New Concepts for Refrigerant Leak Detection and Mixture Measurement

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ABSTRACT

Since the discovery that chlorofluorocarbons (CFCs) destroy the ozone layer, the need to reduce the release of refrigerants into the environment has become critical. A total ban of ozone-depleting CFCs is expected within a few years, and hydrofluorocarbons (HFCs) and fluorocarbons (FCs) and their mixtures are expected to be used during a transition period. Several HFC and FC refrigerants are currently being considered as CFC substitutes. The electronic refrigerant leak detectors currently on the market were developed to detect CFCs and are not as sensitive to HFCs. Although incremental improvements can be made to these devices to detect HFCs, they often lead to increased false signals. There is no simple device available to measure the composition of a refrigerant mixture. In this paper, we will present two new concepts to aid in the development of two portable instruments that can be used for HFC leak detection and for quantitative measurement of refrigerant mixture compositions. It is believed that the development of simple and easy-to-use portable leak detectors and refrigerant mixture meters is essential to the wide use of alternative refrigerants in industry.

INTRODUCTION

It is well known that CFCs have a serious adverse impact on the global environment because they react with the ozone layer in the stratosphere. As CFCs are an essential chemical component for several industries, reducing the quantities of CFCs released into the air has become critically important. To achieve this goal, major efforts have been made to develop new kinds of refrigerants to replace CFCs. Because most of the impact of CFCs on the ozone layer is due to the chlorine atoms they contain, most new refrigerants used in the future will be FCs or HFCs. FCs and HFCs are expected to be much more expensive than CFCs. Thus, a leak detector able to detect FCs or HFCs is much needed.

Leak testing is an important part of manufacturing refrigeration equipment. Because any serious leak in a compressor is fatal to its normal functioning, an air-conditioner must be leak-tight. Unfortunately, a high percentage of air-conditioner problems are related to refrigerant leakage. A portable leak detector is therefore an important instrument for air-conditioning or refrigeration repair persons. However, most detectors currently available are inadequate for FC or HFC leak detection.

Types of refrigerant leak detectors commercially available include torch, tracer dye, heated anode, and corona discharge detectors. The torch method uses a change in the color of a flame to detect leaks. Since chlorinated compounds produce green flames, the torch can be used to detect leaks of CFCs, such as R-12. However, it is not useful for detecting FCs or HFCs because their chemical makeup does not include chlorine atoms. Also, it is unsafe to use a torch leak detector in an environment with flammable or explosive gases, such as a gasoline station. In the tracer dye approach, a dye solution is injected into an air-conditioner and an ultraviolet light is used to make the dye fluoresce so that gross leaks may be located. The corona discharge leak detector applies a voltage to a sharp pointed element to produce a corona that generates a standing current. The presence of a refrigerant gas modifies the discharge condition and reduces the standing current, which in turn triggers the leak signal. Although this type of leak detector can be used to detect various refrigerants, it can also be triggered by other compounds. For example, a corona discharge leak detector can give a false warning in the presence of gasoline vapor. Also, the very sharp tip required eventually will erode, which reduces sensitivity by changing the amount of corona.

In our research, we developed an atmospheric proportional counter leak detector to detect leaks not only of CFCs, but also of FCs and HFCs. We expect it to be not only highly sensitive, but also highly selective.

Some CFC refrigerants are expected to be replaced by HFC or FC mixtures. However, no simple instruments are available to measure fractions of individual components in refrigerant blends. When leaks develop, it is difficult to recharge the refrigerant device to the correct ratio of refrigerant mixtures. In this work, we developed a novel idea to measure refrigerant ratios based on the mobility of charged particles in refrigerant mixtures.

