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Technical Paper #1

Ammonia Leak Detection in Refrigeration Systems

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Abstract

Codes and standards require that ammonia refrigeration systems be monitored for leaks. Various technologies can detect ammonia, including electrochemical, infrared, solid state, polymer thin-film capacitive, and charge carrier injection, and these all have unique strengths and weaknesses. Recognizing that refrigerated areas can present challenging operating conditions to ammonia sensors, end users must be careful to choose the appropriate technology to suit their particular application. Changing temperatures and humidity levels in the application/process will sometimes affect the ammonia level or the lifetime of the sensor. Other gases and odors plant may cause the sensor to respond and can lead to unnecessary and costly false alarms. How can end users decide what to do? The paper will review the pros and cons of each technology, and discuss factors that influence sensor effectiveness and sensitivity.

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Introduction

Ammonia, a common refrigerant, is a highly versatile chemical that has been widely used in numerous industrial applications since the 19th century. It is environmentally friendly in that it does not contribute to the depletion of the ozone layer or to global warming. Since the numerous restrictions on CFC and HCFC refrigerants have been implemented, and with increasing attention focusing on the environment, the demand for ammonia as a refrigerant has increased.

Besides being an environmentally friendly, naturally occurring substance, ammonia also has excellent thermodynamic and thermophysical properties. Despite its advantages, however, users must remember that it can be a hazardous chemical and must be treated with respect. It must be handled in a safe manner and it requires reliable leak detection instrumentation to ensure both personnel and product safety.

Ammonia

Under normal atmospheric conditions, ammonia is a colorless gas that is lighter than air and has a distinctive odor detectable with the human nose at a concentration level of just 5 parts per million (ppm). Its low odor threshold is an advantage with regard to personnel safety. Ammonia is a “bio-corrosive” chemical; thus, it is of concern to agencies concerned with worker safety such as the Occupational Safety and Health Administration (OSHA), the National Institute of Occupational Safety and Health (NIOSH), and the American Conference of Governmental Hygienists (ACGIH), and they have established many guidelines for the safe limits of ammonia concentration in the air. (Table 1)

Symptoms of exposure to ammonia vary with concentration, and range from minor irritation of the eyes and throat to fatal respiratory complications. (IIAR, 1983) In most cases, before ammonia concentrations build to a level that might be harmful to

a person, an ammonia leak detection device will alarm and the personnel would exit the area. However, an unexpected ammonia leak may endanger lives, cause the plant to be shut down for repairs, and cause expensive damage to food product within a plant.

Code Requirements for Ammonia Detection

Numerous codes and regulations require ammonia detectors. Insurance underwriters, as well as building, mechanical, and fire codes, have established specific requirements for ammonia detection. (IRC, 2002) The following is a partial list of such requirements:

- ANSI/ASHRAE Standard 15-2001: Safety Standard for Refrigeration Systems (ASHRAE, 2001)
- ANSI/IIAR 2-1999: Equipment, Design, and Installation of Ammonia Mechanical Refrigerating Systems (IIAR, 1999)
- Factory Mutual Bulletin DS 7-13 (Factory Mutual, 2001)
- IIAR Bulletin 111: Guidelines for Ammonia Machinery Room Ventilation (IIAR, 1991)
- ISA – S92.03.01-1998: Performance Requirements for Ammonia Detection Instruments (25-500 ppm full scale) (ISA, 1999)
- ISA – S92.03.02-1999: Installation, Operation, and Maintenance of Ammonia Detection Instruments (25-500ppm full scale) (ISA, 1993)

Ammonia Sensing Technologies

The purpose of ammonia detection for refrigeration applications is to sense and communicate the presence of ammonia to protect people and property. Such applications can be very demanding. The temperature range over which they must operate is great (i.e., from -50°F to +120°F). Also, fluctuating humidity levels and

various odors may lead a sensor to alarm even when ammonia is not present. These demanding operating conditions make it very difficult to choose a reliable ammonia leak detection device.

Numerous types of sensors can be used to detect ammonia for refrigeration applications, including electrochemical, solid-state, infrared, charge carrier injection, and polymer thin film - capacitive. Each of these is discussed below.

