Performance Characteristics of Air-Conditioner Under Tropical Ambient Condition

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PERFORMANCE CHARACTERISTICS OF AIR-CONDITIONER UNDER TROPICAL AMBIENT CONDITION

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ABSTRACT

Various types of compressor with different pumping mechanisms are available to use in the refrigeration cycle for the air-conditioner. However, an air-conditioner having the best performance compressor is recognized from the point of view of energy saving.

In this study, the performance characteristics of an air-conditioner driven by different types of compressor are investigated under various ambient temperature conditions. Based on this study, the compressor suitable for the air-conditioner used in tropical ambient condition (high ambient air temperature) is suggested.

1. INTRODUCTION

The air-conditioner capacity is usually decided either JIS (Japan industrial institute) or ARI (American refrigeration institute) standard condition. Under those conditions, for cooling operation, the ambient conditions, i.e. dry-bulb (db) and wet-bulb (wb) temperatures, at outdoor and indoor sides of the air-conditioner are 35℃/24℃ (db/wb) and 27℃/19℃ (db/wb) respectively. But, at each part of the globe, the outdoors-ambient temperature is quite different, which affects the air-conditioner performance. Many papers have been written with a view to improve system components, such as compressors [1,2] and heat exchangers [3,4], and optimizing complete systems [5,6]. However, it is not clear the performance of an air-conditioner using different types of compressor under high ambient air temperature.

The aim of this paper is to investigate the performance of an air-conditioner using different types of compressor under tropical ambient condition, i.e. the ambient air temperature of above 35℃, without changing the indoor side room ambient condition. In the investigation, the compressors of reciprocating type, rotary type and scroll types of both high-pressure and low-pressure shells are used.

2. TESTING EQUIPMENT & TESTING PROCEDURE

For a designed air-conditioner, the discharge pressure changes by changing the ambient air temperature as the heat transfer capacity of the air-conditioner is decided under the certain testing condition. In this study, the performances of different types of compressor are investigated by varying the discharge pressure. Further the performances of an air-conditioner mounted with each type of compressor are examined under tropical ambient condition i.e. at high ambient air temperature. The testing equipment & testing procedure are described below:

2.1 Compressor Performance

In this study, the compressors of reciprocating type, rotary type and scroll types of both high-pressure & low-pressure shells are taken for investigation. The compressors have the same capacity under ARI compressor testing condition. The specifications of the compressors are shown in Table 1.

In the experiment, the compressor is connected to the refrigeration cycle as shown in the Figure 1. Refrigerant discharged by the compressor is supplied to the air-cooled condenser where the refrigerant cools to liquid by rejecting heat to the ambient air. The liquid refrigerant, then, flows to the evaporator through an expansion valve. In the evaporator, the refrigerant evaporates by absorbing heat from the water, and it again sucked by the compressor. The evaporator is the shell & tube type heat exchanger in which the refrigerant flows to the tube and water is used as secondary medium. An electric heater was used to control the water temperature.

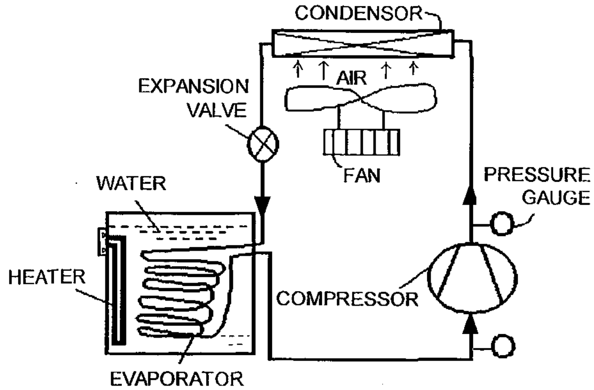

Fig. 1 Experimental setup for compressor performance test

The electric power inputs of the compressor and the heater were measured with the digital power meters respectively. The suction and discharge pressures of the compressor were measured with the Brudon type pressure gauges, and the temperature at each point of the cycle was measured with the C-C thermocouple.

