特集

環境対応車用の最新の空調技術*

Recent Air-Conditioning Technologies for Environment-Friendly Vehicles

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This paper reports recent Air-Conditioning (hereinafter referred to as A/C) technologies applied to various types of environment friendly vehicles.
In recent years, regulations for CO_2 emission and fuel consumption are tightened worldwide. In order to follow such regulations, vehicle manufacturers are launching various environment friendly vehicles such as Idle-Start-Stop Vehicle (ISSV), Hybrid Vehicle (HV), Plug-in Hybrid Vehicle (PHV), Electric Vehicle (EV) and so on, in addition to basic efficiency improvement of the combustion engine. Required function and performance of the A/C system are also diverse according to those types of vehicles. As an effective solution to each function, outline of ejector system, cold storage A/C system, heat pump system and Fresh/Recirculation-2-layer HVAC unit (HVAC stands for Heating, Ventilating and Air-Conditioning) are described in this paper.

Key words：Electrified vehicles, Fuel economy, Power saving, Ejector, Cold storage A/C, Heat pump, 2-layer HVAC unit

1．INTRODUCTION

For reduction of fuel consumption and CO_2 emission, recent vehicle trend is electrification to reduce engine operation time in addition to efficiency improvement of internal combustion engines. **Table 1** summarizes requirements of A/C system for those vehicles and applied A/C technologies. As unfavorable side effects of fuel economy improvement, in summer, ratio of fuel consumption for A/C is increased and in consequence the gap between advertised fuel economy and actual one is increased. Therefore A/C system is also required to improve its efficiency. Also in winter, vehicle efficiency improvement reduces waste heat and it may require additional heating source to compensate for the lack of cabin heating capacity. Reducing required cabin cooling/heating capacity by reducing thermal load is a good way to address both issues above. In addition, reduction of engine operating time requires a cooling/heating method during engine non-operation time. These issues and applied technologies are described in the following chapters.

Table 1 Applied air conditioning technologies for variety of vehicle types

Requirement		Type of vehicles				
		Engine always working	Frequent ← Engine operating ratio → Seldom / None			
		Conventional internal combustion engine vehicle	Idling-start-stop vehicle	Hybrid vehicle	Plug-in hybrid vehicle	Electric vehicle
Cooling	A/C efficiency improvement	Ejector system, Internal heat exchanger				
	Keep comfort during engine off	Not required (compressor is belt driven by engine)	Cold storage A/C	Electric driven compressor		
	Thermal load reduction	Personal A/C system Fresh/Recirculation 2-layer HVAC unit, Humidity sensor				
Heating	Keep comfort during engine off	Not required (water pump is belt driven by engine)	Electric driven water pump		[Main heating technologies (>4kW)] Heat pump system, High voltage PTC heater	
	Compensation for heat shortage	[Auxiliary heating technologies (<2kW)] Low voltage PTC heater				

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2. ISSUES ON COOLING AND APPLIED TECHNOLOGIES

2.1 A/C Cycle Efficiency Improvement

A/C system efficiency improvement is important to improve actual fuel consumption for Internal-Combustion-Engine Vehicles (ICEVs), ISSVs and HVs, and also to extend cruising range on battery for PHVs and EVs. A/C component such as compressor and heat exchangers are continuously being improved for higher efficiency. In addition, efficiency improvement technologies of A/C cycle itself have also been realized such as internal heat exchanger, ejector system and so on. As a technology for drastically improving the A/C efficiency, the ejector system's principle, structure and effect are described as follows:

[Ejector System]

(1) Principle

Conventional refrigeration cycle must have energy loss in the expansion process by making turbulence. Ejector is a kind of hydraulic pump and it can recover this expansion energy loss and utilize it to enhance system efficiency.

The ejector consists of nozzle, mixing area and diffuser as shown in **Fig. 1** 1). At the nozzle, high pressure and high temperature refrigerant is expanded ideally and the pressure energy is converted to kinetic energy. For this reason, refrigerant flow speed at nozzle outlet is accelerated and this flow becomes driving flow sucking low pressure refrigerant by pressure difference, and then those driving flow and sucked flow are mixed at mixing section. After that, the mixed refrigerant is gradually decelerated through the diffuser by its gradual increase of cross sectional area, and pressure at ejector outlet is risen by converting kinetic energy to pressure energy. In this whole process, the ejector can rise ejector outlet pressure, i.e. compressor suction pressure, and as a result compressor power consumption is reduced and refrigeration efficiency is increased.