Electrochemical

In the electrochemical sensing process, ammonia gas diffuses across a permeable membrane into an electrolyte solution within the sensor unit. (Figure 1) Measurement, counter and reference electrodes are located within the electrolyte solution. The unit applies a constant voltage across the electrodes, causing an electrical current to flow through the electrolyte solution from one electrode to the other. When ammonia is absent, the unit develops a steady state reference current. When ammonia gas is present in the atmosphere and has diffused into the electrolyte solution, it chemically oxidizes or reduces at the measurement electrode, causing the current to change in proportion to the amount of gas present. (Kiesele and Wittich, 2000)

In most cases the electrolyte is ammonia-specific, and therefore has few cross sensitivity problems with other gases. Electrochemical sensors may operate across a broad range of temperature, from -40°F to +150°F, and relative humidity, typically from 5 to 95%. Certain environmental conditions, such as prolonged high temperatures and humidity, will deplete the electrolyte in the cell more rapidly, shortening the life of the sensor. Exposure to quantities of ammonia also affects sensor life by depleting the electrolyte, sometimes causing the sensor to fail silently. (IRC, 2002) The typical calibration interval for electrochemical sensors is 6 months, but this interval depends on the environmental conditions where the sensor is located. The sensor can be calibrated and adjusted in the field.

Polymer Thin Film – Capacitive

Polymer thin film – capacitive sensors detect changes in the capacitance caused by absorbed ammonia. These sensors have a polymer film that serves as a dielectric between the capacitor plates. Two resistors control the temperature of the capacitor: one heats the system and the other measures the sensor temperature and controls the heater resistor. (Figure 2)

The unit maintains a specific collection temperature, at which the polymer layer absorbs ammonia and water molecules. To measure the ammonia concentration, the water must be removed. This is accomplished by rapidly heating the sensor to cause the gases to desorb, then cooling the sensor back to the collection temperature. Refer to the graph showing capacitance as a function of time during the heating/cooling cycle. (Figure 3) Between the heating and cooling curves, the ammonia absorption causes hysteresis. The amount of hysteresis is proportional to the amount of ammonia present. (Fotis, 2002)

This technology is very selective to ammonia, which reduces cross-sensitivity to other background gases. It has an operating range of -40°F to $+140^{\circ}\text{F}$ and 0 to 100% relative humidity. The time required for the water desorption process may slow the response time of the sensor. (IRC, 2002) The sensor has no parts that degrade significantly from exposure to ammonia, and has a lifespan of at least three years, according to a manufacturer. Units require calibration annually using one of two methods. The owner may test it using a certified gas sample, or the probe may be sent to the manufacturer for calibration.

Charge Carrier Injection

Charge carrier injection sensors selectively bind ammonia with a gas-sensitive material. (IRC 2002) The unit injects an ammonia charge carrier into an air sample,

which absorbs ammonia molecules. The air sample is drawn into the new sensor material. Electrodes in the sensor determine the ammonia concentration.

These sensors are less prone to false alarms than typical solid-state sensors. (IRC 2002) This technology can operate in conditions from -45°F to $+140^{\circ}\text{F}$ and from 0% to 99% relative humidity. The response time of this sensor is about ten seconds. The probability of nuisance alarms increases in the 15 ppm to 35 ppm range because of the detection limits of this technology. (IRC, 2002) These units require annual calibration, and have a lifetime of five years, according to a manufacturer.

Solid-state

Solid-state sensors are typically made with a sensing material composed of a metal oxide and a catalyst. (Figure 4) The conductivity of this material changes in the presence of ammonia gas. The sensing material will absorb an amount of ammonia gas proportional to the concentration present; once the ammonia concentration decreases, the ammonia desorbs out of the material.

In general, background gases may interfere with these sensors, but installing filters on the sensing element can minimize this interference. Because the solid-state sensor is not consumed in the ammonia detection process, these sensors last at least five years. (IRC, 2002) They require calibration every six to eight months, and this may be done in the field.

Infrared

The principle underlying infrared (IR) technology is the characteristic of each gas to absorb IR at a particular frequency. IR sensors contain a chamber with an IR source at one end and an IR detector at the other. Any ammonia gas present in the chamber will absorb a particular IR wavelength. The IR detector measures the amount of IR getting through at that wavelength. The difference between the

strength of the wavelength received and the strength of the wavelength emitted is the amount of IR absorbed by the gas. The ratio between these IR received and the IR emitted indicates the gas concentration. (Figure 5)

Infrared sensors are very ammonia-specific, and therefore have low cross-sensitivity to other materials. Another strength of this type of sensor is its ability to detect high concentrations (1-2%). Some manufacturers recommend that its lower setpoint be set to sense at 5,000 ppm. (IRC, 2002) The technology tends to be fairly expensive compared to other technologies, and should typically be used in high concentrations. (Table 2).

