it becomes a gas cycle without phase transition (supercritical cycle). The Brayton cycle, commonly used for gas engines, is applied as basic cycle for this air refrigeration system. It differs from the general Brayton cycle in the reversion of heat dissipation and heat absorption, so in this system adiabatic compression leads to heat dissipation and adiabatic expansion is followed by heat absorption. As shown in Figure 1, adiabatic compression (1→2)、heat dissipation Q_1(2→3)、adiabatic expansion (3→4)、heat absorption Q_2(4→1) is conducted in the gas phase. That is to say, the process of heat dissipation Q_1 and heat absorption Q_2 is a cycle conducted in the gas phase with a constant pressure change not followed by condensation and evaporation. It is a simple system because the equipment consists of compressor, heat exchanger (heat absorption and heat dissipation) and expander.

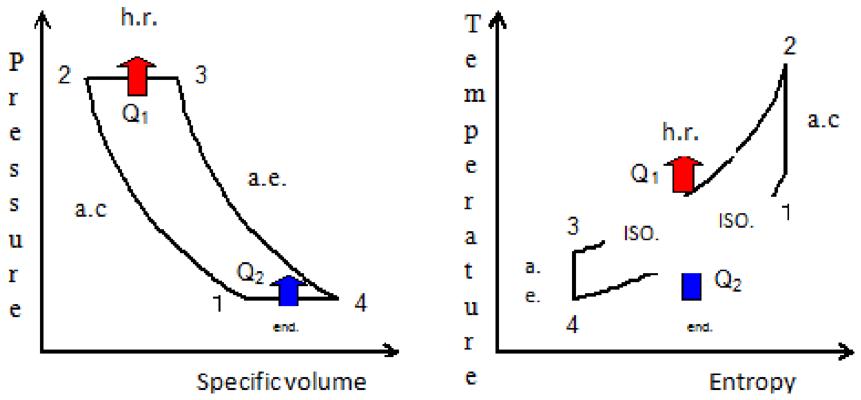


Figure 1　Basic principle of air refrigeration cycle

a.e.　: adiabatic expansion　　end . : endothermic　　iso. : isotonicity

a.c. : adiabatic compression　　h.r. : heat release

The COP (Coefficient of Performance) of the air refrigeration cycle depends on the efficiency of the equipment mentioned above, and by cooling down to -60℃, the COP is still about 1.2, even with a Carnot efficiency of 100%.

3. INTRODUCTION TO "PASCAL AIR"

3.1 System Overview

The air refrigeration system "Pascal Air" directly circulates ultra-low temperature air as refrigerant inside a refrigerator/freezer and it is composed of three parts: an expander-integrated compressor (compression and expansion), a primary cooler (heat dissipation) and a heat-recovery heat exchanger (heat recovery).

Figure 2 shows a general flow diagram of the system.

