Safety Aspects of an A/C System with Carbon Dioxide as Refrigerant

SAE Subcommittee Safety of Refrigerant Systems
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Introduction

A carbon dioxide based air conditioning raised the following safety concerns: the possible exposure to refrigerant under high pressure, to high concentrations of refrigerant, to high noise levels in the event of component rupture and to flying debris in the event of component rupture. This paper considers the risk of high CO2 concentration in a vehicle cabin. Because the refrigerant in a carbon dioxide based air conditioning system is under high pressure it expands to much larger volume when released into the atmosphere. There is therefore a risk that displacement of air might pose as health hazard when the refrigerant is released into a confined space such as vehicle cabin or workshop pit area. Since the safety thresholds of carbon dioxide are well known, the theoretical and measured carbon dioxide concentration in a cabin quantify the possible refrigerant charge at a defined cabin space.

Carbon dioxide

Carbon dioxide replaces air, and causes lack of oxygen. At presence of sufficient oxygen, CO2 has a narcotic effect at stronger concentration. With smaller amounts, CO2 has a stimulating effect on the respiratory center. Due to the acidic characteristics of CO2, a certain local irritating can appear, particularly on the mucous membrane of nose, throat and eyes as well as induce coughing.

The symptoms associated with the inhalation of air containing carbon dioxide are, with increasing carbon dioxide concentrations. The data, valued for adults with good health, are as follows (source: AGA Gas Handbook) [2]

2%	50% increase in breathing rate
3%	10 Minutes short term exposure limit; 100% increase in breathing rate
5%	300% increase in breathing rate, headache and sweating may begin after about an hour *(Com.: this will tolerated by most persons, but it is physical burdening)*
8%	Short time exposure limit
8-10%	Headache after 10 or 15 minutes. Dizziness, buzzing in the ears, blood pressure increase, high pulse rate, excitation, and nausea.
10-18%	After a few minutes, cramps similar to epileptic fits, loss of con-sciousness, and shock (i.e.; a sharp drop in blood pressure) The victims recover very quickly in fresh air.
18-20%	Symptoms similar those of a stroke

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Carbon dioxide can be lethal at concentration at about 12%, the lowest ever reported lethal concentration of CO_2 is 9% for 5 (!) minutes [3].

Vehicle tests I

In the experiment the spatial and temporal CO_2 distribution was measured in the vehicle cabin. Carbon Dioxide was brought in between evaporator and heater core with a hose via the water drainage. This configuration allows to simulate a sudden release of the total refrigerant charge into the compartment. The measuring were made at two medium size vehicle within a sealed room at room temperature. The induced carbon dioxide mass was determined by a calibrated volume-flow and the time. The tests were made with various CO_2 charges. For measurement, six concentrations of CO_2 distributed at different positions in the cabin were detected. The air flow through the compartment was varied by the blower. At recirculation mode the air door was sealed with tape in addition.

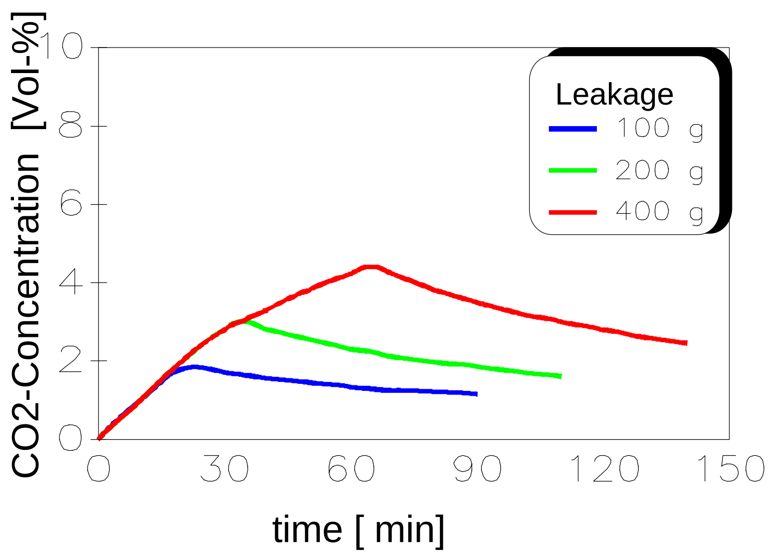

Figure 1 CO2 concentration in a vehicle cabin with different CO2 charges for a simulated evaporator leakage, Vol.-flow is 200 litre/hr, 100 % recirc.