INSTRUMENTATION

A. Proportional Counter Refrigerant Leak Detector

The schematic of this instrument is shown in Fig. 1. A proportional counter serves as a detector. Proportional counters have been used extensively in nuclear physics research to detect a single event of radioactive decay. When a radioactive element decays, the ejected energetic particles (α decay: He^{+2}, β decay: electron, γ: photon) can usually produce many electrons and ion pairs by the collision and cascade processes. The number of electron and ion pairs produced is determined by the type of ejected particle and its energy, and by the kind of gas medium and its density. However, when these electron-ion pairs are produced in a strong electric field, electrons are accelerated toward a positively biased electrode while the positively charged ions drift in the opposite direction. The electrons, if accelerated to sufficient velocity, can produce more electron-ion pairs by ionizing other gas molecules. Thus, the amplification of the initial negative charge can be achieved. In a proportional counter, a small-diameter wire is used as an electrode to collect electrons. For a cylindrical configuration, the strongest electric field gradient is close to the wire, where the most amplification occurs. Since the amplification depends on the field gradient, the gain of a proportional counter is dependent on the central wire voltage. The signal of a proportional counter is proportional to the number of electrons produced. The proportional counter's high sensitivity for detecting electrons was illustrated by the demonstration of single atom detection[1] using laser ionization and a proportional counter. However, up to now, proportional counters have been used only in a sealed-chamber form containing a few selected counting gases such as P-10 (10% methane and 90% argon), which is tailor-made to give high gain with few spurious counts. Any electronegative gases, such as O_2 and halogens, have traditionally been intentionally excluded to maximize the gain of the proportional counter. Thus, to our knowledge, there have been no reports of using a proportional counter in an open chamber with air serving as the counting gas. In this work, we report the first use of air as the counting gas so that a proportional counter can possibly be used for detecting halogenated compounds in the air. When electronegative gases such as CFC, HFC, or FC are present in air, a certain percentage of electrons will be attached to these molecules. The negative ion formed cannot be accelerated by the electric field to a sufficiently high velocity to create more ionization. Thus, the amplification factor of the proportional counter is drastically reduced. From the reduction of the amplification and the resulting reduction in the amplitude of the pulses from the proportional counter, the presence of electronegative molecules in the gas can be deduced.

In a laboratory bench-top setup, an Alpha source is mounted inside a proportional counter so that a large fraction of the ionization tracks produced are roughly parallel to the central wire, which is at a positive high voltage. The electrons produced are attracted toward the wire and are amplified as they get close to the wire, resulting in a measurable pulse from the amplifier. The presence of electronegative gas molecules, such as HFC molecules, reduces the number of free electrons that reach the wire, thereby reducing the pulse amplitude as shown in Fig. 2.

The pulse height distribution from a proportional counter operated using a standard counting gas (P-10) is higher than the pulse height distribution obtained using air at one atmosphere as the counting gas. It is clear that the reduction of counts at higher pulse amplitudes is due to electron attachment. When a very minor amount of refrigerant is added to the air, further reduction of counts at higher pulses is observed. This reduction indicates that the electron attachment by the refrigerant is much stronger than the electron attachment by the oxygen molecules. Of course, the detection sensitivities for various refrigerants are different since the electron attachment cross-sections are expected to be different for various halogenated compounds.[2] For example, SF_6 is well known to have high thermal electron attachment cross-sections. This instrument should be able to detect SF_6 with very high sensitivity. For most refrigerants, the electron attachment cross-sections are not known. However, it is expected that the sensitivity for detecting CFCs is higher than the sensitivity for FCs and HFCs because chlorinated compounds tend to have high electron attachment cross-sections.

B. Refrigerants Ratiometer

Because of the strong electron attachment of most CFC, HFC, and FC refrigerants, it is expected that the electron drift velocity in various refrigerants will be different. The mobility of charged particles should be the function of the ratio of each component in a blend. If the mobility of charged particles is a linear function of the percentage of a selected refrigerant, a simple measurement of the drift velocity of charged particles can be used to determine the percentage of selected refrigerants in a blend.[3] A schematic of the ratiometer is shown in Fig. 3. The instrument consists primarily of a surface (28) that releases electrons when illuminated by a flash of UV light (40); the electrons drift to the opposite plate (26) because of the electric field created by a dc power supply (30), and the drift time is measured by a recording instrument (38). A short-duration pulsed flash lamp is used to produce electrons that will drift toward the anode following the electric field. By measurement of the drift times for known blends, a calibration curve can possibly be obtained. Thus, the percentage of each component in the blend can be determined by the calibration, provided that each component in the blend is known.

RESULTS AND DISCUSSION

Leak Detector. Since CFCs such as R-12 (CF_2Cl_2) are expected to be banned by 1996, most tests of the proportional counter leak detector were aimed at detecting HFCs such as R-134A (CF_3CH_2F), which is currently in use in air conditioners in a few selected cars. R-134A is expected to be used in all the new automobile air conditioners.

