



# Experimental evaluation of the possibility of ignition and flame propagation in accumulated difluoromethane (R32) from a kerosene cigarette lighter



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## ARTICLE INFO

### Article history:

Received 21 February 2015

Received in revised form

8 March 2016

Accepted 9 April 2016

Available online 13 April 2016

### Keywords:

Refrigerant

Difluoromethane

Ignition

Flame propagation

Kerosene cigarette lighter

## ABSTRACT

The possibility of ignition and flame propagation in accumulated difluoromethane ( $\text{CH}_2\text{F}_2$ , R32) was examined experimentally, simulating a situation in which a service operative uses a kerosene lighter for smoking. To simulate the situation where a kerosene cigarette lighter is used in accumulated R32, electrodes fixed in the windbreak of the lighter were remotely supplied with electricity to generate sparks of various durations but of similar energies to those of actual sparks generated by rubbing a flint to ignite the fuel in the lighter. We identified several cases of ignition and formation of an open flame in the windbreak of the lighter, and the flame propagated to the accumulated R32 when it was supplied with sufficient energy from the spark. Gas chromatographic analyses confirmed that the mixture in the windbreak of the kerosene lighter consisted mainly of vaporized fuel and air, with no R32. Therefore, even if the lighter is located in accumulated R32, an open flame can be generated in the windbreak of the kerosene cigarette lighter through ignition by the spark energy generated by friction between the flint and the flint wheel. Our results confirmed that there is a real possibility of ignition and flame propagation when a kerosene cigarette lighter is used in accumulated R32 under the leak rate conditions of the present experiment.

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## 1. Introduction

In the field of refrigerating and air-conditioning engineering, there is a worldwide trend toward the development and use of alternative refrigerants that have no ozone-depleting potential and low global-warming potential. For example, there are strong expectations that difluoromethane (R32), 2,3,3,3-tetrafluoroprop-1-ene (R1234yf), and (*E*)-1,3,3,3-tetrafluoroprop-1-ene [R1234ze(E)] will be used as alternative refrigerants, and several items of equipment containing these refrigerants have already been commercialized in Japan.

However, unlike the refrigerants in current use, such as R410A [difluoromethane (R32)/pentafluoroethane (R125) azeotrope], or R134a (1,1,1,2-tetrafluoroethane), these alternative refrigerants have a degree of flammability, although this is lower than that of most flammable gases. The fundamental combustion behaviors of

the alternative refrigerants, such as their flammability limits, their minimum ignition energies, their burning velocities, and their quenching distances, have been examined and reported by several researchers (for example, see: Takizawa et al., 2015, 2009; Saburi et al., 2014; Spatz and Minor, 2008). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has defined a refrigerant of class A2L as one that meets all the following conditions: (1) it exhibits flame propagation at 60 °C and 101.3 kPa, (2) it has an LFL of more than 0.10 kg/m<sup>3</sup>, (3) it has a heat of combustion of less than 19 MJ/kg, and (4) it has a burning velocity of less than 10 cm/s at 23.0 °C and 101.3 kPa (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2013). This classification has subsequently been adopted by the International Organization for Standards (ISO) in its ISO817 standard (International Organization for Standards, 2014). On the basis of these researches and standards, there has been worldwide progress in risk assessment and the development of guidelines for A2L refrigerants (for examples, see: DOE, 2014; Australian Institute of Refrigeration, Airconditioning, and Heating, 2013; British Refrigeration Association, 2012). In Japan (Japan Society of

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Refrigerating and Air Conditioning Engineers, 2015), these risk evaluations of A2L refrigerant based on the physical hazard have been conducted by the New Energy and Industrial Technology Development Organization (NEDO), and they have led these researches conducted in the world.

In some handling situation, several A2L refrigerants, such as R1234yf, are classified in Japan as flammable gases, like hydrogen, propane, etc., although the actual combustibility of the refrigerants is markedly lower (for examples, see: Takizawa et al., 2015, 2009). Therefore, if A2L refrigerants are to be used in air-conditioning systems, it will be necessary to reconsider their classification and to relax standards for their handling on the basis of risk management for foreseeable actual handling situations and occasional accident scenarios, and it has been widely required not only in Japan but also all over the world.

We have therefore conducted a series of experimental evaluations of the physical hazards associated with A2L refrigerant, assuming occasional accident scenarios in situations in which A2L refrigerants are likely to be handled, which were assumed by the risk assessment conducted by The Japan Refrigeration and Air Conditioning Industry Association (for examples, see: Takaichi and Taira, 2015; Watanabe, 2015; Yajima, 2015). We have reported the possibilities of ignition of A2L refrigerants in several service and maintenance situations, such as the case of leakage of refrigerant from a pinhole in a pipe or hose, or leakage of a refrigerant into equipment such as a refrigerant-collection device (Imamura et al., 2015), and we have also reported experimental evaluations for the case in which A2L refrigerant in an air conditioner is used at the same time as a fossil-fuel heating system in a general living space (Imamura et al., 2012).

