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The Use of n-Perflourcarbons as RICH Radiators

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Abstract

RICH detectors in high energy physics demand a sufficiently high and stable refractive index and a long radiation length combined with good transparency extending into the UV range. n-Perflourcarbons fulfill all these criteria and show chemically inert behavior. In this paper an overview of n-Perflourcarbons used for RICH detectors will be given. As an example of the experimental techniques for purification and recuperation, the C₄F₁₀ system for the LHCb RICH 1 detector will be discussed. The purification of the C₄F₁₀ gas cycle is based on a cascade of two membranes. The selected membranes let smaller molecules such as N₂ pass 16 times more effectively than C₄F₁₀. The recuperation system liquefies the C₄F₁₀ by cooling it down to -40°C. The liquid n-Perflourcarbon is extracted and the remaining light gases such as Ar go to the waste line. Laboratory tests have proved the capability of this system in 20 recuperation runs, with an average loss of less than 10% of the C₄F₁₀ per recuperation cycle.

Key words: RICH, n-Perflourcarbons, C₄F₁₀ recovery
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1. Introduction

Ring Imaging CHERENKOV (RICH) detectors are used as well as other techniques for particle identification in high energy physics applications. A good RICH radiator should provide a stable and high enough refractive index, good transparency and long radiation length. As the Cherenkov light intensity spectrum extends to the UV range, the Cherenkov radiators’ transparency and refractive index stability should extend up to 200 nm or less, depending on the photon detector used. n-Perflourcarbons fulfill the above specifications.

2. Optical Properties

The family of n-Perflourcarbons offers a wide range of refractive indices as exemplified in Table 1. In Fig. 1 the extinction coefficients as a function of wavelength are shown for different n-Perflourcarbons. The molar extinction coefficient $\epsilon$ is a measure of how strongly a chemical species absorbs light at a given wavelength. The absorbance $A$ of a sample depends on the path length $l$, the concentration $c$ and the extinction coefficient $\epsilon$ via the Beer-Lambert law:

$$A = \epsilon \cdot c \cdot l.$$
Choosing a lighter fluorocarbon will enhance the transparency in the 140 nm region, which is useful when using CsI photo-cathodes. Fig. 2 shows the refractive index as a function of photon energy for the example of C$_5$F$_{12}$. The chromatic dispersion $d$ is defined as the change of refractive index $n$ as a function of the wavelength $\lambda$:

$$d(\lambda) = \frac{\delta n}{\delta \lambda}.$$  

From the slope of the graph in Fig. 2, it can be seen that $n$ changes by $2 \cdot 10^{-4}$ per eV at 7 eV photon energy. This corresponds to a chromatic dispersion of:

$$\frac{\delta n}{\delta \lambda} (177 \text{ nm}) = 7.78 \cdot 10^{-6} \text{nm}^{-1}.$$  

2.1. Contaminations

In addition to the radiator itself, contaminations will lead to absorption. In Fig. 3 the effects of water, oxygen and CO$_2$ are shown. These gases, which as part of the ambient air, have a high chance of entering the system, start to play an important role below 190 nm. In systems with photon detection mainly above this range, these contaminations should nevertheless be kept at the 10 ppm level. Organic pollutants such as benzene influence the transparency of the RICH radiator from 300 nm downwards, as can be seen in Fig. 4. With an absorption coefficient of around 0.8 cm$^{-1}$ hPa$^{-1}$ at 200 nm benzene must be carefully removed to parts per billion levels.

2.2. Cleaning

In order to achieve low levels of gas or fluid impurities, several types of filters should be considered. Drying is achieved by activated alumina Al$_2$O$_3$, silica gel and molecular sieves. The removal of oxygen can be achieved by using filters with copper or chromium reactants and molecular sieves. Aromatics can be efficiently removed by activated carbon with internal surfaces around 400 to 1600 m$^2$/g [2]. Membrane filters, which can be either molecular sieve films $^1$ or composite hollow fiber membranes, allow separation of gases with different kinetic diameters, thus separating even neutral gases, see Fig. 5. The RICH radiators CF$_4$ and C$_4$F$_{10}$ are 16 times

$^1$ Ube Europe GmbH, Düsseldorf, Germany.
Fig. 3. Absorption as a function of wavelength for water, oxygen and CO$_2$ [2], [4a–c].

less likely to pass through the membrane compared to nitrogen. With the help of liquefaction or distil-

lation, light gases and heavy fluids can be separated from the radiator gas.

