Reference : Spearpoint M J. Fire detection. New Zealand Science Teacher, No. 117, pp.14-16. 2008.

Fire detection

Technology provides many ways in which we can detect the presence of fire as *Michael Spearpoint*, Department of Civil and Natural Resources Engineering at the University of Canterbury explains:

The ability to detect the presence of fire is a vital part of an overall fire safety strategy. Without a means of detection we are unable to alert occupants, activate many other fire safety measures or summon the fire service. Humans make very good fire detectors as we are able to feel heat, see flames, see and smell smoke and hear a fire. However, humans are not always available or reliable so we look to technology to substitute for these abilities.

This article examines the various types of technology used in modern buildings, tunnels, vehicles etc. to detect unwanted and potentially life-threatening fires. In selecting a detection system there is a need to balance responsiveness, reliability, cost and the potential for false alarms (sometimes referred to as ‘nuisance activations’) and no one type of system provides an optimum solution. The detection of fires involves a whole range of fundamental scientific principles as well as the application of advanced technological developments.

Feel heat

Humans can feel the presence of heat although our ability to discriminate small changes and survive extreme temperatures is limited. Historically, heat detection systems are the oldest technology used to detect a fire. Heat detection involves the principles of heat transfer and in particular conduction and convection processes. The melting of materials, the expansion of heated substances and the changes in the electrical properties of materials when heated have all been used as ways to detect fires.

One of the first systems to use the melting of materials to detect heat was in the invention of the automatic sprinkler system in the 1860’s. A metal solder with a low melting temperature was used to keep caps or plugs in place in a network of water filled pipes. The hot gases generated by a fire would melt the solder, allowing the caps or plugs to drop away and water to flow. The melting of eutectic metals (alloys of bismuth, cadmium, lean and tin) is still used in some forms of heat detector although the mechanism is not as common as it used to be. The majority of modern sprinkler systems use the same basic technology that was developed over the past century but the expansion of a fluid in a frangible glass bulb to release water from a sprinkler head is more prevalent than the use of a melting solder. Activation temperatures of sprinkler systems can range from 57 ˚C to over 200 ˚C and an activation temperature of 68 ˚C is common in most building installations.

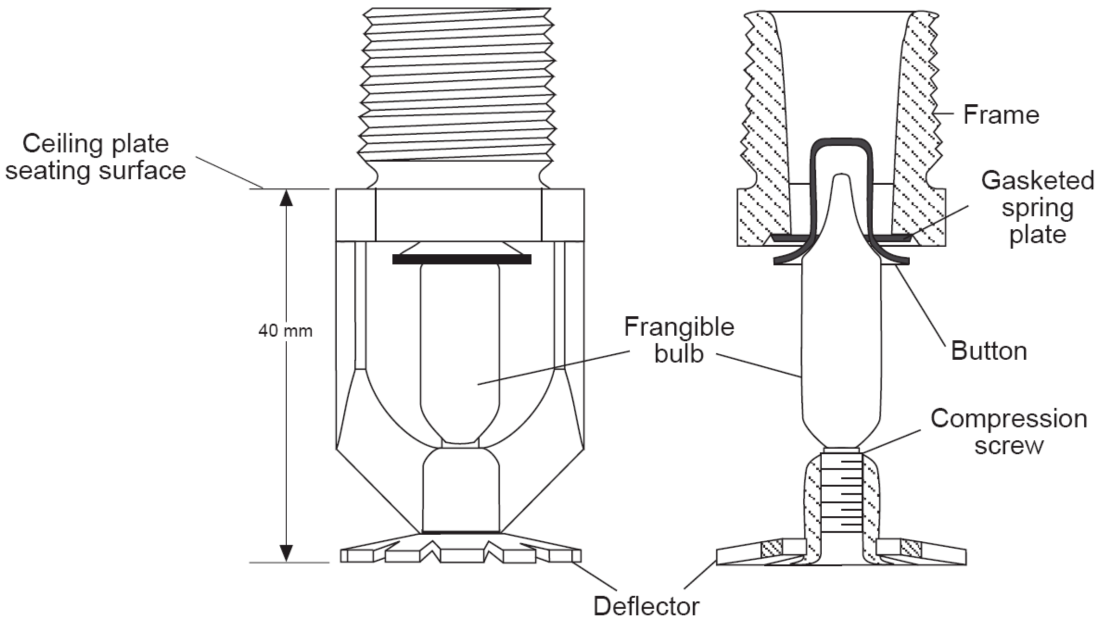

Figure 1 : Frangible bulb sprinkler head.

