

GUIDANCE ON THE USE OF NON-CERTIFIED ELECTRICAL EQUIPMENT IN LABORATORY FUME CUPBOARDS

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This paper discusses a practical approach to realistic zoning of fume cupboards and the location of equipment with regard to the zoning within the fume cupboard is considered. A methodology is provided for the examination of laboratory equipment to determine its suitability for use in a potentially explosive atmosphere. Examples are given of the examination of several pieces of common laboratory electrical equipment, illustrating the potential areas of concern, and possible solutions to reduce the risk of fire or explosion from such equipment. A method is given to enable suitably competent persons to identify whether ignition hazards exist, whether modification to the equipment is practical or whether the equipment is unsuitable for use in the proposed location.

INTRODUCTION

In the Fine Chemicals industry, there is a tendency to manufacture short runs of differing products, generally requiring some prior research using laboratory facilities. As many products use flammable solvents for their manufacture, it is inevitable that flammable liquids are handled at Laboratory scale. Whilst there is good guidance available for the classification of hazardous areas in plant-scale environments, that for laboratory-scale operations is poor or non-existent. It is often assumed that fume cupboards, being well ventilated with a large throughput of air, are classed as non-hazardous but this can be erroneous as under some conditions, particularly loss of containment, explosive atmospheres can exist in fume cupboards for protracted periods.

In this paper, the practicalities of hazardous area classification are examined, and guidance is given on considering the location of equipment within a fume cupboard to minimise the risk of ignition of any explosive atmosphere that may exist. As little laboratory equipment is available which is certified as suitable for use in hazardous areas, a methodology for the examination of laboratory equipment is given, to determine whether the equipment can be classed as "unsuitable" for use in a hazardous area, or whether it can be classed as "not unsuitable". This is not an attempt at self-certifying equipment, and a clear distinction has to be understood in the definition of the term "unsuitable" and "not unsuitable". The former means what it says on the tin – it is definitely unsuitable for use in a potentially explosive atmosphere as there would be obvious parts of the equipment which would constitute a potential or permanent source of ignition. The term "not unsuitable" means that whilst it is not certified for use in a explosive atmosphere, it has been examined and there are no obvious indications that it would be a source of ignition if it were to be exposed to a explosive atmosphere. Three examples of the methodology are given to illustrate its application.

EXISTING STANDARDS

There are two well established standards for the classification of hazardous areas - the European Standard BS EN 60079-10:2003 (BSI, 2003) and the Institute of Energy Code of Practice Part 15 (Institute of Energy, 2005). Both of these standards are intended for industrial situations, rather than laboratory situations. However, each does include a small section giving advice for laboratory situations.

The European Standard BS EN 60079-10:2003 is aimed at large-scale industrial areas, and in Section 4.2, it suggests that if the inventory of flammable material is "small", then the methodology laid down in the standard may be inappropriate. Unfortunately, it does not define the quantity that would be considered as "small". Therefore it could be inferred from this statement that for a laboratory handling a few litres of flammable materials, no area classification would be required. The Institute of Energy guidance suggests that for laboratories and small-scale users where the inventory is less than 25 litres, the area can be classified as non-hazardous if it is well ventilated. Since there is no definition of "well ventilated" in the standard, it would be unwise to indiscriminately adopt a non-hazardous classification where the inventory is less than 25 litres.

From the first of these two standards, it would seem that a laboratory fume cupboard would not require an area classification exercise to be carried out, and that such a fume cupboard would be non-hazardous. From the second, it could be argued that since the inventory is less than 25 litres, and a fume cupboard is well ventilated, again the area could be classified as non-hazardous. A typical laboratory fume cupboard is illustrated in Figure 1.

