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DEVELOPMENT OF THE CIRCULATING COMPOSITION SENSING CIRCUIT FOR A MULTIPLE SPLIT TYPE AIR CONDITIONER WITH R-407C

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ABSTRACT

A composition sensing circuit (C.S. circuit) which detects the circulating composition of R-407C in the refrigeration cycle has been developed. The C.S. circuit consists of a heat exchanger, a capillary tube, two temperature detectors and one pressure detector. In the C.S. circuit, the circulating composition is indirectly detected from the temperature and pressure information using vapor-liquid equilibria for R-32/R-125/R-134a mixtures. The experiments were carried out to evaluate the circulating composition detection accuracy of the C.S. circuit. The results showed that the detection accuracy of R-32 and R-125 were within 1%, and that of R-134a was within 2%. This accuracy is satisfactory for performance stabilization and reliability improvement of the multiple split type air conditioners with R-407C.

INTRODUCTION

For protection of the ozone layer, R-407C(R-32/R-125/R-134a ; 23/25/52wt.%) is selected as an alternative refrigerant for multiple split type air conditioners, which consist of one outdoor unit and several indoor units and are widely used as building air conditioners in Japan. In multiple split type air conditioners with a zeotropic refrigerant mixture, R-407C, the circulating composition does not agree with the initially charged composition due to the composition distribution in the gas-liquid two phase regions. Especially when liquid refrigerant is stored in the accumulator at the evaporator outlet, the circulating composition is greatly different from the charged composition. If the circulating composition in the cycle changes, the relationship between the pressure and the saturation temperature of the refrigerant changes, and the cooling or heating capacities also change. Therefore, it is important to detect the circulating composition in the refrigeration cycle for performance stabilization and reliability improvement.

In the multiple split type air conditioners with R-407C, the circulating composition sensing circuit (C.S. circuit) which has been newly developed was introduced to exactly detect the circulating composition of refrigerant in the refrigerating cycle. In the C.S. circuit, the circulating composition is calculated from the temperature and pressure information using vapor-liquid equilibria for R-32/R-125/R-134a mixtures. This paper presents the configuration and the principle of the C.S. circuit and the experimental results of the circulating composition detection accuracy with the C.S. circuit.

NECESSITY OF THE CIRCULATING COMPOSITION SENSING

In a refrigeration cycle using a zeotropic refrigerant, the circulating composition does not agree with the initially charged composition. This is because in the gas-liquid two-phase region the mass fraction of the more volatile component in the gas phase is larger than that in the liquid phase, and the vapor velocity is larger then the liquid velocity [1]. Figure 1 shows the experimental results of the circulating composition, which were measured by the gas chromatograph in the multiple split type air conditioner charged with R-407C. The circulating composition changed from 16/21/63 wt. % to 31/31/38 wt. % with respect to the charged composition of 23/25/52 wt. %.

When the liquid refrigerant is stored in the accumulator which is installed at the outlet of the evaporator, or when the vapor refrigerant was charged to the cycle from the cylinder, the circulating composition shows a tendency in which the more volatile components(R-32 and R-125) in the circulating composition increase more than those in the charged composition. On the other hand, when the liquid refrigerant is accumulated in stopping indoor units in the heating mode, or when the vapor refrigerant leaked from the cycle, the circulating composition shows a tendency in which the less volatile component(R-134a) in the circulating composition increases more than that in the charged composition.

If the circulating composition in the cycle changes, the saturation temperature and the pressure characteristics of the refrigerant changes, as shown in Figure 2. The circulating composition change shown in Figure 1 causes that the saturation temperature on the same pressure changes by approximately 10 ℃. In the conventional multiple spilt type air conditioner with R-22, high and low pressure detected by the pressure transducers are controlled by the rotational frequency of the compressor and the outdoor fan, so that the condensing and evaporating temperatures, which are calculated by the detected pressures, could be maintained at desired temperatures respectively, even if the number of operating indoor unit changes[2]. In this control, the relationship between the saturation temperature and the pressure is important information.

Therefore, in the multiple split type air conditioner with R-407C, it is important to detect the circulating composition in the cycle and to get the condensing and evaporation temperatures accurately for performance stabilization and reliability improvement.