Refrigerant R407C was used as a working fluid. The refrigeration cycle was operated at 50 rps and a steady operation of the cycle was maintained under the suction absolute pressure of 0.55MPa, and the suction superheat and the condenser subcool of 13℃ and 8℃ respectively. Data were recorded, for each compressor, at steady operation of the cycle under discharge absolute pressure of 2.36MPa, 2.55MPa and 2.85MPa respectively.

2.2 Air-conditioner Performance

The performance characteristics of an air-conditioner installed with different types of compressor were investigated by varying the outdoors ambient temperature. In the experiment, the split type air-conditioner with one indoor and one outdoor unit was used. The indoor unit consists of an air-cooled heat exchanger (so-called evaporator), and the outdoor unit consists of a compressor, an air-cooled heat exchanger (so-called condenser) and an expansion devise. The specifications of the tested air-conditioner are shown in Table 2.

Figure 2 shows the experimental set up of the air-conditioner. In order to control the ambient conditions at the evaporator side and the condenser side of the air-conditioner, the indoor and the outdoor units were placed in two separate insulated rooms. The indoor side room ambient condition, i.e. dry-bulb (db) and wet-bulb (wb) temperatures of air, was maintained at JIS standard cooling condition by using an electric heater and a humidifier. On the other hand, a water-cooled fan coil unit and a humidifier were used to control the condenser side (outdoor unit) room ambient condition (db/wb).

Table 1. Specification of the experimental compressors

Specification	Compressor type			
	Recipro.	Rotary	Scroll	
			L.P. shell	H.P. shell
Cooling capacity [kW]	7.06	7.06	7.06	7.06
Frequency [Hz]	50	50	50	50
Volt [V]	240	240	240	420
Phase	Single	Single	Single	Three

Table 2. Specification of the experimental air-conditioner

Air-conditioner	Air flow rate	Heat exchanger			
		Tube		Fin	
	m3/h	Length [m]	Diameter [m]	Pitch [m]	Thickness [m]
Condenser side	2590	48	0.00893	0.0018	0.0011
Evaporator side	900	28	0.00893	0.0018	0.0011

In order to form a refrigeration cycle, both of the indoor and outdoor units were joined with the copper tubes. The electric power input (including the compressor and the fan motors of indoor and outdoor units) of the refrigeration cycle and the room heater were measured with the digital power meters respectively. The temperature at each point of the cycle was measured with the C-C thermocouples. Suction and discharge pressures of the compressor were measured with the Brudon type pressure gauges respectively.

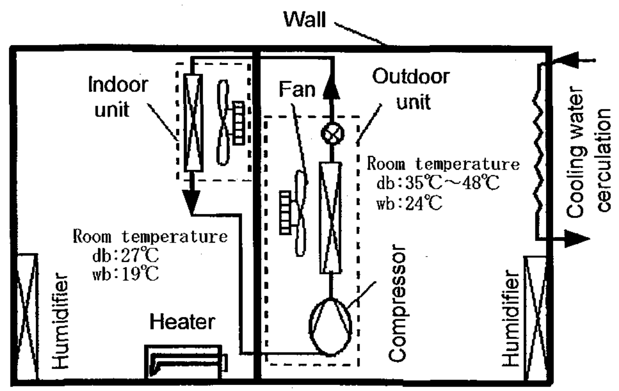

Fig. 2 Experimental setup for air-conditioner performance test

In the experiment, the refrigeration cycle was operated at 50 rps, and at constant airflow through the evaporator and the condenser sides. The ambient conditions of both rooms were maintained at JIS standard cooling condition [evaporator and condenser sides rooms ambient air temperatures of 27℃/19℃ (db/wb) and 35℃/24℃ (db/wb) respectively], and a steady operation of the refrigeration cycle was maintained under suction superheat and condenser subcool of 10℃ and 8℃ respectively. Data were recorded at steady operation of the refrigeration cycle mounted with each type of compressor by varying only the condenser side (outdoor unit) room air temperature (db) of 35℃, 42℃ and 48℃ respectively. Refrigerant R407C was used as a working fluid.