Heat detectors can also be used as part of an automatic fire alarm system. Older devices used the differential expansion of dissimilar metals as a bi-metallic strip or the expansion of solid conductors to make or break circuits at a fixed temperature. The expansion of a gas (i.e. air) as a response to a rise in temperature has also been used as a form of fire detection. The mechanical force on a diaphragm as part of a detection chamber can be used to close the contacts of an electrical circuit. To avoid changes in barometric pressure causing nuisance alarms if the air chamber was completely sealed, a small orifice is used to adjust for slow changes but is sized so that rapid temperature changes exceed the orifice venting rate and the pressure rises in the detection chamber. This arrangement is designed to respond when temperature rises of 7 ˚C to 8 ˚C or above occur.

More recently the capability of the electrical properties of materials to change when heated has been employed. Conductors subject to a thermal gradient generate a voltage and the voltage difference across dissimilar conductors can be used to sense a temperature change in a device known as the thermocouple. In the thermistor, the change in resistance with temperature of a generally ceramic or polymer material is used to sense a temperature change. A thermistor is often employed as the heat sensing element in a modern heat detector.

Fire detection systems are sometimes required to cover large distances such as in tunnels or in complex buildings containing large amounts of cabling. The principle of melting materials is also used here where two conducting cables are separated by a sheath which melts and creates a short circuit. Fibre optic cables have also been introduced as a fire detection device for these situations. The presence of heat from a fire alters the transmission characteristics of the cable which can be measured by a receiver and so indicate the presence of a significant temperature change.

Heat detection devices are generally reliable and cheap when compared to other technologies. They are also less likely to give nuisance activations because most day-to-day environ-mental factors are unlikely to generate sufficient heat to cause an accidental activation. However they have a relatively slow response time as the hot fire gases have to travel to the sensor. Even though heat detection systems have been around for several hundred years, advancements in our understanding of heat transfer and the application of new technologies are still being used to improve their capability.

See smoke

Humans are able to discern the characteristic behaviour of smoke that is coming from a fire although not all fires generate smoke that might be visible to the naked eye. There are various technological mechanisms which we can use to 'see' smoke and the simplest approach is to use a combination of a light transmitter and receiver to create a beam that can be obscured by the presence of smoke particles. The electrical signal generated at the receiver changes as a function of the attenuation of the beam and thus detection is achieved. A similar approach is to instead use the ability of smoke particles to scatter light from a transmitter to a receiver except in this case the electrical signal at the receiver increases with smoke concentration. A more sophisticated system uses an aspirating pump to draw smoke into a sampling pipe network and to use laser beam refraction as the means of detection. The ionisation smoke sensor uses a small radioactive source used to ionise air in a detection chamber. Two charged plates are inserted into the chamber and the ionised air molecules generate a current across the plates. If smoke particles enter the detection chamber they capture some of the ionised air molecules and reduce current. This change in current is then used to determine whether the device activates.