Because there are no chlorine atoms in R-134A, most commercially available refrigerant leak detectors are inadequate for detecting small R-134A leaks. The results of experimental tests on R-134A and R-12 indicate that a leakage rate of 2 oz/year of R-134A and 0.02 oz/year of R-12 can be detected readily with the present bench-top proportional counter setup. The refrigerant leak detection sensitivity in this device is affected by several factors, including the electric field configuration, the field strength, the number of electrons produced, the free electron energy level, and the electron attachment cross-section of a particular refrigerant. Some of the factors affecting the detection sensitivity are predictable; others are not known. For example, the detection sensitivity is expected to be proportional to the square root of the number of electrons produced, but the electron attachment cross-section of R-134A and its possible energy dependency are not known. Detector performance optimization experiments are being carried out to improve the refrigerant leak detection sensitivity.

The selectivity of this leak detector is inherently higher than that of a corona discharge type because this detector responds only to the electron attachment process. A corona discharge can be modified by a number of common vapors and even by water vapor, creating an operational difficulty when used in variable environments. Erosion of the sharp pointed tip in the corona discharge device is also a problem. The heated anode detector consumes more power than a proportional counter, which makes it more difficult for it to be battery powered.

Since halogenated compounds are among the most toxic wastes, this instrument may be useful in the field to detect trichloroethylene (TCE) and polychlorinatedbiphenyls (PCBs) as well as refrigerants. Although the instrument cannot identify individual halogenated chemicals, the averaging effect of halogenated compounds can make it valuable for identifying halogenated compounds in high-contamination zones quickly.

Ratiometer. Experimental results for the refrigerant ratiometer are shown in Fig. 3 for R-12 and R-134A blends. Indications are that the drift time is about linearly proportional to the percentage of R-12. Thus, the percentage of R-12 in the blend that contains R-12 and R-134A can be determined. More blends will be tested in the near future.

CONCLUSION

We have invented two new devices with much potential for development as simple instruments for use in the field for sensitive measurement of refrigerants.

ACKNOWLEDGEMENTS

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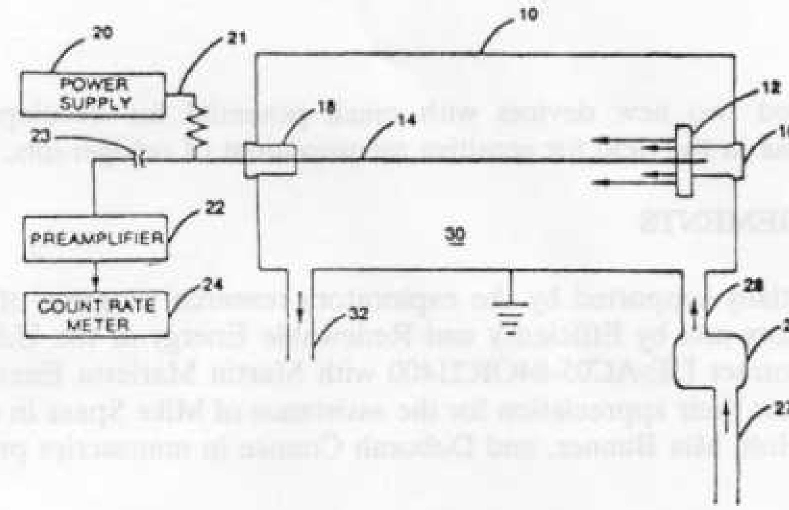

