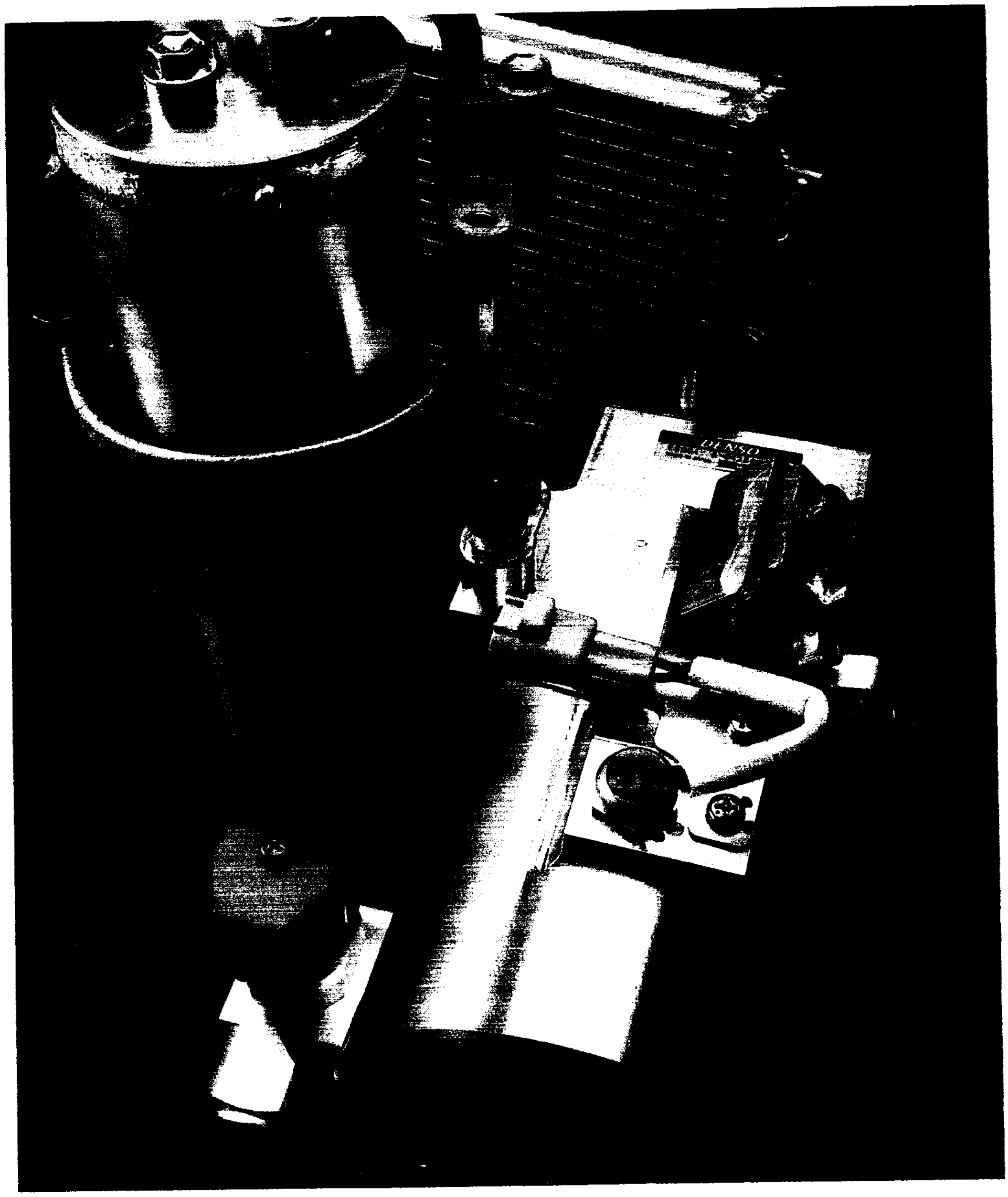

Denso introduces the world's first CO_2 car air conditioning system for Toyota's fuel cell hybrid vehicle (FCHV-4).

World's First CO_2 Air Conditioning System

by Satoshi Itoh, Denso

A high global warming potential of 1,300

Concerns regarding the effect of global warming have been growing in recent years. In August 2003, the European Commission adopted a proposal for a regulation to reduce emissions of fluorinated greenhouse gases. Fluorinated greenhouse gases include hydrofluorocarbon 134a (HFC-134a), which is widely used as refrigerant for air conditioners. Although this substance does not harm the ozone layer, it does have a high global warming potential (GWP) of 1,300. This proposal, phasing out HFC-134a and replacing it with alternatives with a GWP of 150 or less, is expected to be effective starting in 2005.