<u>Results:</u>

Figure 1 shows the CO_2 concentration in a closed vehicle in a closed room without air circulation for different escaping CO_2 charges. The CO_2-volume flow was kept constant at 200 litre/hr. At a concentration at 4% the reduction rate of concentration is 0.5% in 10 minutes.

In lowest blower setting in fresh air mode and a CO_2 volume flow of 200 liter/hr. the concentration is rather constant between 1 and 1.5 % over the entire time. When the flow is stopped, the concentration dropped soon to normal level.

When the blower ran in recirculated air mode, taking no fresh air from outside the vehicle, the concentration decayed at steady state, with no difference in concentration between head level and foot level. With 400 g CO_2, the maximum concentration was measured between 4.1 to 4.5%.

With a charge of 600g and with 600 liter/hr the maximum concentration was about 5.3%. With the blower switched off, the concentration at foot level was high and reached nearly 8% and on the seat surfaces front and backseat 4 % were reached. The concentration at head level was below 1%.

When the ventilation fan runs in maximum at fresh air mode, taking its supply from outside the car, the CO2 took less than 1 minute to reduce from 4 % to less than 1%.

Vehicle Tests II

A medium sized car, three doors, without A/C system has been chosen as test vehicle. A hose leads from the CO_2 bottle though the engine compartment into the inlet of recirculated air of the HVAC. The inlet of fresh air is permanently closed. The mass of spilled CO_2 is measured as difference in weight with a highly sensible scale. Additionally the CO_2 volume flow is measured with a flow meter. The CO_2 concentration will be measured with an infra-red (IR) sensor. The IR CO_2 sensor is a transducer for the measurement of the CO_2 partial pressure in the atmosphere, by the absorption of infra-red radiation. The accuracy is ± 5 % of the measured value.

The following parameters were regarded :

a) concentration profile inside the passenger compartment,
b) reduction of inner volume due to passengers sitting in the car
c) influence of release time
d) blower off

An instantaneous release of a certain amount of CO_2 inside the passenger compartment would result in a theoretical maximum peak concentration inside the cabin as listed in Table 2.

500g gaseous CO_2 were released with 1500 liter/hr into the passenger compartment (see Figure 2.) The maximum measured concentration of 6.3 % vol. was at the vent center just before stopping the release. The difference in CO_2 concentration on different positions inside the car was in the range of the statistical error (0.3%). After the spill stopped, the concentration decreased rapidly. Concentrations lower than 1 % are reached after approximately 50 Minutes.

The release rate has the most significant influence on the measured CO2 peak concentration. By decreasing the rate from 1500 liter/hr down to 500 l/h the peak concentration of CO_2 drops from 6.3 % vol. to 3.9 % vol. (see Figure 3).

One test was conducted with 5 Dummies inside the passenger compartment, each with a volume of approximately 70 liters. The measured peak concentration after releasing 500 g CO_2 with 1500 liter/hr was 6.7 % vol. That's approximately 0.4 % higher than without Dummies.

Leaking CO_2 inside the car while the blower is switched off leads to the absolutely same results as with test vehicle I. The peak concentration at the seat level decreases within 10 minutes from 4% vol. to values lower than 2 % vol.

In all cases the opening of the door lead to a very rapid decrease of the CO_2 concentration inside the car. However, with closed doors CO2 disappears with a rate of 1.5 % vol. per 10 minutes. That's approximately 3 times higher as in test I.