CONFIGURATION AND PRINCIPLE OF THE C.S. CIRCUIT

Configuration of the C.S. Circuit

The C.S. circuit consists of a heat exchanger, a capillary tube, two temperature detectors and one pressure detector, as shown in Figure 3. Figure 4 shows the changes of states of the refrigerant in the C.S. circuit with the pressure-enthalpy diagram. A part of the vapor refrigerants discharged from the compressor flows into the heat exchanger and is condensed by the low pressure refrigerant into liquid. The liquid refrigerant is depressurized by the capillary tube, and the low pressure gas-liquid two-phase refrigerant flows into the heat exchanger and is evaporated by the high pressure refrigerant. The vapor refrigerant flows into the suction pipe of the compressor. In the C.S. circuit, a temperature detector (T_1) is provided at an inlet portion of the capillary tube, while a temperature detector (T_2) and a pressure detector (P_L) are provided at an outlet portion of the capillary tube.

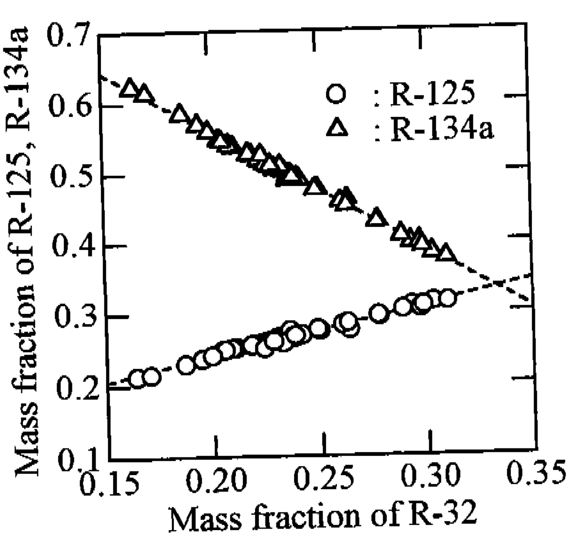

Figure 1 Experimental results of the circulating composition

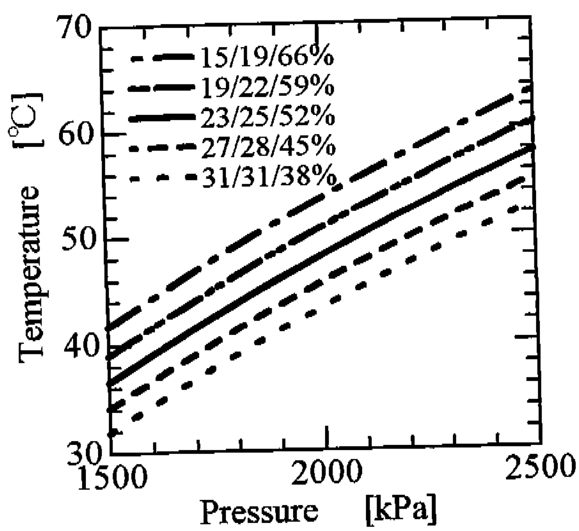

Figure 2 Relationship between saturation temperature and pressure

Principle of Circulating Composition Sensing

In the C.S. circuit, the circulating composition is indirectly detected from the temperature and pressure information using the vapor-liquid equilibrium for R-32/R-125/R-134a mixtures and the relationship on the compositions of R-32 and R-125. We explain the basic principle of the circulating composition sensing of the C.S. circuit with the pressure-enthalpy diagram and the vapor-liquid equilibrium diagram of R-32/R-125/R-134a mixtures, as shown in Figure 4 and 5.

A part of the refrigerant, which was discharged from the compressor, is cooled and liquefied by the heat exchanger. The liquid refrigerant temperature T_1 at the inlet of the capillary is detected by the temperature detector, and the enthalpy H at this point can be known from this temperature. Since the change of the refrigerant in the capillary tube is an isenthalpic expansion, so that the enthalpy at the outlet of the capillary tube is also equal to H. The pressure P_L at the outlet of the capillary tube is detected by the pressure detector, and quality of the gas-liquid two-phase refrigerant Xr can be known from the pressure P_L and the enthalpy H. Namely, the temperature T_1, pressure P_L, and quality Xr of the gas-liquid two-phase refrigerant at the outlet of the capillary tube can be detected from the information from the two temperature detector and one pressure detector.

Figure 5 shows the basic principle of the circulating composition sensing, and illustrates the state of vapor-liquid equilibrium of R-32, R-125 and R-134a. The horizontal axis indicates the mass fraction of R-32, and the vertical axis indicates the mass fraction of R-125. The two solid lines in Figure 5 show the saturated vapor curve and the saturated liquid curve respectively, and the region located between these two curves represents the vapor-liquid two-phase state. In addition, the broken line in Figure 5 is a curve which shows the gas-liquid two-phase state with quality Xr fixed. From the information on the temperature T_1, pressure P_L, and quality Xr of the gas-liquid two-phase refrigerant at the outlet of the capillary tube detected by the C.S. circuit, it can be appreciated