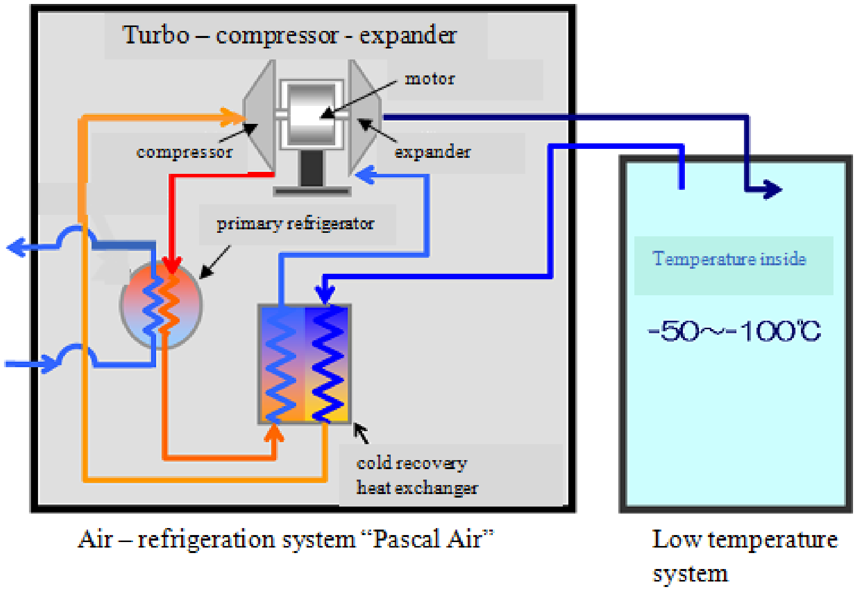


Figure 2 : "Pascal Air" flow diagram

When the temperature inside the refrigerator is -60℃, ①-60℃ air at atmospheric pressure from inside the refrigerator is absorbed and sent to the heat recovery heat exchanger. ②In the heat-recovery heat exchanger it exchanges heat with air cooled down to 40℃ from the primary cooler and becomes 35℃ air. ③35℃ air is compressed by the turbo compressor and becomes air of 90℃ and 1.8 atmospheres. After that heat is dissipated in the primary cooler down to 40℃.④40℃ air exchanges heat with -60℃ air absorbed from inside the refrigerator and is cooled down to -55℃. ⑤1.8 atmospheres, -55℃ air is adiabatically expanded in the turbo expander, becomes -80℃ air at atmospheric pressure and is blown into the refrigerator. Figure 3 shows the outer appearance of the refrigeration system unit. It is an outdoor installation type and its machine case specifications are: Width 3100[mm], Length 4600[mm], Height 3100[mm]. Thanks to these dimensions it can be transported by a low-bed trailer.

Figure 3　Outer appearance of refrigeration system unit outdoor use

3.2 System characteristics

The turbo type compressor and expander have a coaxial structure with a built-in motor placed in the center, and because the adiabatic expansion work generated by the expander and transmitted by the motor can be used as auxiliary power for the compressor, the compressor power is reduced to 2/3 and operation becomes highly efficient. Figure 4 shows the outer appearance of the turbo-type expander-integrated compressor. Table 1 shows the standard specifications of “Pascal Air”. It is an open cycle by directly using the air of inside the refrigerator/warehouse and since it is operated with low pressure with a maximum working pressure of less than 0.2MPa, the high pressure gas safety law is not applicable. Facility rearrangements or new cooling objects are only handled with duct rerouting. Refrigerant filling and recovery or large-scale construction are not needed, so operating costs and maintenance are reduced.

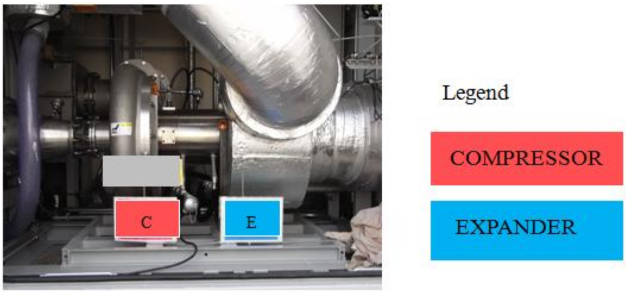


Figure 4 Turbo-type expander-integrated

Table 1 Standard specifications of "Pascal Air"

Refrigerant	Air
Refrigeration capacity	30 kW
Compressor power	60 kW
Temperature (inside the refrigerator /blowout)	-60/-80℃
Max. working pressure	0.2 MPa

4. FIELD CASE "PASCAL AIR"

Ultra-low temperature refrigerators for tuna and bonito fish storage are suitable to demonstrate its characteristics. The first test of a prototype was conducted in an existing ultra-low temperature refrigerator (nominal capacity 1795 tons, -50℃、Yaizu City, Shizuoka Prefecture). For 4 months, from July to the end of October 2008, when the heat load is usually at its highest, continuous operation was performed (accumulated operating time of 3000 hours). The system did not freeze due to humid air and there was no duct obstruction triggered by frost. The energy saving rate during the test period was about 20%, but at this time Pascal Air was operating in combination with the existing R22 two-stage type screw compressor.

During this field test, the temperature inside the refrigerator/warehouse was -50 to -55℃. A temperature of -60℃ improves the energy-saving rate surely.

Figure 5 shows the installation of “Pascal Air” in the machine room.

Figure 5 Installation of Pascal Air

Figure 6 is the interior of the existing ultra-low temperature refrigerator/warehouse, figure 7 is the interior of the “Pascal Air” ultra-low temperature refrigerator / warehouse.