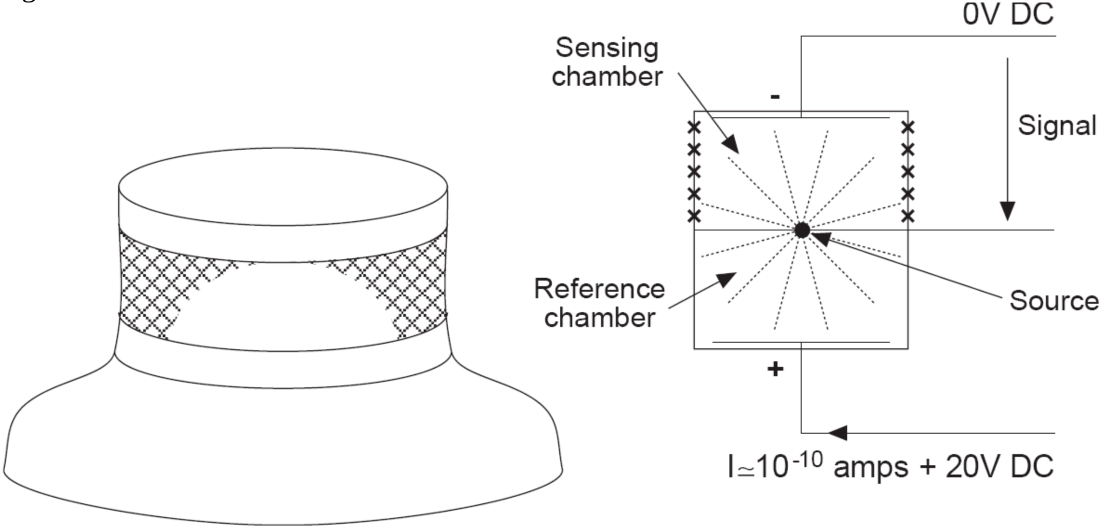

Figure 2 : Ionisation chamber smoke detector.

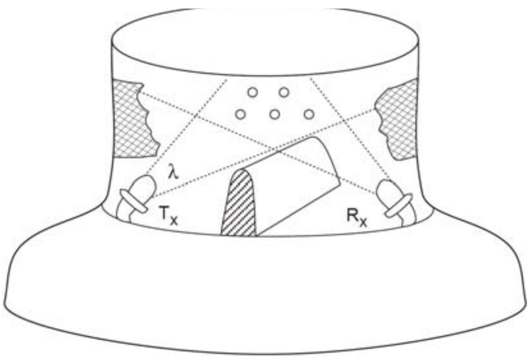

Figure 3 : Photoelectric smoke detector.

The design of smoke detectors is a complex problem as the ability to detect smoke depends not only on the concentration of smoke but its colour and particle size distribution, both of which dynamically change with the way in which a fire develops and the distance away from a fire. The fuels involved in a fire and process in which they burn also affects the characteristics of the smoke. Smouldering fires generate larger, darker smoke particulates visible to the naked eye while flaming fires generate a greater number of smaller, lighter colour particles. Smaller smoke particles can coagulate into a lesser number of larger particles as the smoke travels downstream from the fire source. Smoke detector design also has to consider temperature and humidity as well as the ease in which smoke particles can enter a detection chamber.

Smoke detection systems are relatively sensitive. Aspirating systems are highly sensitive and are used in spaces such as computer rooms. Beam systems can cover large unobstructed areas in the order of 100 m or more such as found in warehouses or shopping malls. Light scatter and ionisation detectors are relatively cheap and reliable. They are found in home smoke alarms and similar devices used in many commercial applications. Smoke detectors can also be installed in the return air ducts of heating, ventilation and air-conditioning (HVAC) systems so that smoke drawn in can be detected allowing the system to be shut-down before smoke is distributed around a building. The sensitivity of the sensors used in smoke detectors means that they are more prone to nuisance activations and they cannot easily distinguish between smoke particles or any other 'particulate' matter such as dust or steam. Ionisation sensors are not as sensitive as light scatter sensors for detecting the relatively large smoke particles produced in smouldering fires.

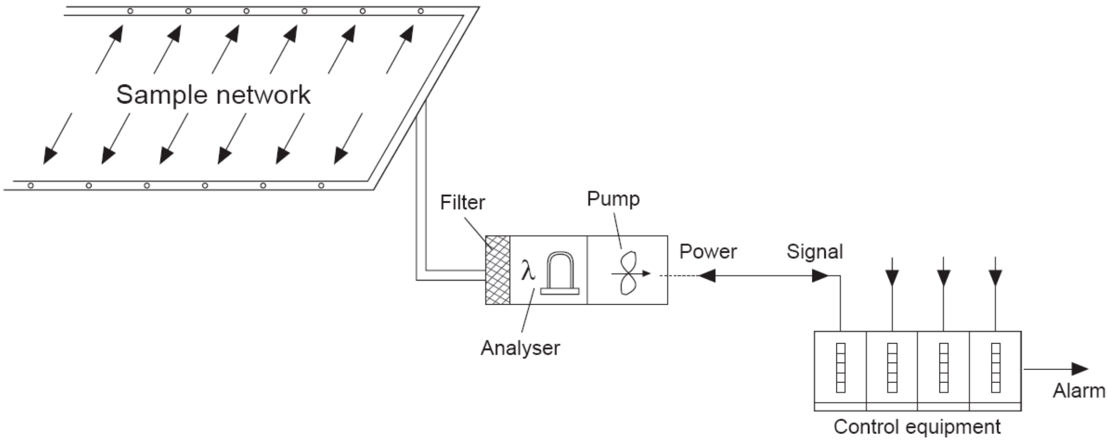

Figure 4 : Aspirating smoke detector.