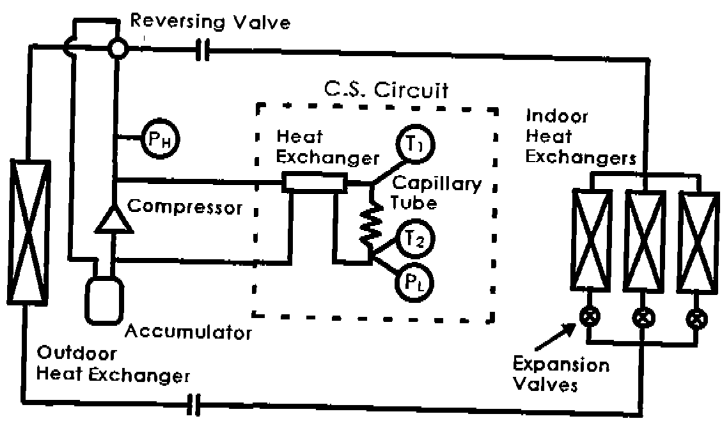

Figure 3 Configuration of the C.S. circuit

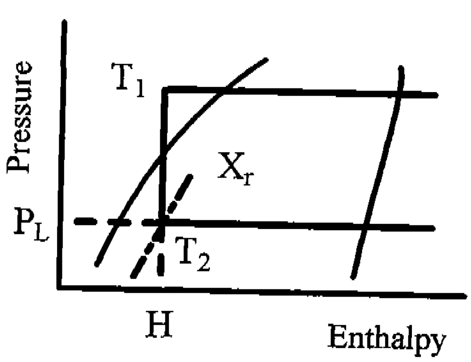

Figure 4 Pressure -Enthalpy diagram

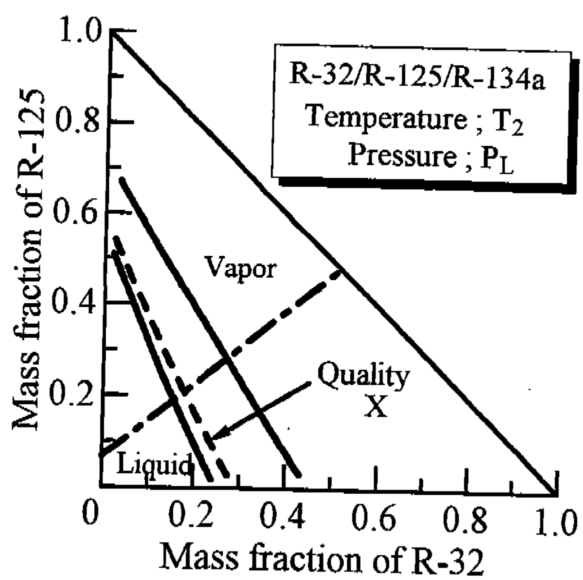

Figure 5 Basic principle of the C.S. circuit

that the circulating composition in the cycle is present on the broken line in Figure 5.

On the other hand, the dot-dashed line in Figure 5 shows the relationship on the compositions of R-32 and R-125 which obtained from the experimental results on the circulating composition of R-32, R-125, and R-134a shown in Figure 1, and the circulating compositions are present on this dot-dashed line. Accordingly, the circulating composition of R-32 and the circulating composition of R-125 are determined as a point of intersection of the broken line and dot-dashed line in Figure 5, and then the circulating composition of R-134a is determined, thereby making it possible to determine the circulating composition of R-32, R-125, and R-134a.

DETECTION ACCURACY

Experimental Equipment and Procedure

We made a prototype of the C.S. circuit to evaluate the circulating composition detection accuracy of the C.S. circuit. The C.S. circuit and the refrigerant cycle of the experimental equipment are illustrated in Figure 6, and these main specifications are listed in Table 1. The heat exchanger of the C.S. circuit is constructed of a double tube type heat exchanger in which high pressure refrigerant flows through the outer annulus space and low pressure refrigerant flows the inner tube. The refrigerant temperature at the inlet of the capillary tube is measured by a copper-constantan thermocouple, and the refrigerant temperature and pressure at the outlet of the capillary tube are measured by a thermocouple and a strain-gauge pressure transducers, respectively.