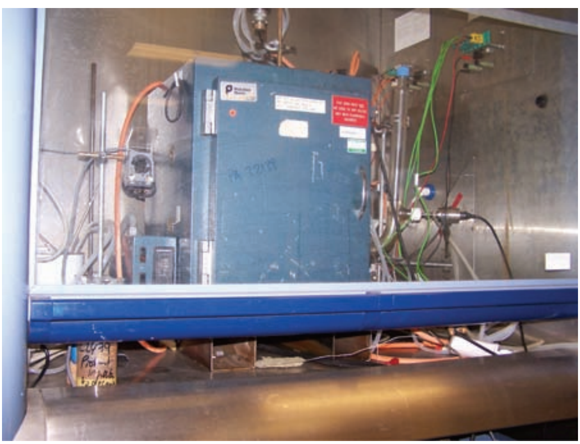

Figure 1. A typical fume cupboard containing equipment

Whilst it is possible for the methodology of the European Standard BS EN 60079-10:2003 to be applied to a fume cupboard, it would be necessary to be able to estimate release rates of any flammable vapours or gases to be able to determine the extent of any hazardous areas. Although typical releases such as vapour emanating from a boiling flask without a condenser can be determined from the heat input, it would be difficult to calculate a release rate for the foreseeable event of total loss of containment – the gross spillage of the contents of a beaker or flask. Consequently, the application of the method of European Standard BS EN 60079-10:2003 to a small laboratory fume cupboard is fraught with difficulty.

However, if the fume cupboard is classified as non-hazardous, the corollary is that sources of ignition would be acceptable. Clearly it would seem unacceptable to have a lit Bunsen burner in a fume cupboard containing a flask full of boiling solvent, so therefore good sense suggests that a fume cupboard containing solvents should at least have some sort of area classification exercise undertaken to establish the hazards present and the risk of an ignition occurring.

ZONING OF FUME CUPBOARDS

Whilst the above would suggest that fume cupboards are non-hazardous, this is far from realistic. Whilst a small enclosed process is being operated, this may be the case, but when the process is started or completed, the reality is one where spillages can occur quite easily. In the case of a spillage of flammable solvent, there is a considerable time whilst the solvent evaporates, and hence an explosive atmosphere will be present. In practice, the following need to be considered:

LARGE SCALE

Where the inventory is of a scale larger than about 5 litres, a walk-in type of fume cupboard in a pilot-scale laboratory would be more appropriate than a standard fume cupboard, and typically for such large-scale equipment, suitably certified electrical equipment is available and therefore should be used. Clearly the scale is such that it would be appropriate to use the methodology of BS EN 60079: Part 10, and further discussion is not necessary in this paper.

BENCH SCALE

This is more typical of a standard laboratory fume cupboard as illustrated in Figure 1. This is rather too small to be considered for treatment using the methodology of BS EN 60079: Part 10, and an alternative approach is required. Whilst it is easy to dismiss the risk of explosive atmospheres occurring as being insignificant or of being a trivial size, in practice, care is required to determine the likelihood of flammable material existing in the fume cupboard whilst not contained within the equipment. Operations such as pouring liquids into flasks, filtering, emptying equipment and cleaning out afterwards can all expect to form explosive atmospheres under normal and foreseeable circumstances. Clearly for very small inventories such as less than 1 gram, the extent and duration of any explosive atmosphere in a well-ventilated fume cupboard will be negligible.

VENTILATION QUALITY AND RELIABILITY

In most fume cupboards, the extraction rate is determined more by the need to maintain a minimum face velocity to prevent the escape of material from the cupboard than the dilution of emitted gases or vapours. However, for a typical face velocity of 1 m s^{-1}, and an access opening of 300 mm over a 1 m wide fume cupboard, the air throughput amounts to 0.3 m^3s^{-1}, which would safety dilute to less than 0.25% an evolved vapour rate of 0.075 m^3s^{-1}, which is far in excess of that likely to be released by an experiment which was considered safe to be undertaken within a standard laboratory fume cupboard. Where larger-than-bench scale experiments are to be undertaken, an alternative containment method may be required, and this is discussed briefly later.

The reliability of the ventilation also needs to be considered. Where an extraction system has a standby fan with automatic change-over on failure, the extraction can be deemed reliable, but where there is no standby, or the site is on an electricity supply with a known high rate of loss of power, then the reliability should be considered as low. In this case, consideration should be given to the use of standby supplies, automatic shut-offs for the experimental equipment and standby emergency cooling.

INVENTORIES

Gases present a particular hazard, as many flammable gases are heavy and spread along level surfaces, so explosive atmospheres at the base of the fume cupboard can easily form. Unless the gases are released during the experiment, they are often piped into the fume cupboard, and therefore the inventory is only limited by the supply, be it a cylinder external to the fume cupboard or natural gas piped in from the gas mains. Hydrogen and any other light gases present a hazard towards the top of the cupboard as they can accumulate in the top of the cupboard. Therefore the lighting needs to be either separate from the cupboard (such as shining through sealed glass partitions) or be suitably certified for the gases present.