(2) Structure

Ejector and its plumbing parts enclosed by dotted line in **Fig. 2** 1) which are integrated into the evaporator. This integration makes the system simple and the packaging easy. The evaporator has two-layer cores in the air flow direction, and sucked refrigerant, which has relatively lower pressure flows in the downwind core, and mixed refrigerant, which has relatively higher pressure, flows in the upwind core in order to cool air efficiently.

(3) Effect

As shown in **Fig. 3** 1), the ejector system can reduce the power consumption up to 24% when comparing with conventional refrigeration cycle. This effect corresponds to 2.5% fuel saving effect. Thus this ejector system can contribute a lot to enhance actual fuel economy.

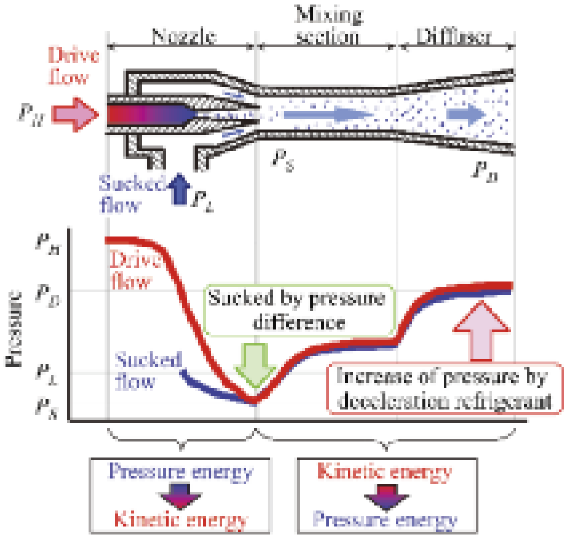

Fig. 1　Ejector operating principle

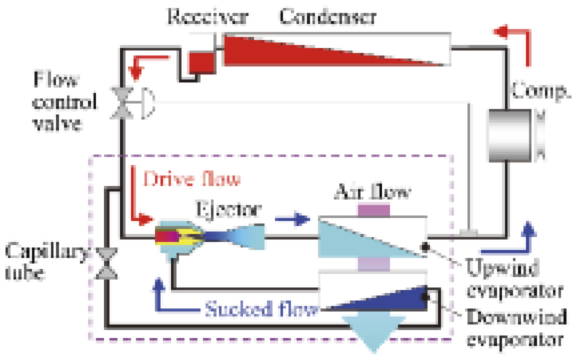

Fig. 2　Ejector cycle schematic

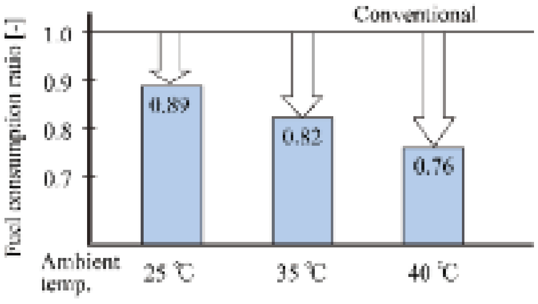

Fig. 3　Fuel saving effect by ejector system

2.2 Cooling during Engine Non-operation

For ICEVs, cooling is operated by belt driven compressor which is driven by the engine through a belt. HVs, PHVs and EVs have high voltage circuit and it can drive an electric compressor independently of engine operation. Thus electric compressor supplies cooling while the engine is off. On the other hand ISSVs, generally don't have a high voltage circuit and cannot drive a belt driven compressor during engine off time for traffic light and so on. In order to keep thermal comfort in the cabin, the engine has to restart when vent temperature reaches a certain level. This reduces the fuel saving benefit of ISSVs. As a countermeasure of this issue, the below described cold storage A/C system has been already introduced into the market:

[Cold Storage A/C System]

(1) Principle

Cold energy is stored in a cold storage medium when engine is running and the energy is released when the engine is stopped and it extends engine off duration while maintaining thermal cabin comfort. Cold storage capacity is set to be able to release coolness for about 1 minute at 28°C ambient temperature, which can cover most cases of short stops such as traffic light and so on.