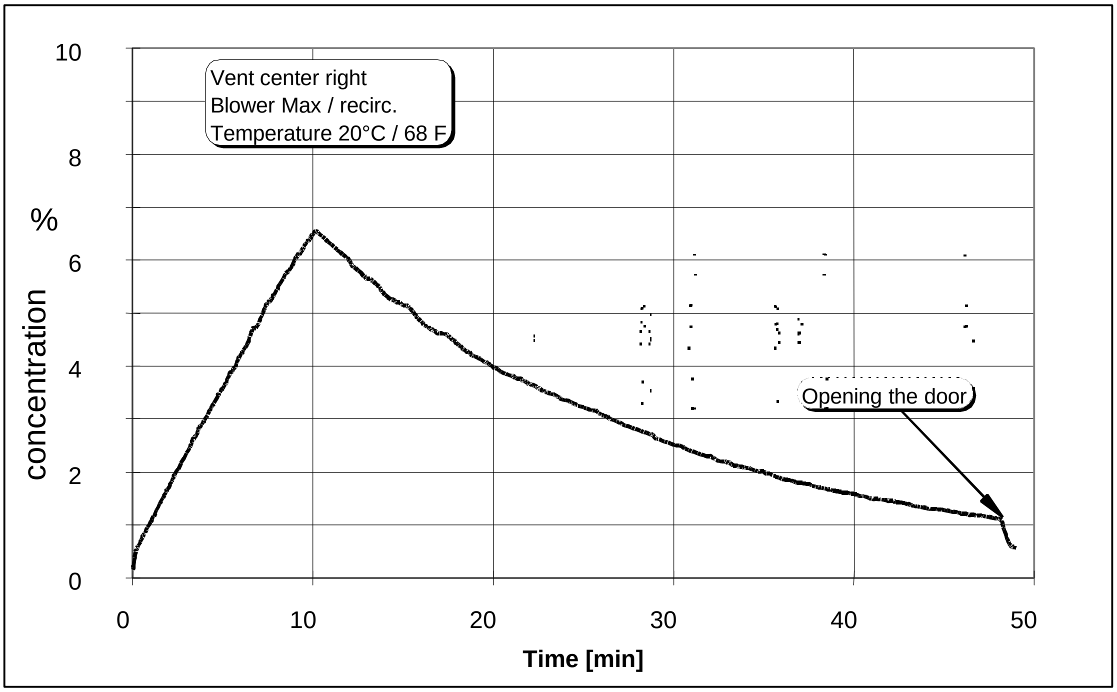

Figure 2: Experimental results of a continuous release of 500 g CO_2 with 1500 l/h into the passenger compartment of a midsize vehicle.

No.	Rate [liter/hr]	Sensor Position	Peak Concentration	Blower step	Comment
1	1500	Vent center right	6.3	max	Diff. sensor positions
2	1500	Vent center right	6.7	max	With 5 Dummies
3	500	Vent center right	3.9	max	
4	1500	Seat level co-driver	4.1	off	

Table 1: Test matrix of vehicle test II. Release of 500 g CO2 inside a passenger compartment of a midsize car with different rates. Ambient temperature 20°C / 68°F