Conclusion

With so many ammonia-sensing technologies in the market today, it is important to choose the optimal sensor for your application. Consider all the relevant factors for your application, including the concentration range to be measured, environmental conditions, background gases that may interfere with the sensor, reliability of the sensor, calibration schedule, and lifetime cost.

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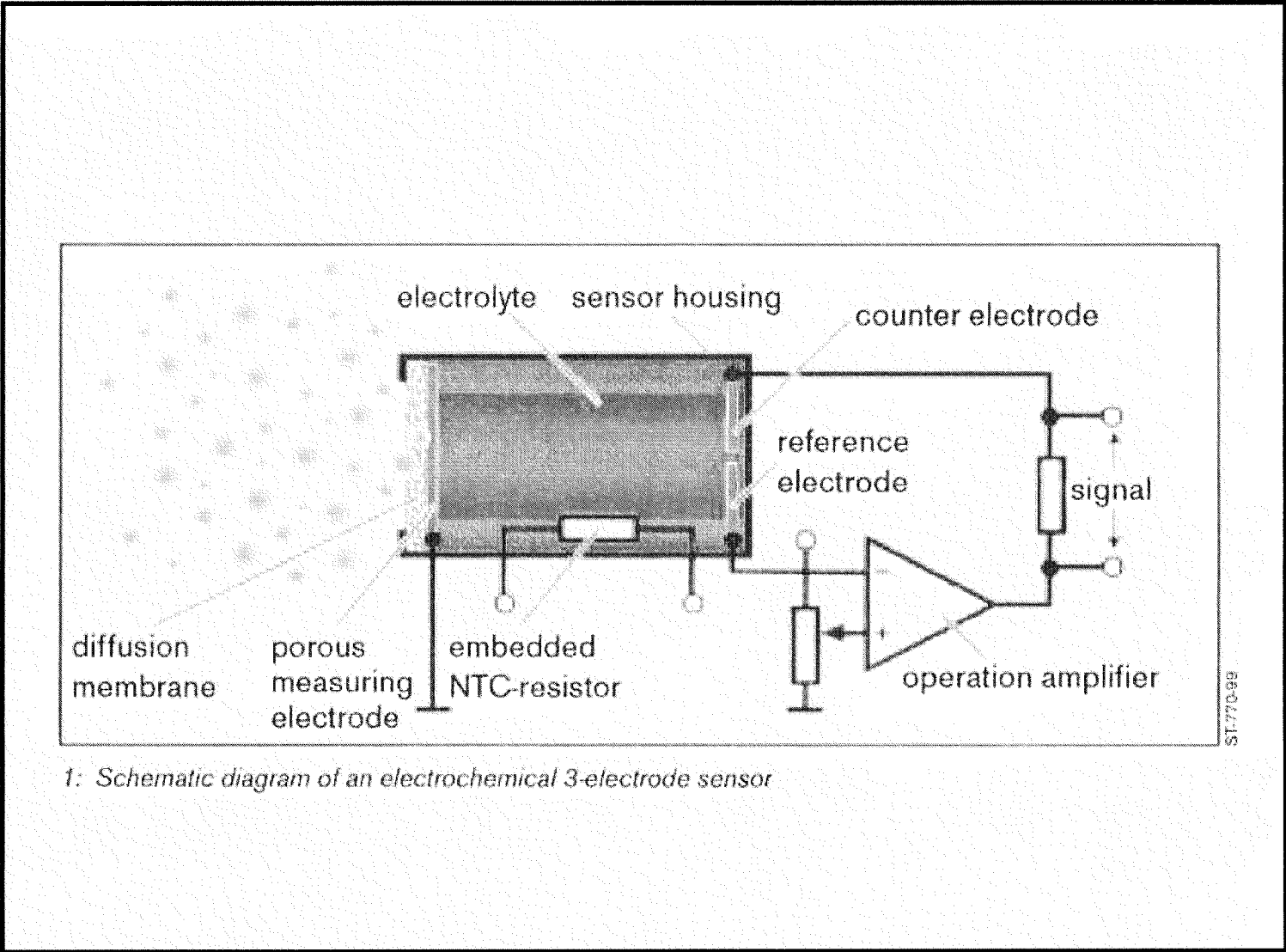
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Figure 1: Electrochemical Cell