(2) Structure

In the cold storage A/C system, cold storage evaporator is used instead of conventional evaporator. The conventional evaporators consist of many flat tubes and corrugated fins by aligning them alternatively. In the cold storage evaporator, some of those fins are replaced with closed cases which contain a cold storage medium as shown in **Fig. 4** [2]. This structure is relatively simple and has an advantage in packaging compatibility with the conventional evaporator.

(3) Effect

Fig. 5 [2] shows test result of outlet air temperature after engine stops with comparing between conventional evaporator and cold storage one. Cold storage evaporator suppressed temperature rising speed at around 10°C by effect of cold storage medium, and extended time to reach to 15°C, which is upper limit to feel coolness, up to 54 seconds. This is more than double the 19 seconds of the conventional evaporator result.

When this time extension effect of cold storage A/C system is converted to fuel saving effect, of course this is much depended on frequency and duration of vehicle stop, this effect can be expressed in **Fig. 6** [2]. This chart shows when the vehicle stop ratio is higher, more fuel saving effect is obtained. Especially in heavy traffic areas, this effect is remarkable. Even in areas with relatively small vehicle stop ratio, not small fuel saving effect can be expected.

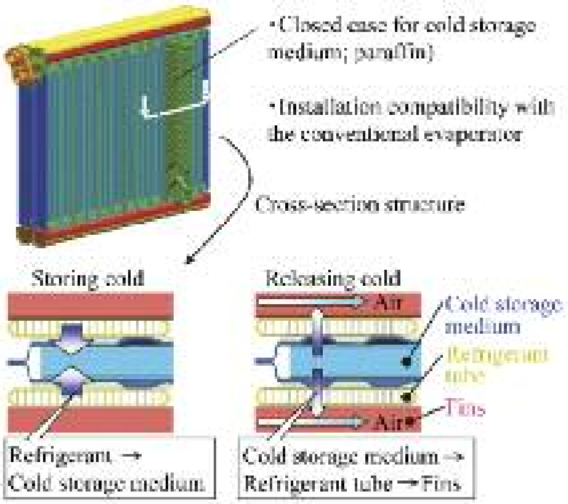

Fig. 4 Basic structure of cold storage evaporator

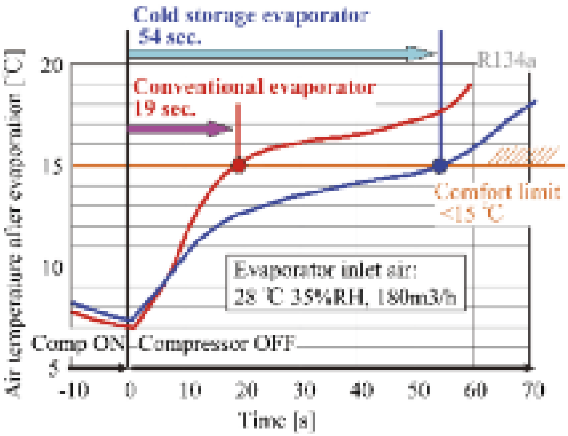

Fig. 5 Extension of cold release period with cold storage

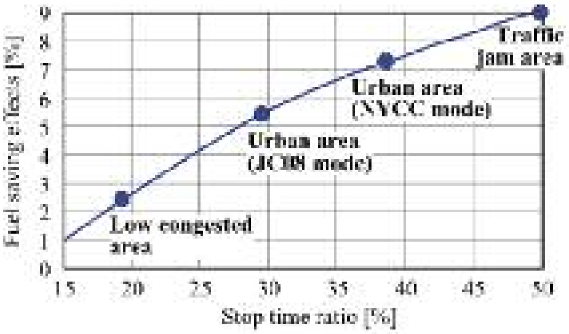

Fig. 6 Relationship between stop time ratio and fuel saving effects

2.3 Cooling Thermal Load Reduction

For energy saving for cooling, in addition to efficiency improvement of A/C system which is mentioned in chapter 2.1, thermal load reduction, i.e. reduction of required cooling capacity, is also important. Specifically, personal A/C system, which cools only surroundings of vehicle occupants, and seat ventilation system, which can efficiently cool due to direct contact to vehicle occupants, are effective.