3. RESULTS AND DISCUSSIONS

Performance characteristics of an air-conditioner mounted with different types of compressor have been investigated under tropical ambient condition i.e. the outdoor air temperature of above 35℃. The investigation has been done in two ways.

1) Compressor performance
2) Air-conditioner performance

3.1 Compressor Performance

The performances of different types of compressor have been investigated by varying the discharge pressure of 2.35MPa, 2.55MPa and 2.85MPa as the condensing pressure of the designed air-conditioner changes with the outdoor air temperature. In the investigation, the compressors of reciprocating type, rotary type and scroll types of both low-pressure and high-pressure shells are taken. The results are discussed below:

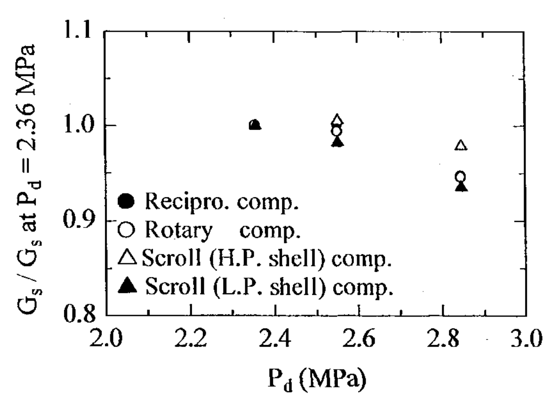

Fig. 3 Mass flow rate of compressor under variable discharge pressure

Figure 3 shows the change of refrigerant mass flow rate (G_s) for each type of compressor with increasing the discharge pressure (P_d). The mass flow rates G_s for each type of compressor are normalized by the value at the discharge pressure of 2.36MPa. Figure shows that, the mass flow rate G_s decreases with increasing the discharge pressure since the refrigerant gas leakage from the compression pocket inside the compressor increases due to the increasing discharge pressure. But, the decreasing tendency of G_s for each type of compressor is quite different. The result is favorably good for the scroll type compressor with high-pressure shell as compared with the other compressors. This is due to the fact that, the scroll type compressor with high-pressure shell used in this experiment had a provision of oil injection in the compression pocket, which seems to decrease the internal gas leakage of the compressor. While, the compressors of reciprocating type and scroll type with low-pressure shell show the comparatively poor value of G_s at high discharge pressure.

Figure 4 shows the change of electrical power input (L) of each type of compressor against the discharge pressure (P_d). The results of L for each compressor are normalized with each value at the discharge pressure of 2.36MPa. The electrical power input L for each compressor increases with increasing the discharge pressure due to the increasing compression power as well as the mechanical loss. But, the degree of increase for each compressor is quite different. For the scroll type compressors with both low-pressure and high-pressure shells, the results show the highest increasing slope while the increasing slope is comparatively low for the reciprocating type compressor. This is because, for the scroll type compressor with low-pressure shell, the internal gas leakage between the compression chambers increases the compression power. On the other hand, for the high-pressure shell scroll type compressor, the dissociation of refrigeration gas from the injection oil increases the mass of refrigerant in the compression pocket, which increases the compression power. However, for the reciprocating type compressor, the power recovery due to the re-expansion of compressed gas in the clearance volume and the internal gas leakage tend to decrease the increasing tendency of the electrical power input.