Liquids present the greatest risk if spillage or other loss of containment occurs. If the liquid is above its flash point, then any spillage will accumulate on the base of the cupboard, and form a large pool which readily evaporates. Liquids approaching the boiling point will evaporate quickly initially until cooled by the base of the fume cupboard. Clearly immediately above the liquid surface, the atmosphere will be substantially pure vapour, but as the air flow through the cupboard mixes with the vapour, the concentration of the vapour will pass from over-rich, through stoichiometric, and the lower explosive limit, before being diluted to be non-explosive. This occurs over a relatively narrow height, so the base of the fume cupboard should therefore be classified probably as a Zone 1 area. Some estimate of the depth of the explosive zone can be gleaned from Hughes (1970) quoted by Lees (1996), who suggests that for spillage of 1 litre of petrol onto the ground resulted in explosive atmospheres being formed at least 6 m away, but the height of the explosive atmosphere was only a few centimetres.

Vapours present the same potential problems as gases, but can condense and form liquid pools, so both scenarios would have to be taken into account. Evaporation rates from small pools of liquid was investigated by Clancy (1974), and this may be used for small-scale spills such as occur in fume cupboards. There are alternative commercial software packages for modelling pool spread from spillages, but most are concerned with industrial scale quantities of a tonne upwards.

RELEASES

Any flammable releases of a continuous nature will be diluted constantly with the air flowing through the fume cupboard. Clearly if the vapour is pure, the concentration immediately around the point of release will be non-explosive as it is above the upper limit. Since there is an imposed flow through the fume cupboard, the vapour disperse and mixes with the air passing through the fume cupboard, and so the theoretical explosive zone will be a right circular cone extending from the point of release towards the rear extraction vent of the fume cupboard. The cone will be truncated at the base when it reaches the lower explosive limit. The volume of this zone (and hence its length) will depend on the dilution by the airflow. Since the airflow is usually much larger than the release rate, the resultant zone would be of negligible extent. However, sudden releases such as loss of containment or failure of a condenser will result in much larger zones. In practice, the zone is unlikely to be a cone - in fact due to the turbulence, the conical zone will vary in size, shape and location, and so an assumption will have to made on the likely size and approximate locations where it could be.

EQUIPMENT INSIDE FUME CUPBOARDS AND AIRFLOW MODIFICATION

The quality of the ventilation is difficult to determine in practice. Whilst it is simple to determine the total air flow through any one fume cupboard, the distribution of air within that fume cupboard is not straightforward. An empty fume cupboard behaves aerodynamically differently from one that is filled with equipment. Looking at the fume cupboard in Figure 1, it can be seen that the air flow will not be as designed with the cupboard empty. With the sash at the bottom in the normal position, the air enters through a horizontal slot, and passes through the cupboard to the rear, where it is extracted at both the top and bottom. Hence the air flow along the base of the cupboard is particularly prone to disturbance. The more equipment that is installed, the greater the air velocity through the remaining volume of the cupboard. Hence it is necessary to ensure that equipment is installed in a position where the airflow is disturbed as little as possible. This means locating it as centrally as possible, so it is not close to the front air inlet, the sides, or too close to the extraction points at the rear.

In Figure 1, it can be seen that the oven has been positioned on square hollow sections passing from front to rear, to allow the airflow to be disturbed as little as possible.

These are sometimes referred to as "technical bricks" as they do not impede the air flow to the same extent as a normal brick would do. Consequently, it is best to ensure that any equipment containing a potential ignition source is installed within fume cupboards in a position such that it is neither on the base nor at the top, and ideally it should be mid-way between the front and rear of the fume cupboard, so that any leakage of flammable vapours or gases will be carried towards the rear extraction port of the fume cupboard.

LABORATORY ELECTRICAL EQUIPMENT AND NON-CERTIFIED EQUIPMENT

Where electrical equipment is available in a certified form that is suitable for use in potentially explosive atmospheres, then this must be used. This applies even if the equipment is only available on a long delivery or is very expensive – cost or time cannot be used as mitigating circumstances for not using such equipment. If such equipment is not available, then the only choice is to asses the risk of the equipment that is available to be a potential source of ignition.

This is not an attempt to self-certify equipment as meeting the requirements of any standards for electrical equipment for use in explosive atmospheres, but is merely a methodology to examine the equipment to reject that equipment which has obvious potential ignition sources. This examination should be undertaken by a competent person, and not delegated to the Portable Apparatus Inspector, who is very unlikely to understand the hazards and risks involved. If necessary, both an Electrical Engineer and a person skilled in the art of Area Classification should examine the equipment together and come to an agreement on its suitability.