FIGURE 1. SCHEMATIC OF A PROPORTIONAL COUNTER REFRIGERATOR LEAK DETECTOR

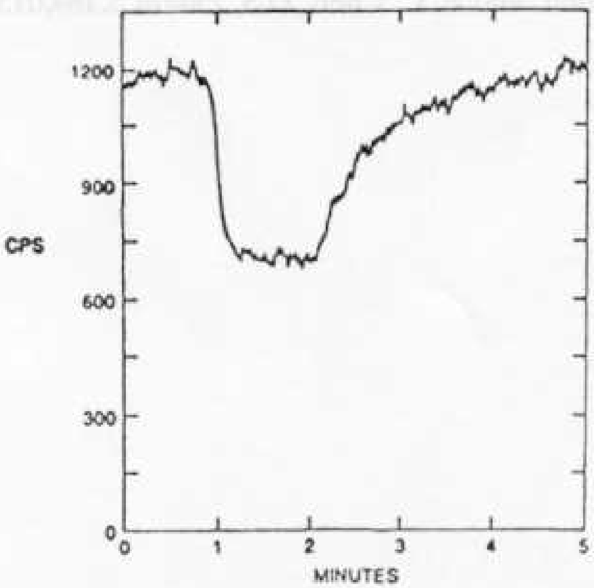

FIGURE 2. ELECTRONIC SIGNAL IN THE PRESENCE OF A REFRIGERANT LEAK

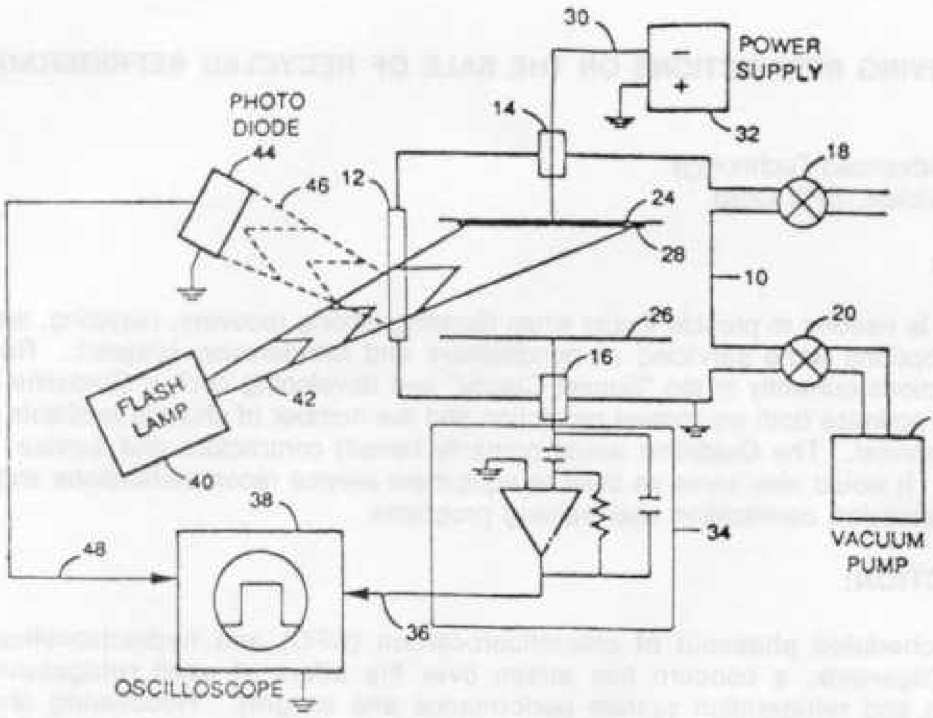

FIGURE 3. SCHEMATIC OF A REFRIGERANT RATIOMETER

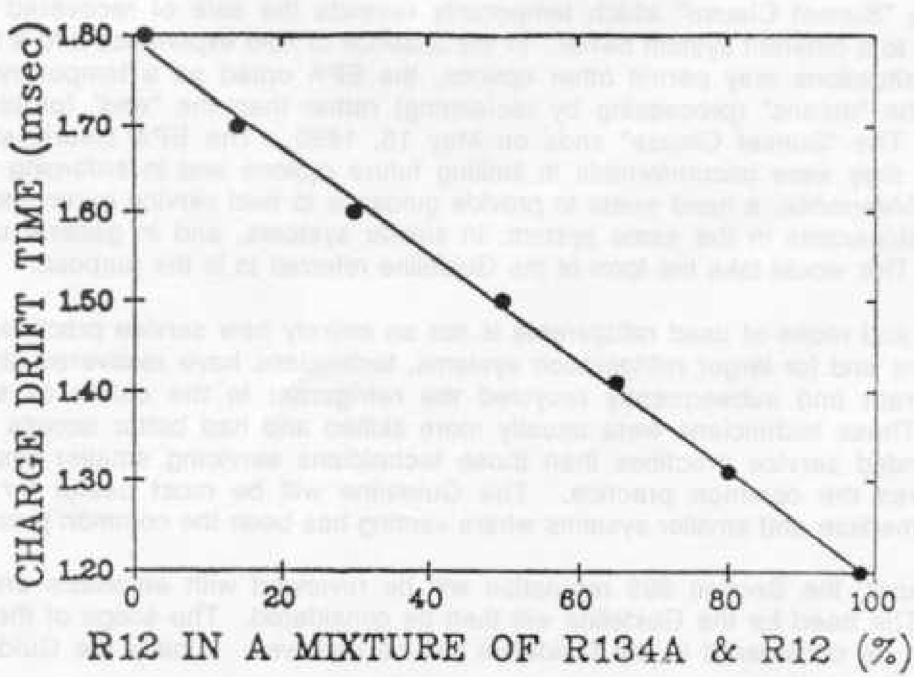

FIGURE 4. NEGATIVE CHARGE DRIFT TIME VERSUS THE RATIO OF R-12 TO R-134A IN A MIXTURE