Currently, there are three alternatives that comply with the proposal of the European Commission: carbon dioxide (CO_2), HFC-152a and hydrocarbon (HC). Among these substances, CO_2 is the most promising alternative, considering its low GWP – 1/1,300 of that of HFC-134a – and its incom-

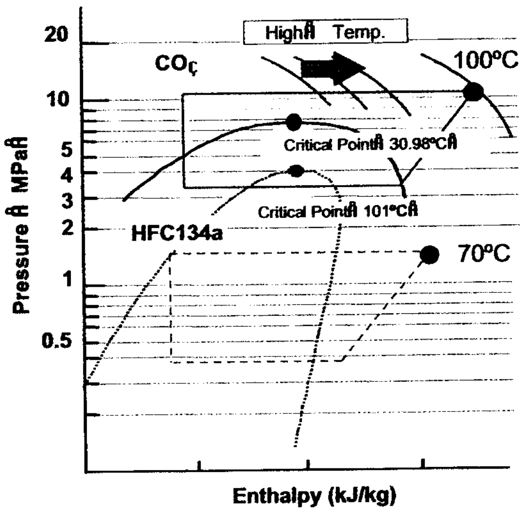

Figure 1: Mollier chart of CO_2 refrigerant.

ıustibility. Denso developed the world's first CO_2 car air conditioning system and supplied it for Toyota's fuel cell hybrid vehicle (FCHV-4) in December 2002.

Features of the CO_2 Refrigerant

Figure 1 shows the Mollier charts of CO_2 and HFC-134a systems, indicating their refrigerating cycle capabilities when used as refrigerants. As shown in the Figure, CO_2 has a critical temperature higher than that of HFC-134a (the critical temperature is the temperature above which a substance cannot exist in a liquid state regardless of the pressure), and a high-pressure side temperature normally exceeds the critical point in the refrigerating cycle. This results in an operating pressure that is seven to ten times higher than that of HFC-134a, and thus requires more robust components than the system using HFC-134a. Meanwhile, the CO_2 system has a lower theoretical Coefficient of Performance (COP = cooling capability / compressor consumption) than that of the HFC-134 system. Therefore, in order to develop the world's first CO_2 air conditioning system, Denso focused on developing new components that improved the COP and could withstand high pressure.

Additionally, CO_2 has an excellent heating capability that can be used for a heat-pump system. This feature is effective especially for electric or hybrid vehicles that do not have a heat source that is sufficient for heating the cabin. For this reason, the CO_2 air conditioning system for FCHV-4 has a heat-pump function.

Compressor

The compressor for the CO_2 air conditioning system is unique. It is designed to withstand a high pressure and reduce its power consumption to improve the COP of the system. The compressor used for FCHV-4 is a scroll type and is driven electrically rather than by an engine via a belt. The electric compressor can be made hermetic, which makes refrigerant leakage unlikely. In addition, since the compressor can be controlled by a motor regardless of the engine speed, the CO_2 air conditioning system can be operated efficiently in any driving conditions in order to provide comfortable air to passengers.

In the compressor, when a movable scroll rotates and compresses the refrigerant to a specific high pressure in the compression chamber, a thrust force is applied to the movable scroll in an axial direction in proportion to the specific high pressure. This increases the friction force between the movable scroll and a housing. In order to prevent the thrust force from increasing the friction force, some of the refrigerant in the compression chamber is introduced into a space between the movable scroll and the housing at the opposite side of the compression chamber. This structure allows the thrust force to be diminished and the friction force to be reduced in order to improve the compressor consumption.

The CO_2 air conditioning system for FCHV-4 has a heat-pump function

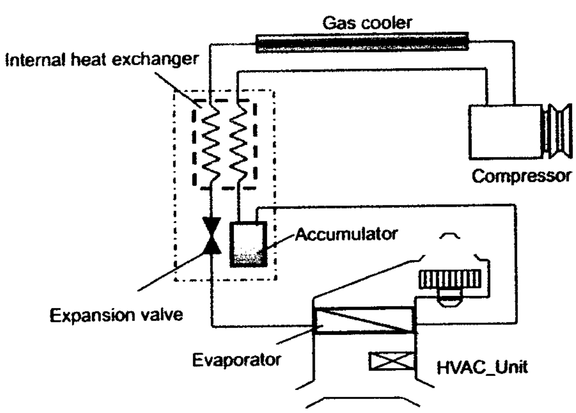

Figure 2: Basic structure of CO_2 air conditioning system.

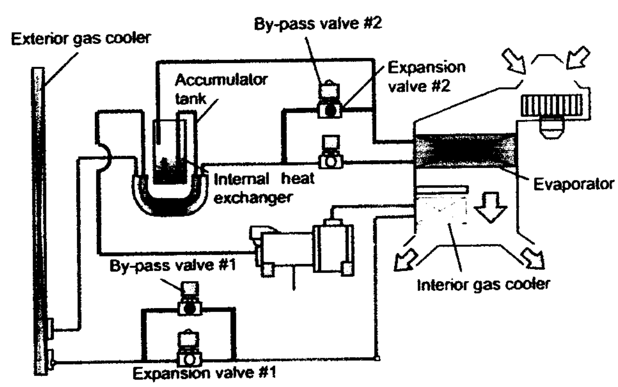

Figure 3: CO_2 air conditioning system configuration for FCHV.