1: Schematic diagram of an electrochemical 3-electrode sensor

Figure 2: Polymer Thin Film Sensor

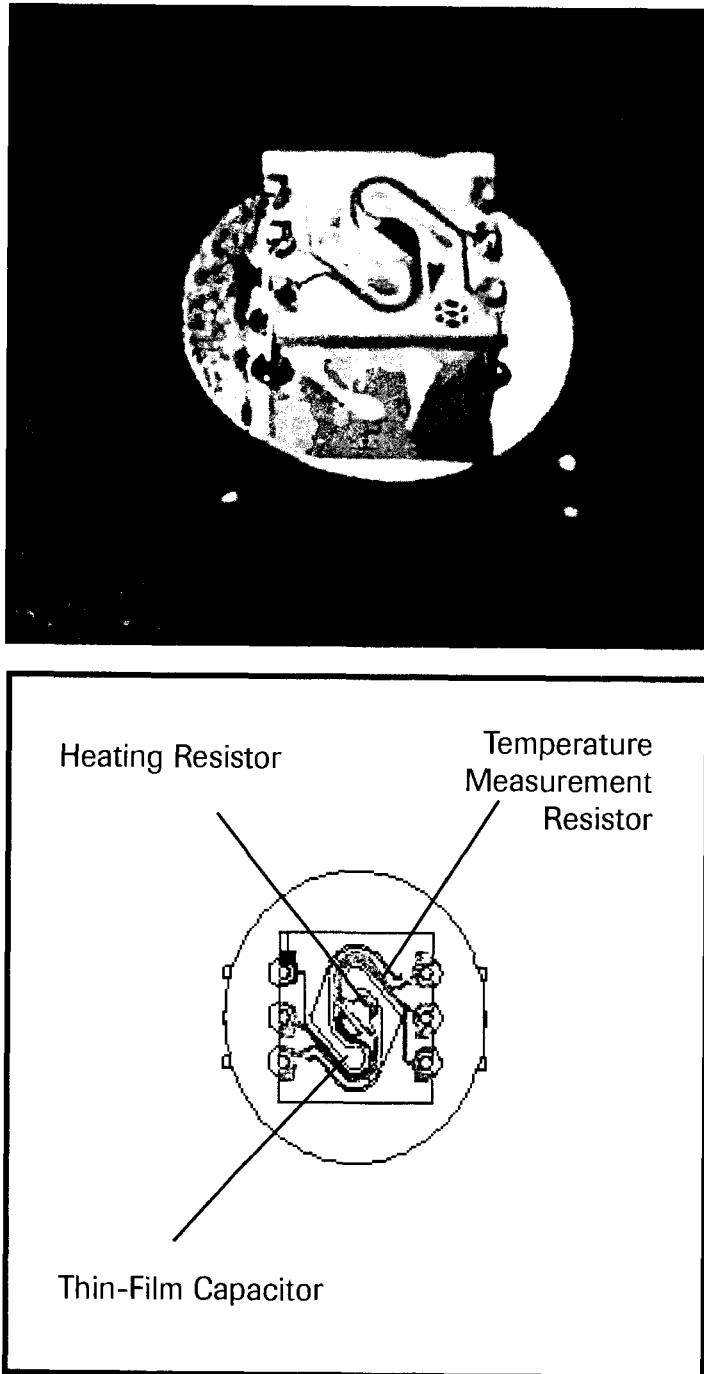


Figure 3: Hysteresis of Polymer Thin Film Sensor

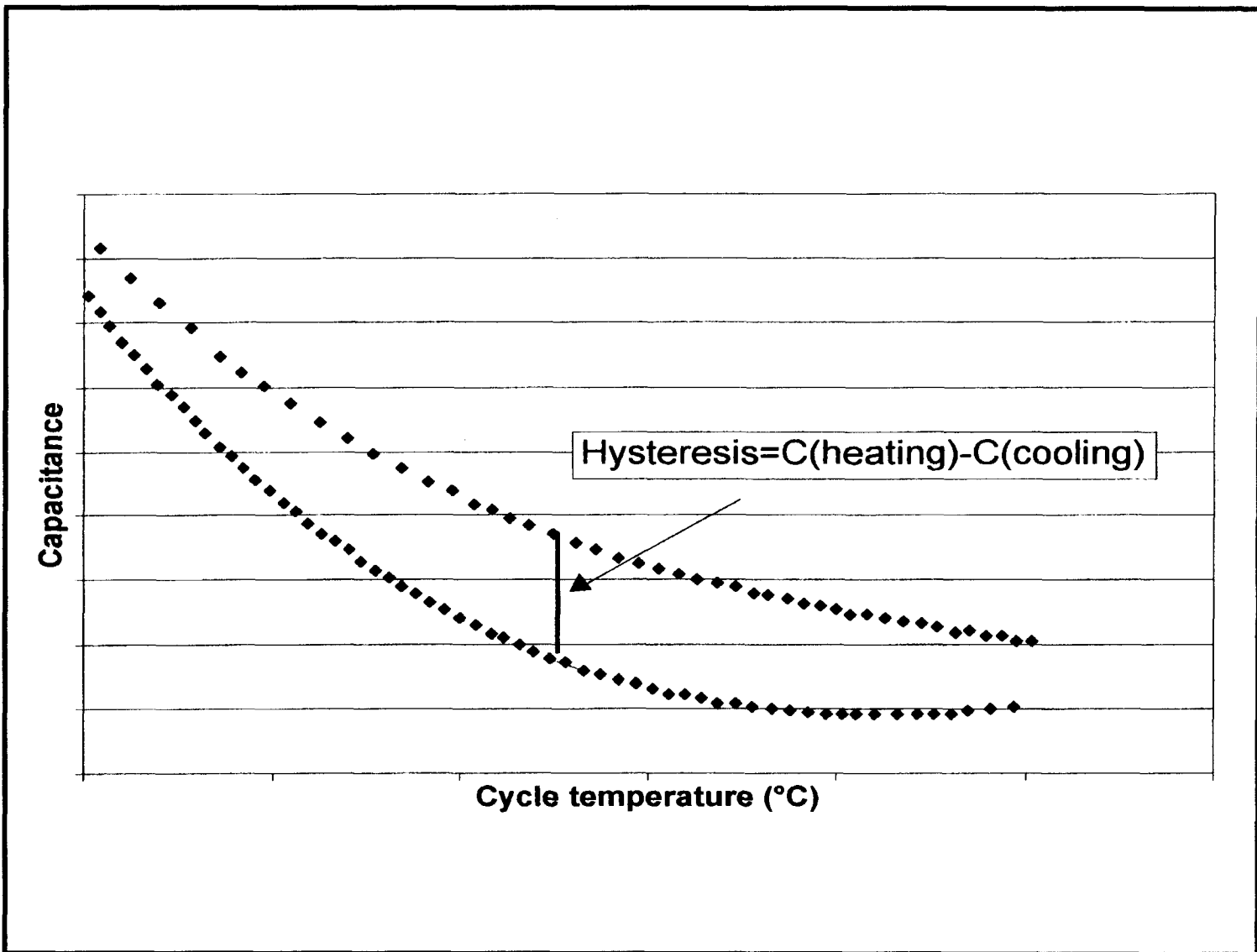


Figure 4: Solid State Sensor

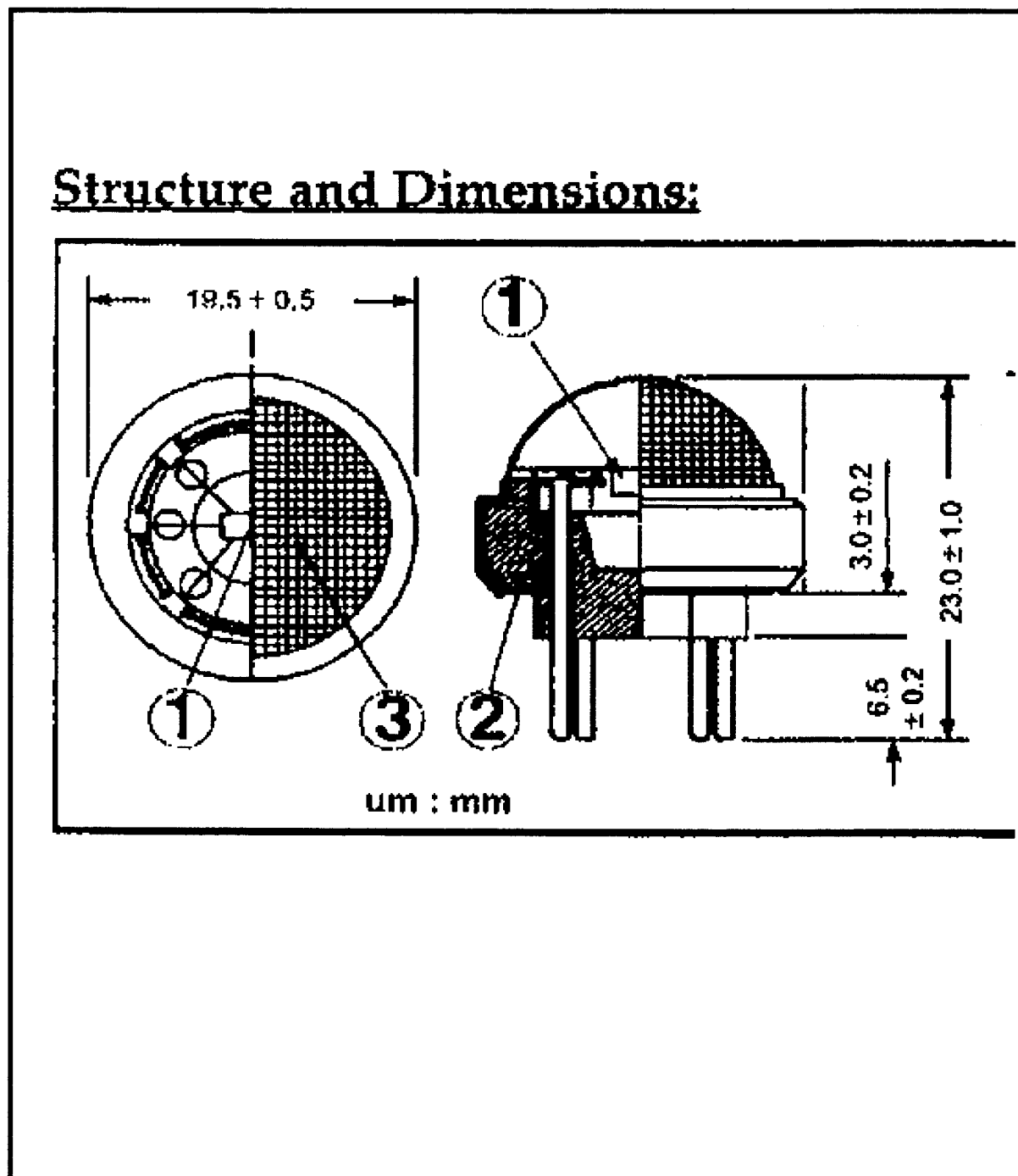


Figure 5: Infrared Sensor

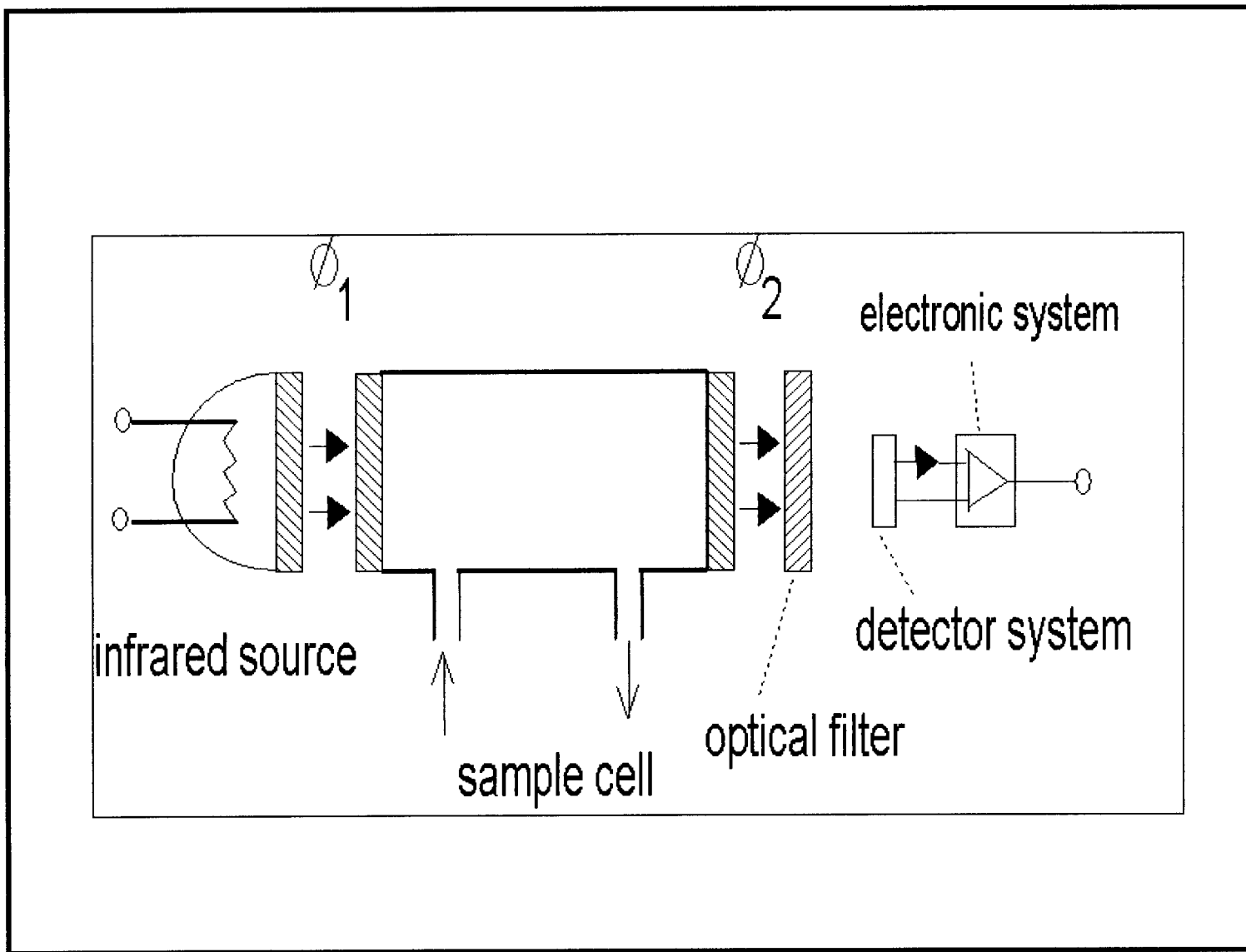


Table 1: Anhydrous Ammonia Exposure Effects

| Vapor Concentration (ppm) | Effects | Exposure Period/ Comments |
|----------------------------------|---|--|
| 5 – 10 ppm | Odor threshold | Continuous |