Similar to heat detectors, our understanding of combustion, smoke particulate generation and the dynamics of smoke flow continues to develop which in turn improves our ability to establish the presence of a fire through smoke detection.

See flames

Technology allows us to see more of the electro-magnetic radiation spectrum than we can perceive with the naked eye and we can use this ability to detect the presence of flames. We utilise devices that have photovoltaic, solid-state or ionisable gas-filled tube elements that respond to particular regions of spectrum. Electro-magnetic radiation signals at infra-red, visible and/or ultra-violet wavelengths are normally identified and combination IR/UV devices are available.

Flame detection systems provide very rapid detection times and ideally suited to cover large high-hazard volumes such as aircraft hangers. However these systems require that there is a direct line of sight between the flames and the sensor and so they are not suited to areas in which there are a large number of obstructions. Some detectors are used in industrial applications such as timber mills where it is necessary to protect the plant from fires that might be caused by sparks travelling in ducts. Flame detectors are susceptible to nuisance activations from other electro-magnetic sources such as solar energy although good design and filtering systems can significantly reduce their likelihood.

We can also use other 'visible' characteristics of flames as a means of fire detection. It has been found that flames flicker in a 5 to 30 Hz flame frequency range and this phenomenon has been employed by some types of IR detectors. Sophisticated digital image processing using video cameras is now being used in special applications such power generation turbine halls to see flames and also see the smoke produced by a fire. Similar to some types of intruder detection systems, we could also use the change in received signal from an ultra-sonic transmitter. The device fills a protected space with a pattern of ultra-sonic waves that change when the composition of the space alters such as the presence of a flame. However, the use of ultra-sonic transmitters for fire detection is not something found in practice.

Smell smoke

Fire detection systems analogous to the human's ability to smell smoke are available although there is nothing commercially available that can replicate the complexity of the human olfactory system. There are a number gases present in fires that could be used to detect its occurrence and these include H_2O, CO, CO_2, HCl, HCN, HF, H_2S, NH_3 and various oxides of nitrogen.

Sensors for individual flammable gases or combustion products are available and they typically use a catalytic-type elements or a metal oxide semiconductor element in which the element's electrical properties change in proportion to the gas concentration. These sensors are sensitive and also often reasonably selective so that they only detect a specific gas. The devices are generally expensive when compared to other detection technologies and they may require regular maintenance or calibration. The end result is that they are normally only used for special applications such as the off-shore and petro-chemical industry. The exception to this is that carbon monoxide detectors specifically for fire safety applications are now available for the domestic and commercial market. Another gas sensing technique works in a similar way to the beam detection method for smoke except in this case a chemically treated material is placed in the path of the beam. The material undergoes a colour change when exposed to the detectable gas thus altering the electrical signal generated at a receiver.

Research has been ongoing to create artificial noses that use a combination of chemical sensors and "neural-net" software techniques to try and detect fires but this work is very difficult and has yet to produce anything that is of practical use.

Hear fire

Humans sometimes become aware of a fire by hearing unusual sounds; the catastrophic failure of the cathode ray tube in a television set is one way. Fires in themselves produce very little if any sound but changes in materials when they are heated can produce noise that might be used to detect a fire. Characteristic 'cracking' sounds in heated materials such as a wall lining might also be used to decide whether there was a fire in a neighbouring room. At present there is nothing particularly available in terms of detector technology that uses sound for its decision making although some research has been carried out investigating the sounds generated by heated materials.

Conclusion

Fire has always been a potential threat to humans (and most land-based creatures), so the ability to detect a fire is something that has been part of our evolution. There are many ways in which can use the principles of physics and chemistry to provide a technological solution to fire detection and these methods often mimic human abilities. Over the past 150 years modern fire detectors have saved many lives and prevented a great deal of property damage. Although no technology is perfect, the economic benefits of installing automatic fire detection systems in conjunction with other fire safety measures has been demonstrated many times over.

References / Suggested reading

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All diagrams sourced from Buchanan A H (ed). Fire engineering design guide (2nd ed.). Centre for Advanced Engineering of New Zealand, Christchurch, New Zealand, 2001.