In the above risk assessment, the influences of varieties of ignition source, such as lighter, appliances, electrical circuit, on the ignition and flame propagation of A2L refrigerant are focused, and to clarify them is widely expected (for examples, see: Takaichi and Taira, 2015; Watanabe, 2015; Yajima, 2015). Therefore we have focused on the situation in which a service operative uses a portable lighter to smoke in an atmosphere where A2L refrigerant has accumulated, and then the evaluation result using a portable piezoelectric cigarette lighter was already reported (Imamura et al., 2013). Here, we describe our experimental evaluation of the possibilities of ignition and flame propagation in the case where a service operative uses a kerosene cigarette lighter with a flint-and-wheel ignition system to smoke which is listed as the conceivable ignition source by above risk assessment in atmosphere where R32 has accumulated as a result of leakage from an air-conditioning systems.

## 2. Experiments

### 2.1. Experimental studies on ignition of A2L refrigerant

Fig. 1 is a schematic representation of our experimental setup.

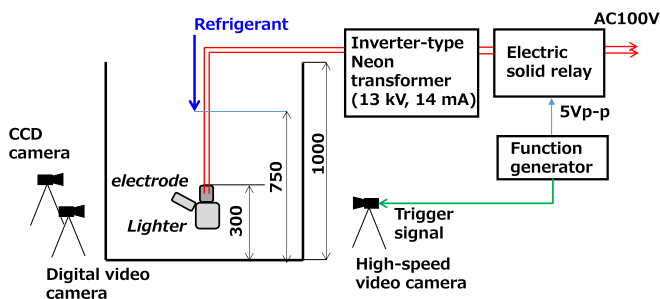


Fig. 1. Schematic representation of the experimental apparatus. Units: mm.

R32 was used as the test A2L refrigerant. The acrylic pool measuring 1000 mm × 1000 mm × 1000 mm was fixed to conduct the ignition test.

A commercial kerosene cigarette lighter was located at the 300 mm above the center of the base of the pool as an ignition source. R32 was leaked downwards into an acrylic pool measuring 1000 × 1000 × 1000 mm from a position 750 mm above the base of the pool at a leakage rate of 10 g/min. The total leak amount of R32 into the pool was 220 g. The concentration at the position where the lighter was located was approximately 16 vol%, which is within the flammable range and slightly lower than the stoichiometric concentration of 17.4%. To prevent mixing and turbulence of the accumulated R32, the gas in the windbreak of the kerosene lighter was ignited by means of a spark from a pair of electrodes (2-mm-diameter, stainless steel, gap length: 2 mm) placed near the wick. The ac electric sparks were generated in the gap between the electrodes by using an inverter-type neon transformer (CR-N16; Kodera Electronics, Co., Ltd., Gifu). A solid-state electric relay (GSR-20L-D32Z; Misumi Group Inc., Tokyo) was inserted between the circuit of the transformer and the electrodes to control the energy for igniting the fuel of the lighter. Switching of the electrical supply to the solid-state relay was controlled by means of a rectangular wave signal of 5 V dc, generated by a function generator (33120A; Agilent Technologies, Santa Clara, CA). The time for which electricity was supplied to the solid-state electric relay (referred to as the 'energization time') was 50, 100, or 500 ms. These energization times were determined based on the visually comparison of spark emission between actual spark generated by rubbing a flint against a flint wheel directly and ac spark. In each ignition test, the switching action to energize the relay was repeated ten times at intervals of 5 s. The generated voltage between the gap of the electrodes was measured by means of a high-voltage probe (P6015, Tektronix Inc., Beaverton, OR), and the generated current was measured by means of a current transformer (Model 2100, Pearson Electronics, Inc., Palo Alto, CA). The energy of electric spark was estimated by integration of the generated voltage and current over the energization time.

Just before the ignition test, the concentrations of the accumulated A2L refrigerant were measured by means of Fourier-transform infrared spectroscopy with an FT-IR4200 spectrometer (JASCO Corp., Tokyo). The sample gas was extracted to the FT-IR through a 6.35-mm-diameter copper tube attached to a valve switching box. Concentrations were measured at heights of 0, 100, 300, 500, 750, and 1000 mm above the center of the base of the pool.

Video recordings of the kerosene lighter and its surroundings containing R32 were made by using a high-speed camera (FAST-CAM SA-X; Photron Ltd., Tokyo), a digital video camera (HC-V520M, Panasonic Corp., Osaka), and a CCD camera (MTV-53KM21H, Mintron Enterprise, Co., Ltd., New Taipei City). The timing of the beginning of energization of the solid-state relay and that of commencement of the video recording by the high-speed camera were synchronized by means of a trigger signal generated by a function generator.

### 2.2. Analysis of the composition of the gaseous mixture in the windbreak of the kerosene lighter

The composition of the mixture in the windbreak (volume: 2.72 mL) of the lighter in an atmosphere of accumulated R32 was analyzed by a gas chromatography/mass spectrometry (GC/MS; GC-17A, Shimadzu Corp., Kyoto). A 2.0-m-long vinyl tube with an internal diameter of 4 mm (total volume 25.12 mL) was inserted into the windbreak. A 26 mL gas sample, which included air from the extraction tube and the gaseous mixture from the windbreak, was

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