3. ISSUES ON HEATING AND APPLIED TECHNOLOGIES

3.1 Lack of Heat Source

In ICEVs, engine coolant is heated by engine waste heat and it is introduced to heater core inside the HVAC unit which heats the cabin air. Therefore engine efficiency improvement may cause lack of cabin heating performance. In such case, auxiliary heater such as low voltage PTC heater and/or heating load reduction by personal heating, like cooling, may be required.

Since many cases in PHVs and all cases in EVs, engine doesn't run, a heating source other than engine waste heat is required. Relatively high capacity heating sources such as high voltage PTC heater, heat pump system can be applied. Efficient heating method is preferred since required cabin heating energy is sometimes same level as vehicle running energy and it affects to cruising range is a lot. In principle only heat pump system can exceed 1.0 in efficiency (Coefficient Of Performance: COP) and it is explained below:

[Heat Pump System]

(1) Principle

High pressure and high temperature refrigerant is discharged from the compressor, and it is provided to cabin condenser located inside the HVAC unit and heats the cabin air by the condensing heat. The condensed refrigerant becomes low pressure and low temperature through an expansion valve and heat is drawn from ambient air at an outside heat exchanger, then refrigerant returns to the compressor. In addition to the compressor work, thermal energy drawn from ambient air at the outside heat exchanger can be released to cabin, thus the output energy used for heating is more than the input power of the compressor.

(2) Structure

HVAC unit has a cabin condenser which heats air in heating mode and an evaporator which cools air in cooling mode. Outside the cabin, there is an outside heat exchanger which works as an evaporator in heating mode and as a condenser in cooling mode.

(3) Effect

A vehicle test result of warm up is shown in **Fig. 7**. In this test, center of cabin temperature was measured in a time series and compared between heat pump system and conventional HV vehicle. This chart obviously shows that a heat pump system can provide much quicker warm up than a conventional vehicle.

Fig. 8 shows estimation of EV cruising range when efficiency of heat pump system (COP) is assumed 2.0. When comparing with high voltage PTC heater, whose efficiency is assumed 0.9, the heat pump system can extend the cruising range around 40%.

Thus, a heat pump system can contributes for not only thermal comfort but also energy saving.

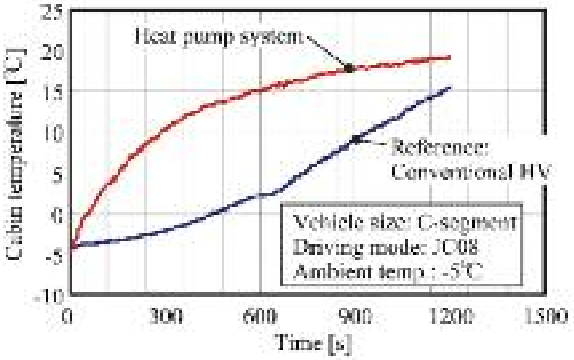

Fig. 7 Transient cabin temp. during warm up

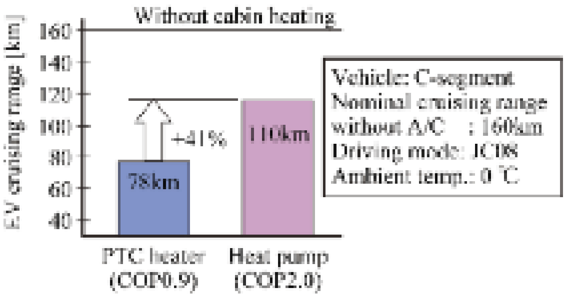

Fig. 8 EV cruising range influence by cabin heating

3.2　Heating during Engine Non-operation

Generally since ICEVs circulates engine coolant by a water pump driven by the engine through a belt, coolant cannot be circulated while engine stops. ISSVs and HVs, therefore, are equipped with electric driven water pump which allows engine coolant to circulate independently of the engine operation. Of course the engine doesn't make waste heat while it is stopped but it could supply hot coolant to cabin for short stops due to its big thermal inertia. PHVs and EVs can provide cabin heating by engine independent heat source as mentioned in chapter 3.1.