3. C$_4$F$_{10}$ Recovery System for LHCb

C$_4$F$_{10}$ is widely used in RICH detectors such as COMPASS, DELPHI, HERA-B, HERMES and LHCb for being a good compromise in terms of UV transparency, refractive index and ease of use. Because of scarce availability, a price of 1 kCHF per m$^3$ [6], and the environmental hazard, C$_4$F$_{10}$ has to be recovered before opening the detector for servicing. Light and noble gases that are used for flushing the gas system can be removed during the recovery process. As the boiling point of C$_4$F$_{10}$ at 1013 hPa is -1.7°C, liquefaction is possible either via liquid nitrogen, or a Freon cooling unit. For LHCb RICH1, the recovery system from HERA-B was refurbished. It consists of a cooling unit running on R404 cooling agent at -40°C and a liquefaction circuit using five heat exchangers (see Fig. 6, 7).

The C$_4$F$_{10}$ enters the recovery system as a gas. It is cooled down by three heat exchangers before entering the liquefier volume. The liquid C$_4$F$_{10}$ leaves the liquefier volume through a valve at the bottom, light gases are vented to the nitrogen output.
Before installation in the LHCb gas system, 20 recovery runs have been performed in the lab. In 13 runs, the C$_4$F$_{10}$ was evaporated with the help of heating bands around the 63 liter source bottle, in seven runs the liquid was displaced by argon and evaporated externally. 200 liters of C$_4$F$_{10}$ per hour have been recuperated with an average yield of 90%. It will take 20 h at 200 l/h to recuperate the 4 m$^3$ of C$_4$F$_{10}$ used in the LHCb RICH 1 detector.

3.1. Obstacles

During the recovery tests described above, a few difficulties had to be overcome. These are described below.

C$_4$F$_{10}$ condenses at 1200 hPa overpressure at 20°C. Higher compression must go along with heating or dilution with a neutral gas. In the refurbished system, the pressure at the input pump of the recovery rack is limited via a bypass and dilution with nitrogen is made possible. The C$_4$F$_{10}$ is relatively impure, with an admixture of different C$_n$F$_m$ of order 5% by fraction. Heavy fluids have a low vapor pressure and remain liquid where the C$_4$F$_{10}$ is evaporated. The lighter n-Perflourcarbons are not liquefied, and thus leave the liquefaction stage together with the nitrogen. Running at -40°C leads to ice buildup in some areas, for example on the tubes of the liquefaction stage and inside the electronic box, which is mounted on the cold surface of the compressor. To prevent ice buildup, the confined part of the rack, housing the liquefaction stage, and the interior of the electronic box are flushed with dry nitrogen. When the liquefier rack is being de-iced, the C$_4$F$_{10}$, which remains after a recovery cycle in the system, evaporates. This C$_4$F$_{10}$ gas should be captured in a storage container. The 63 liter 3M bottles used for this purpose in the lab exhibited corrosion. Therefore the storage containers provided should never be exposed to outside conditions. The rust particles caused by the corrosion of the 63 liter 3M bottles blocked the valves and pressure regulators of the C$_4$F$_{10}$ recovery system and could also pollute the mirrors of the RICH detector. During the lab test, the liquid extraction lines of the bottles had to be refurbished and mechanical filters had to be installed.

4. Conclusions

n-Perflourcarbons are excellent RICH radiators for their stable refractive index, good transparency extending well into the UV region, large radiation length and inert chemical properties. As contaminants would degrade the performance of the radiators, one should exploit suitable methods of filtration. Because of the high price of n-Perflourcarbons, a recovery system is essential. The LHCb RICH 1 C$_4$F$_{10}$ recovery system is based on the HERA-B liquefier. It was shown in laboratory tests that the refurbished recovery system fulfills all requirements.

References

[4a] K. Watanabe, et al., AFCRC Technical Report No. 53-23 (1953);
[5c] H. Du et al., Photochemistry and Photobiology, 68(2), 141-142 (1998);