ITEMS PRESENTING RISK OF IGNITION

ELECTRICAL POWER SWITCHES AND INPUT CONNECTIONS

Any type of switch or connection that is likely to carry a heavy current or a high voltage will present a risk of arcing and the potential to ignite an explosive atmosphere. Where there is the potential for switches to be operated, the switch may be fitted with a small cover to prevent its inadvertent operation. Similarly, where mains connections are made using IEC-320 C14 appliance inlets, a simple clip can be fitted to prevent the withdrawal of the mains lead, as shown in Figure 2. The use of multi-way mains power distribution boards should be avoided within fume cupboards, as the switches can be operated inadvertently. Some types even have overload cut-outs which also could produce sparking, so boards of this type should not be used within fume cupboards.

MOTORS

These are often used in fume cupboards to drive stirrers, small pumps etc. As there are many types of motors used in laboratories, it is difficult to be specific, but there are several

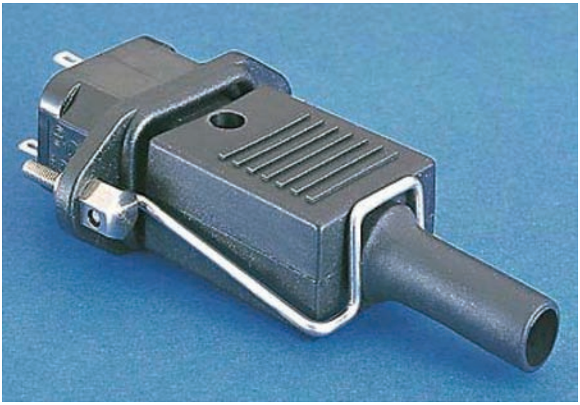

Figure 2. Clip to prevent withdrawal of mains lead (Courtesy of Bulgin components plc)

generic types most commonly seen in laboratory equipment. Small motors can be classified into three categories depending on their likelihood of sparking. These are:

- Types which do not spark under normal use, which include three-phase motors, permanent capacitor motors, stepper motors and shaded pole motors.
- Types which spark when starting, which include single-phase split-phase induction motors and capacitor start motors.
- Types prone to continuous sparking, which include motors with brushes and commutators or slip-rings.

Clearly, motors in the latter two categories would be unsuitable for use in a fume cupboard where an explosive atmosphere could exist. Where is it difficult to identify the type of motor, two series of articles describing different types of small motors were written many years ago by Philpott (1944) and Watts (1951), and include photographs and descriptions of the salient points to allow ready identification of small motor types. The later types of stepper motors are not described by these authors, but are recognisable by the use of a 4, 6 or 8 lead flat ribbon cable and a tendency to "cogging" when rotated by hand as the rotor aligns itself with the magnets within the motor.

As all motors tend to run hot, the maximum temperature that could be expected for the motor windings can be inferred from the motor temperature classification, as described in an IEC Standard (IEC, 1984). Typical temperature classes are given in Table 1 below. Note that sometimes a motor known to be used for short periods only may exceed the maximum service temperature determined by the insulation class. This is because the insulation class is selected to ensure a satisfactory service life assuming continuous isothermal operation. Some motors are also fitted with a re-settable thermal overload trip which would spark when opening under overload, and this can be identified by the reset button on the motor frame.

Table 1. Thermal classes according to IEC 85 (1984)

Thermal class	Temperature, °C
A	105
E	120
B	130
F	155
H	180

HEATERS AND OVENS

Where heating elements are used, there are two types that need to be considered. Firstly, there are those with essentially exposed elements which may well be coiled and supported in a ceramic insulation frame (similar to an electric toaster). Heaters of this type are the classic "Isomantle®" heater for round-bottomed flasks. In general, with electric heaters, the power input is constant, and the surface temperature will rise until it can dissipate all the input power. For a classic "Isomantle®" type of heater used to boil a small flask, the liquid level in the flask will slowly fall as the contents evaporate, and so the heat absorption capacity of the flask will diminish. As the power input is constant, the temperature of the element not in thermal contact with the flask's contents will rise, and may become red hot, thus acting as a potential ignition source.