Figure 6 Existing ultra-low temperature refrigerator

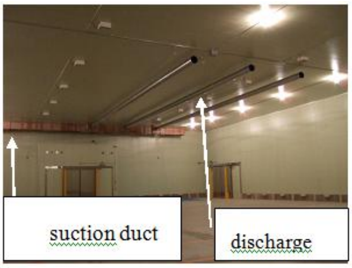


Figure 7 “Pascal Air” ultra-low temperature refrigerator

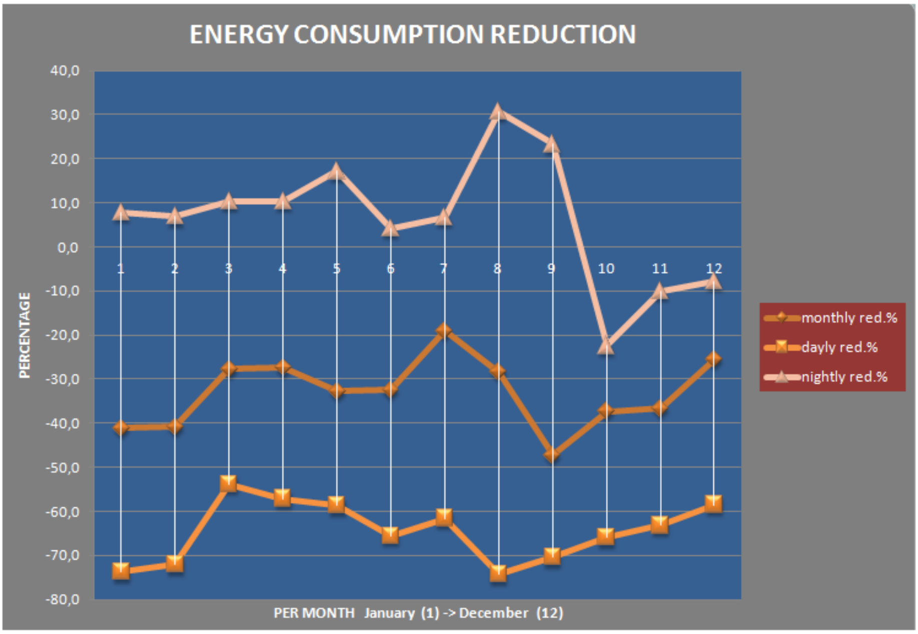
Table 2 shows the standard specifications of the “Pascal Air” – system.

Table 2 Plant specifications of “Pascal Air” - system

Installation date		December 2008	Unit
refrigerator temperature		-60	°C
total capacity		150	kW
nr of machines per room		3	
nr of rooms		2	
operating hours per 8/4/2011	nr 1	6667	hours
	nr 2	5996	hours
	nr 3	6069	hours
	nr 4	6597	hours
	nr 5	6173	hours
	nr 6	7410	hours
performance data per unit		(to be confirmed!)	
suction pressure (35°C)		0,98	bara
discharge pressure (93°C)		1,74	bara
rotation speed (invertor)		12.000 - 18.000	rpm
capacity		30	kW
power consumption		72	kW
air outlet temperature		-80	°C
refrigerator air temperature		-60	°C
gain expander		40	kW

The Graphic 1 shows the energy consumption reduction by using the “Pascal Air” – system in comparison to the conventional system. The total annual energy consumption is 33,1% lower, representing 64,2% reduction on day-regime and 6,1% increase on night regime compared to the conventional system.

The difference of 20℃ between temperature inside the warehouse and air blown into the warehouse makes air circulation stay at 1/10 compared to an air cooler (difference 2～3℃). Result : the cooled products are not dried out, their quality is preserved and the burden on workers is reduced.



Graphic 1 Data “Pascal – Air “ – system

5. CONCLUSION

In terms of COP, the air refrigeration system “Pascal Air” has an advantage over conventional systems, and because its application is limited to ultra-low temperatures below -50℃ - a blank area for natural refrigerants up to now - it sets itself apart from conventional systems. The characteristics of this open system, by using the air inside the warehouse as refrigerant, are still developing. This system is for the ultra-low temperature sectors of food, fisheries etc.

This product was developed by use of joint research results with NEDO (New Energy and Industrial Technology Development Organization), conducted 2003-2005.

6. REFERENCES

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