The refrigerant cycle consists of a compressor, a condenser, an evaporator, an electronic expansion valve, a high-pressure receiver located at the condenser outlet, and an accumulator located at the evaporator outlet. Both the condenser and the evaporator are constructed of double tube type heat exchangers in which the refrigerant flows through the inner tube and the water the outer annulus space. To vary the circulating composition in the refrigerant cycle widely, the amount of the liquid refrigerant in the accumulator or in the high-pressure receiver is controlled by the electronic expansion valve and the amount of charged refrigerant. The circulating composition of the refrigerant cycle is measured by gas chromatographic analysis of samples taken from the compressor discharge pipe. The

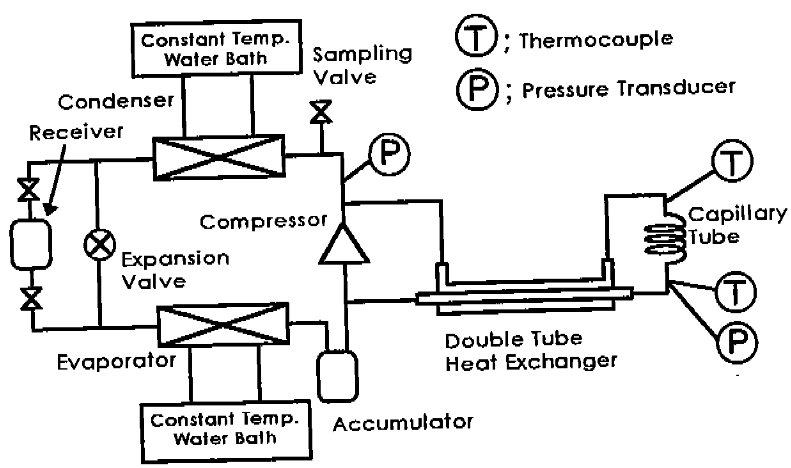

Figure 6 Experimental equipment

Table 1 Main specifications of experimental equipment

Elements		Specifications
C.S. circuit	Heat exchanger	Double tube type (ϕ 6.35mm x ϕ 4.0mm)
	Capillary tube	ϕ 0.6mm Length 2000mm
Refrigerant cycle	Compressor	Rolling piston type (Displacement 13.0 cm^3)
	Condenser	Double tube type (ϕ 18.0mm x ϕ 9.52mm)
	Evaporator	Double tube type (ϕ 18.0mm x ϕ 9.52mm)
	Expansion valve	Electronic expansion valve

condensing and evaporating temperatures are also varied widely by changing the cooling water temperature and the heating water temperature, respectively.

In the experiments, the detected circulating compositions by the C.S. circuit are compared with the measured circulating compositions by the gas chromatograph under the wide ranges of the circulating composition, the condensing temperature, and the evaporating temperature. The thermodynamic properties and gas-liquid equilibria of R-32/R-125/R-134a are all deduced from REFPROP[3].

Experimental Results

Figure 7 shows the circulating composition sensing accuracy of the C.S. circuit. The horizontal axis indicates the circulating composition measured by the gas chromatograph and the vertical axis indicates the circulating composition detected by the C.S. circuit. From these results, it was confirmed that the detection accuracy of R-32 and R-125 were within 1%, and that of R-134a was within 2% for the range from 17/20/63wt% to 29/30/41wt% of the circulating composition.

Figure 8 shows the saturation temperature sensing accuracy by the C.S. circuit. The horizontal axis indicates the condensing and evaporating temperatures calculated from the circulating compositions measured by the gas chromatograph and high and low pressure of refrigerant cycle, respectively. The vertical axis indicates the condensing and evaporating temperature calculated from the circulating compositions detected by the C.S. circuit and high and lowpressure of refrigerant cycle, respectively. In calculations, the saturation temperature is defined as the average value of the dew point temperature and the bubble point temperature. From these results, it was confirmed that the detection accuracy of the condensing temperature was within approximately 0.5℃ for the range from 24℃ to 56℃, and that of the evaporating temperatures was also within approximately 0.5℃ for the range from 2℃ to 16℃, and this detection accuracy is satisfactory for practical use.

To evaluate the transient sensing accuracy of the C.S. circuit, the change in the circulating composition of the refrigerant cycle was measured after the compressor start up. Figure 9 shows the comparison of the circulating composition detected by the C.S. circuit with the circulating composition measured by the gas chromatograph. The circulating compositions detected by the C.S. circuit agree with the measured value about one minute after the compressor start up. The C.S. circuit has an accurate transient detection of the circulating composition for practical use.

CONCLUSIONS

The circulating composition sensing circuit (C.S. circuit) has been developed to achieve the performance stabilization and reliability improvement of the multiple split type air conditioner with R-407C. In this report, the configuration and principle of the C.S. circuit were introduced. In addition, the detection accuracy of the C.S. circuit was evaluated experimentally, and following conclusions were obtained.

(1)The detection accuracy of R-32 and R-125 were within 1%, and that of R-134a was within 2%.