| 25 ppm | Noticeable odor | NIOSH Recommended Exposure Limit for an 8 hr time weighted average |
| 35 ppm | Odorous | NIOSH short-term Exposure Limit for a 15 min. max. exposure |
| 50 ppm | Unpleasant Odor | OSHA Permissible Exposure Limit |
| 100 ppm | Strong Odor | Any Exposure Period |
| 150 ppm | Very strong odor | 50% of the IDLH concentration |
| 300 ppm | Overpowering odor | Immediately Dangerous to Life & Health (IDLH) |
| 400 ppm | Major throat irritation | Ordinarily, no serious results following short exposures |
| 1700 ppm | Convulsive coughing | No exposure permissible (may be fatal < 1/2 hr) |
| 5,000 ppm | Respiratory spasms, strangulation, asphyxia | No exposure permissible (rapidly fatal) |
| 15,000 ppm | Burns & blisters skin | Rapidly fatal |

Table 2: Ammonia Sensor Technology Comparison

| | Temperature | Humidity Range(non-condensing) | Accuracy | Response Time (seconds) | Typical Range) (ppm) | Calibration Interval (months) | Life time of Sensor (years) |
|---------------------------------|-------------|--------------------------------|-------------------------|-------------------------|----------------------|-------------------------------|-----------------------------|
| Electrochemical Sensor | -40...150F | 5-95% | +/- 5% fullscale | < 30 | 0-1000 | 6 | 1-3 |
| Solid State Sensor | -40...150F | 0-95% | +/- 3% full scale | < 30 | 0-10000 | 6-12 | 5-7 |
| Infrared | -40...150F | 0-90% | +/- 5% full scale | < 90 | 0-20000 | 6 | 8-10 |
| Charge Carrier Injection | -45...140F | 0-99% | +/-10% reading | < 10 | 20 - 30000 | 12 | 5 |
| Polymer Thin Film | -40...140F | 0-100% | +/- 10ppm + 20% reading | < 90 | 0-1000 | 12 | 3-5 |