The internal heat exchanger helps to further cool the CO_2 refrigerant by exchanging heat with refrigerant flowing at the low-pressure side of the system

Gas Cooler

The gas cooler corresponds to a conventional condenser and cools the CO_2 refrigerant discharged from the compressor at a high pressure. Because of this high pressure, the tubes in which refrigerant flows and the tank for distributing the refrigerant into the tubes of the gas cooler are strengthened compared to a conventional heat exchanger. Specifically, each tube is five to ten times stronger than a conventional tube. This is achieved by optimising the hole diameter and wall thickness. The tank is reduced in size in order to reduce the area that receives high pressure, without losing the capability to uniformly distribute the refrigerant into the tubes. In addition, the gas cooler uses the multi-tank structure that Denso developed in 1997 for the evaporator. This structure allows refrigerant to flow more efficiently in the gas cooler to exchange heat with air.

Incidentally, in the CO_2 air conditioning system, because CO_2 refrigerant normally exceeds the critical point of CO_2 at the high-pressure side, CO_2 refrigerant is not condensed by the gas cooler. Instead, the expansion valve partially liquefies the CO_2 refrigerant as a result of adiabatic expansion.

Figure 4: Photo of CO_2 air conditioning system for FCHV-4.

Internal Heat Exchanger

The CO_2 air conditioning system incorporates an internal heat exchanger that is installed between the outlet of the gas cooler and the evaporator. The internal heat exchanger, which is not equipped with the conventional HFC-134a, helps to further cool the CO_2 refrigerant by exchanging heat with refrigerant flowing at the low-pressure side of the system. The internal heat exchanger increases the amount of liquid refrigerant at the inlet of the evaporator to increase the cooling performance, resulting in an increased COP of the system.

The internal heat exchanger is integrated into the accumulator and the expansion valve, so that the structure of the CO_2 air conditioning system becomes simple and easy to install. In the HFC-134a refrigerant cycle, the accumulator (receiver) is positioned at the high-pressure side. However, in the CO_2 refrigerant cycle, the accumulator is positioned at the low-pressure side, since CO_2 refrigerant cannot exist as liquid on the high-pressure side. Figure 2 schematically shows the internal heat exchanger in a typical air conditioning system without a heat-pump function.

CO_2 System for Toyota FCHV-4

Figure 3 shows the structure of the CO_2 air conditioning system with a heat-pump function for Toyota's FCHV-4. Table 1 shows specifications of some of the newly developed components for the CO_2 air conditioning system. Denso focused great attention on keeping the overall dimensions of the components the same as those in the HFC-134a air conditioning system.

This system is operated as follows. The heating mode and the cooling mode are switched by opening and closing by-pass valves 1 and 2. Specifically, in the cooling mode, by-pass valve 1 is opened and by-pass valve 2 is closed. Further, the air mix door of an interior gas cooler is fully closed. As a result, CO_2 refrigerant circulates through the compressor, the interior gas cooler, by-pass valve 1, the exterior gas cooler, the internal heat exchanger, expansion valve 2, and the evaporator to cool the air. Although the refrigerant flows in the interior gas cooler between the compressor and the exterior

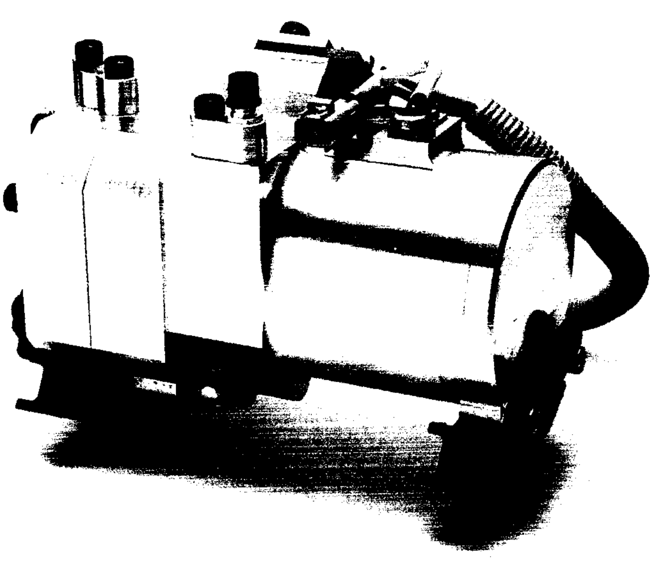

Figure 5: Photo of compressor for FCHV-4 CO_2 air conditioning system.