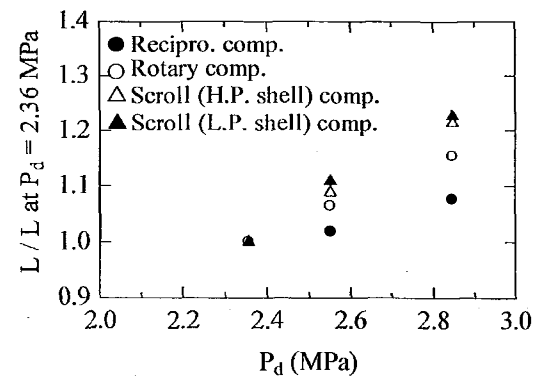

Fig. 4 Electric power input of compressor under variable discharge pressure

Based on the above results, the adiabatic efficiency η_{ad} of each compressor is calculated, and the results are plotted against the discharge pressure (P_d) as shown in the Figure 5. The adiabatic efficiency (η_{ad}) is the ratio of the adiabatic work to the compressor electric power input. In the adiabatic work, the experimental values of, G_s, are used as the values of refrigerant mass flow rate. The results of η_{ad} for each compressor are normalized with each value at the discharge pressure of 2.36Mpa. Figure shows that, the adiabatic efficiency for each type of compressor decreases with increasing the discharge pressure due to the increasing compression power loss and mechanical loss. But, the decreasing tendency for each compressor is quite different. For the scroll type compressor with low-pressure shell, the adiabatic efficiency decreases steeply as compared with the adiabatic efficiency of other compressors. While, for the reciprocating type compressor, the decreasing tendency of adiabatic efficiency is fairly low due to the power recovery caused by the re-expansion of compressed gas in the clearance volume.

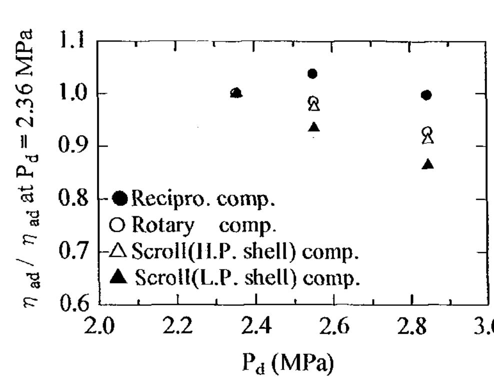

Fig. 5 Adiabatic efficiency of compressor under variable discharge pressure

From the above results, it was clear that, the scroll compressor with high-pressure shell showed a good mass flow characteristic at high discharge pressure. However, from the viewpoint of adiabatic efficiency, the reciprocating type compressor showed the favorably good result among the compressors.

By installing those compressors as a driving agent for an air-conditioner, the performances of an air-conditioner are investigated.

3.2 Air-conditioner Performance

The performance characteristic of an air-conditioner operating with each type of compressor has been investigated by varying the outdoor air temperature while the indoor air temperature was kept constant. The results are discussed below:

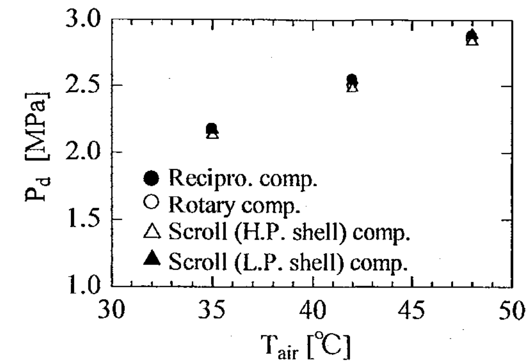

Fig. 6 Change of discharge pressure under variable outdoor air temperature

The changes of discharge pressure (P_d) for an air-conditioner with different types of compressor are shown in the Figure 6 against the outdoor air temperature (T_{air}). The Figure indicates that, the discharge pressure P_d increases with increasing outdoor air temperature. This is because of the decreasing heat transfer capacity of the condenser in the air-conditioner. The increasing values of P_d for the air-conditioner with each type of compressor are almost the same at each outdoor air temperature.

Figure 7 shows the change of cooling capacity (Q_c), electrical power input (L_t) and COP of an air-conditioner with different types of compressor operating under variable outdoor air temperature (T_{air}). The performance results for the air-conditioner with each type of compressor are normalized with each value at outdoor air temperature of 35℃.