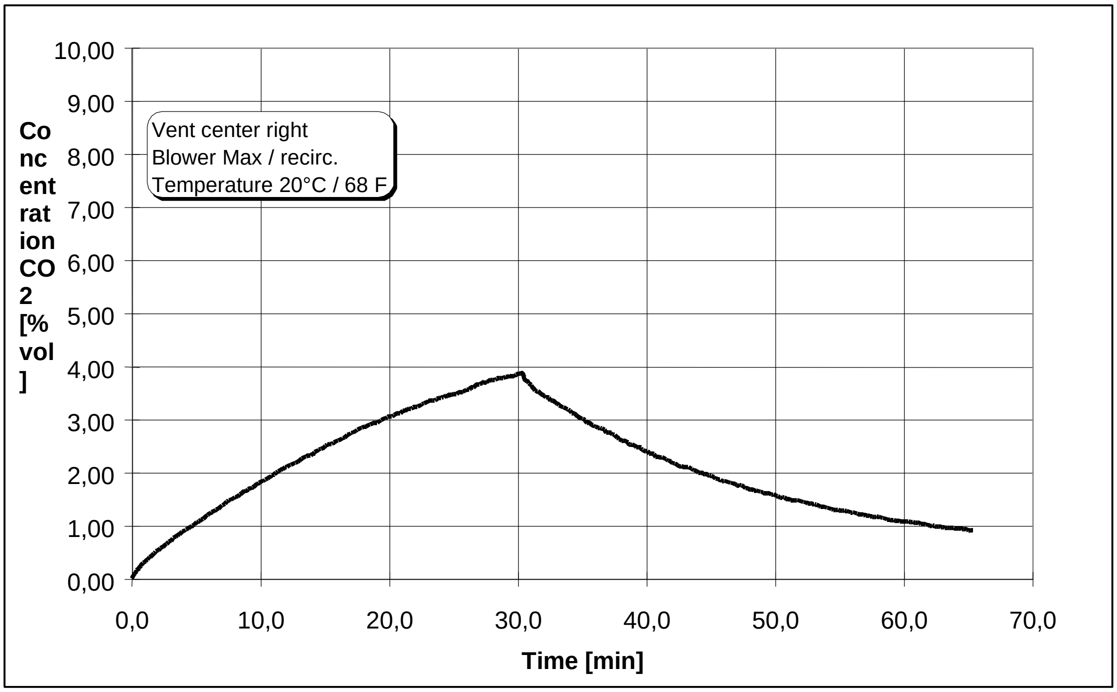

Figure 3: Experimental results of a continuous release of 500 g CO_2 with 500 l/h into the passenger compartment of midsize vehicle.

Refrigerant	Passenger compartment Volume [m^3]	AC System Charge [g]	Refrigerant conc. ppm vol/vol if total AC charge leaks [%]
CO2	1.5	240	8.9
	2.5	225	5
	2.5	400	8.9
	4	600	8.3
Notes: *Theoretical, for illustration only, actual refrigerant charges and passenger compartment volume may be different. Assumes a total leakage of refrigerant charge.*			

Table 2 Refrigerant leakage: theoretical concentrations within passenger compartments

Summary

It must be emphasized that CO2 is a refrigerant with low toxicity. The concentrations of CO2 that can lead to any effects are very high and these could only result in the event of a leak of refrigerant into the passenger compartment under conditions of low fresh air ventilation rates.

The physiological effects on Carbon Dioxide effects are apparent at exposure limits above 2%. Above 5% the change is marked and the human control means system effects became apparent. While not like threatening, at such concentrations this reaction may cause further stress in the subject, who may well be aware of breathing changes, but be enable to detect any cause. The lowest ever reported lethal concentration of carbon dioxide is 9%.

In the experiment the spatial and temporal CO2 distribution of different cars were measured. While at an air flow direct from outside only minor concentrations occur the level at recirculation mode was higher. If the inlet mass of CO2 was small, the concentration in the compartment was low. A charge between 400g and 600 g cause a CO2 concentration of about 5 %, this seemed to be acceptable for the medium size vehicle. There was no influence seen about the concentration level, when the volume flow rise. In case of a non operating blower fan and open outlet nozzles there were layers of CO2 within the cabin, with highest concentration at the floor and the lowest in the head region. When the CO2 flow was interrupted, the CO2 concentration in the compartment declines immediately.
In practice will be a difference of the charge and the escaping charge out of a system. First, not all CO2 can leak out of a system in a limited time, because some CO2 is solved in materials, as lubricant, elastomer. Second due to the pressure reduction in the system due to escaping CO2 the pressure difference to atmosphere falls and the flow rate will be reduced. As general as design rule it seems to be vise to built systems which contain only an insignificant charge of carbon dioxide to human health.
Assuming a leak in the evaporator core with a remarkable loss of refrigerant will lead to a solidification of a certain amount of CO_2 while expanding to ambient pressure. That will stretch the release time of CO_2. Additionally the future total charge of the CO_2 system will be lower than 500 g of CO_2. Both will effect the hazard of CO_2 as refrigerant in a positive manner.

Important safety reminders for Carbon dioxide:

Good ventilation must be provided. Avoid working with carbon dioxide where it can be collect in low or confined areas. Leave the premises immediately in the event of large carbon dioxide release. Before returning to the premises, makes sure that the CO2-concentration is low enough. The carbon dioxide concentration can be analyzed with CO2 sensitive tubes or metered instruments.
Carbon dioxide containers must stand upright when gas is being withdrawn. Cold carbon dioxide can form a very thick mist with moist air. The odor of Carbon dioxide is too weak to warn of dangerous concentrations.
Persons who succumb to Carbon Dioxide poisoning must be taken into the open air quickly. Artificial respiration should be administered if the victims stop breathing

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References:

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[2] K. Ahlberg: AGA Gas- Handbook; AGA AB, Lidingo/Sweden
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