3.3　Heating Thermal Load Reduction

Generally, around 60% of heating thermal load of vehicles is due to ventilation loss and the remaining 40% is due to heat radiation to ambient through, for example, windshield [3]. The ventilation loss can be reduced by increasing cabin air recirculation ratio, but on the other hand, humidity in cabin rises by occupants' breath and it causes fogging on the windshield. As a solution to increase cabin air recirculation ratio without window fogging, 2-layer HVAC unit is introduced below:

[Fresh/Recirculation 2-Layer HVAC Unit]

(1) Principle

Ducted fresh air and recirculated cabin air are separately drawn into the HVAC blower and only dry fresh air is blown out from DEF outlets and wet recirculation air is blown from the FOOT outlets. Generally around 20% of recirculation is limit for anti-fogging, but the 2-layer HVAC unit can increase the recirculation ratio up to around 50% without fogging since only dry air is blown to the windshield.

(2) Structure

Structure of the 2-layer HVAC unit is illustrated in **Fig. 9**. Blower fan has two layers and the HVAC unit has separation plates to prevent mixing fresh air and recirculated cabin air.

(3) Effect

As above mentioned, ventilation loss is around 60% of total heating thermal load. 2-layer HVAC unit can reduce around 30% of total heating thermal load by increasing recirculation ratio up to 50%. As the consequences, the 2-layer HVAC unit helps saving energy for cabin heating and accelerating cabin warm up speed at the same time. The impact on vehicle warm up by the 2-layer HVAC unit is shown in **Fig. 10**. According to this vehicle test result, the 2-layer HVAC unit shortens the time to reach 20°C in cabin temperature by 9 minutes (38%) as compared with full fresh air intake mode, and the cabin temperature at 20 minutes from the start is 5 K higher.

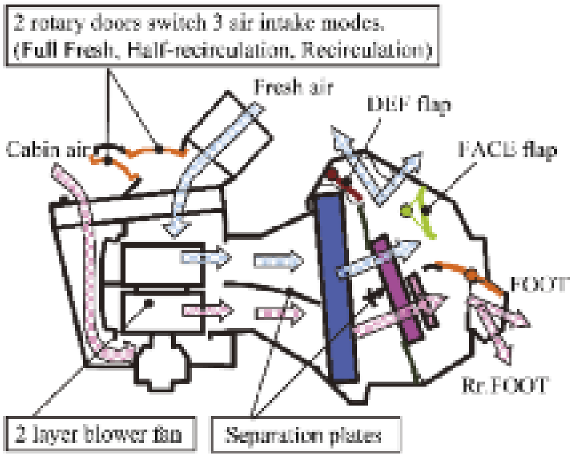

Fig. 9　Fresh/Recirculation 2-layer HVAC unit

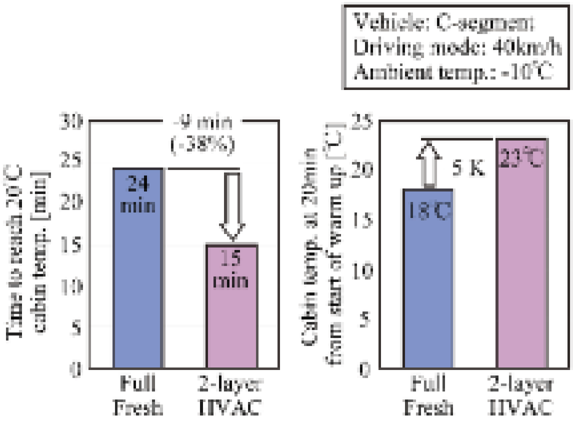

Fig. 10　Quick warm up effect by 2-layer HVAC unit

4．CONCLUSION

A variety of vehicle types and applied A/C technologies for those vehicles are introduced in this paper. Originally the refrigerant cycle was only used to cool the cabin air, but its application is expanding to heat pump system for cabin heating along with expansion of environment friendly vehicles. Therefore efficiency improvement of refrigerant cycle can contribute not only to improve actual fuel economy with A/C operation, but also to make vehicles more attractive by extension of the cruising range of EVs and so on. We will continue to pursue improvement of refrigerant cycle efficiency, in addition, develop thermal technologies to make new high efficiency vehicles more attractive.

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