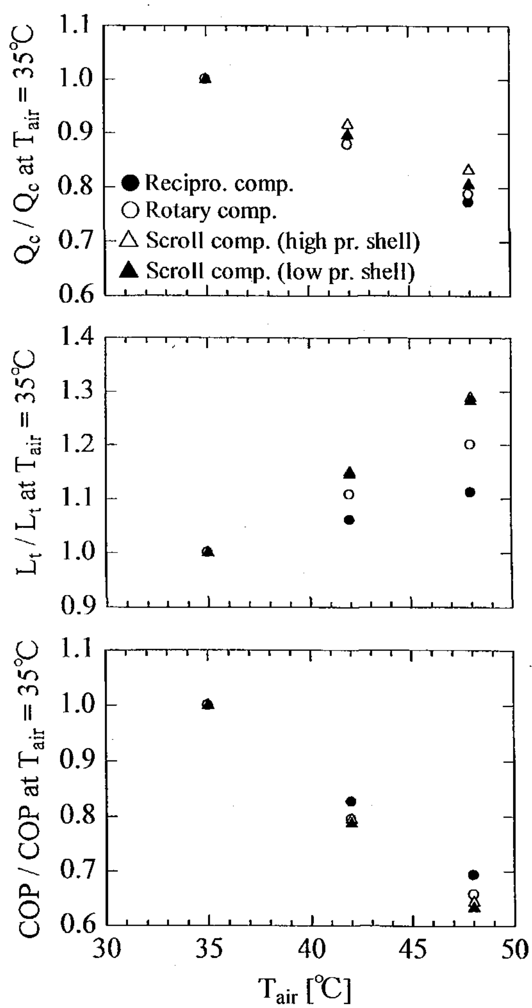

Fig. 7 Air-conditioner performance under variable outdoor air temperature

The cooling capacity, Q_c, as shown in the upper part of the Figure 7, decreases with increasing the outdoor air temperature, T_{air}, due to the decreasing heat transfer capacity of the condenser in the air-conditioner. Since the decreasing heat transfer capacity decreases the refrigerant enthalpy at the condenser outlet as well as increases the condensing pressure that deteriorates the mass flow rate of the compressor. But, the decreasing tendency of, Q_c, for the air-conditioner with each type of compressor is different. At high outdoor ambient temperature, the air-conditioner mounted with scroll type compressor with high-pressure shell shows favorably good cooling performance while, the cooling performance is comparatively poor for the air-conditioner mounted with reciprocating type compressor.

The changes of electric power inputs, L_t, against the outdoor air temperature, T_{air}, are shown in the middle part of the Figure 7. The electric power input, L_t, for an air-conditioner with each type of compressor increases with increasing the outdoor air temperature due to the increasing discharge pressure caused by the decreasing heat transfer capacity of the condenser in the air-conditioner. The results of electric power input for the air-conditioner with each type of compressor show the same increasing tendency as the results of the compressor performance shown in the Figure 4.

Based on the above results, the coefficients of performances (COP) of the air-conditioner mounted with each type of compressor are calculated, and the results are shown in the lower part of the Figure 7. The COP is the ratio of the cooling capacity, Q_c, to the electrical power input L_t. The Figure 7 indicates that, the COP of an air-conditioner mounted with each type of compressor decreases with increasing the outdoor air temperature due to the decreasing both of the condenser and the compressor performances. However, at high outdoor air temperature, the air-conditioner driven by the reciprocating type compressor shows favorably good value of COP while, the value is comparatively poor for the air-conditioner driven by the scroll type compressor with low-pressure shell.

4. CONCLUSIONS

Performance characteristics of an air-conditioner were investigated under tropical ambient condition by using the compressors of reciprocating type, rotary type and scroll types of both high-pressure and low-pressure shells. The results are summarized as follows:

1. The condensing pressure of an air-conditioner increases with increasing the ambient air temperature, which decreased the mass flow rate and the adiabatic efficiency of the compressors. The mass flow characteristic for the scroll type compressor with high-pressure shell was favorably good as compared with the other types of compressor. However, from the point of view of adiabatic efficiency, the reciprocating type compressor showed favorably good value at high discharge pressure due to the power recovery caused by the re-expansion of gas in the clearance volume.

2. The COP of an air-conditioner mounted with each type of compressor decreased with increasing the ambient air temperature due to the decreasing condenser and compressor performances. However, at high ambient air temperature, the air-conditioner driven by the reciprocating type compressor showed favorably good value of COP as compared with the compressors of rotary type and scroll types of both high-pressure and low-pressure shells.

5. REFERANCES

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