(2)The detection accuracy of the condensing and evaporating temperatures were within 0.5℃.

(3) The C.S. circuit had an accurate transient detection of the circulating composition for practical use.

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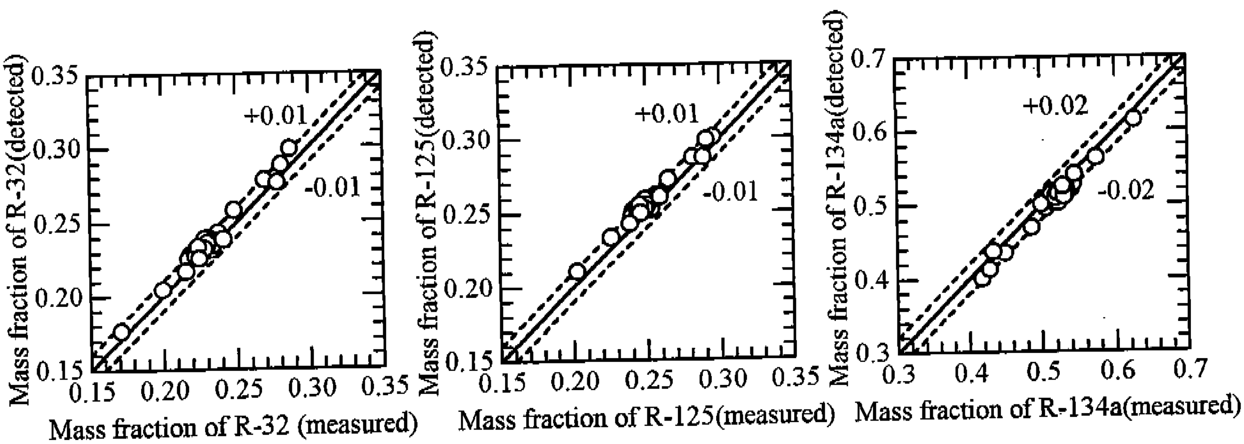
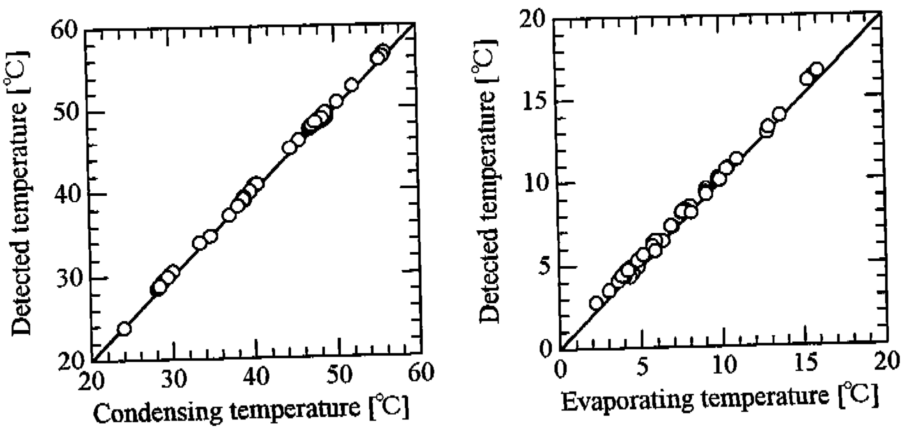


(a) R-32 component (b) R-125 component (c) R-134a component

Figure 7 Circulating composition detection accuracy by the C.S. circuit



(a) Condensing temperature (b) Evaporating temperature

Figure 8 Saturation temperature detection accuracy by the C.S. circuit

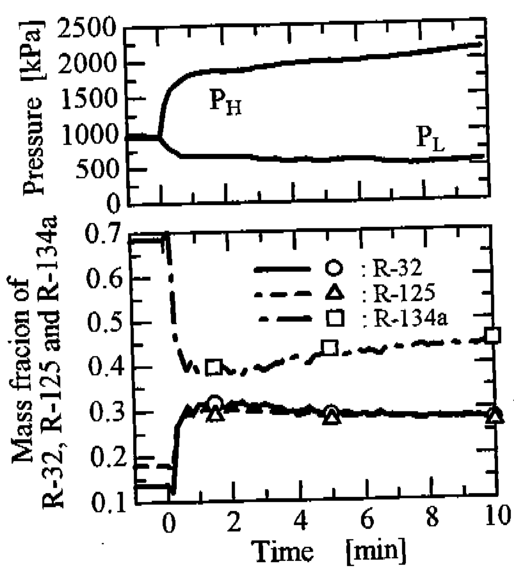


Figure 9 Circulating composition detection accuracy in the compressor start-up