Secondly, there are sheathed elements such as the mineral insulated heating elements as used on electric cooker hobs. The sheathed elements can also run red hot, but some are in such close contact with a large heat sink that their surface temperature may well be restricted simply by the extensive heat sink attached to them. A contact thermocouple or thermal imaging camera can be used to determine the maximum surface temperature. Providing that the maximum surface temperature does not exceed the autoignition temperature of the gases or vapours that are present, there is little risk of ignition. Where hot surfaces are present and are not enclosed, a higher surface temperature may be permissible as autoignition temperature determinations are carried out using enclosed volumes. Further information on the effect of volume on autoignition temperature is given by Coffee (1979).

Ovens present a different problem. Where an oven has no circulating fan and relies on convective heat transfer, the temperature of the heating element may reach red heat. This type of oven is likely to ignite any solvents which may be evaporated from the item being heated, and therefore should not be used. Where the oven is used for isothermal experiments, there is usually a circulating fan which circulates the air through the oven, and over the heating elements. This prevents the element surface temperature from reaching a high value under normal operation. For low power density elements, it may acceptable to use such an oven, providing that the oven is fitted with ventilation to allow solvent vapours to disperse. However, unless the maximum surface temperature is kept low, the same problem of potential ignition of vapours will exist.

In all types of electric heating, the control system requires some examination. Where the control is on and off using a classic thermostat, then the contacts are likely to spark, and such a controller should be located outside the fume cupboard. Where the control is electronic, then the controller may be satisfactory, providing the examination is acceptable as described above. There is also a need to check whether there is an over-temperature trip fitted within the heating system. This may be inaccessible and of the non-resettable thermal fuse type, in which case the heater manufacturer should be asked whether such a device is fitted. Otherwise, standard thermostats may be used as "policemen" in heaters, and these are likely to spark under over-temperature conditions.

RISK REDUCTION BY LOCATION

Location of equipment can play a significant part in risk reduction. Sometimes equipment does not actually need to be located within a fume cupboard - it is often just common practice that it is. An example of this is where a vacuum pump is located within the fume cupboard because of the potential of discharge of noxious materials from the outlet, but the simple modification of adding a flexible hose to the outlet and placing the open end within the fume cupboard with the pump outside is easy. Similarly, heating and cooling systems which circulate a heat transfer liquid are usually located within the fume cupboard as this reduces the length of tubing required to connect to the experimental equipment – but it could be relocated outside, standing on a suitable support so that the increase in tubing length is minimised.

OTHER POTENTIAL IGNITION SOURCES

Apart from electrostatic brush discharges from plastic equipment, there is the potential for frictional heating and impact sparks. Whilst the power, speed and load of much laboratory equipment is usually very small, and therefore unlikely to give rise to frictional heating (Hawksworth et al, 2004), consideration should be given to the potential for this to occur under abnormal conditions. For example, high speed laboratory grinding mills often run at speeds in excess of 8,000 rpm, and the stored energy of the rotor at such speeds can be sufficient to heat up small parts should the mill become choked. Other electrical equipment such as floor polishers and vacuum cleaners may be used in the vicinity of fume cupboards, and their use should be restricted to appropriate locations. If a torch is to be used in a fume cupboard, then an appropriately certified one should be used.

ITEMS NOT PRESENTING A RISK OF IGNITION

ELECTRONIC CIRCUITS AND COMPONENTS

In general, electronic circuits using solid state components exhibit a low risk of ignition. However, items such as resistors can run very hot, but as the surface area is relatively small, ignition is unlikely unless the resistor is enclosed in a small volume where there is little air flow. Whilst there is guidance on the risk of ignition from electronic circuits available in the European Standard EN 50020, (BSI, 1994), the main aspect of inspecting equipment is to identify any obvious high temperature large resistors or high current printed circuit boards.

Keyboards and keypads are often present on electronic laboratory equipment. The common types are membrane switches where there is a smooth plastic film over the keypad area and the keys are sealed within this to prevent water ingress; and computer type keyboards with individual keys. As both these types usually only handle low voltages and currents, typically less than 5 volts and less than 10 mA, they pose little risk of an incendive spark occurring. However, the membrane type may have an insulating plastic membrane which could become electrostatically charged, so the safety of this should be confirmed with published criteria (CENELEC, 2003).

Active electronic components such as transistors, thyristors, integrated circuits etc generally have a maximum operating temperature of about 150°C to avoid destruction of the silicon die within the encapsulation package, so the external temperature will always be less than 150°C. Passive components such as capacitors and inductors generally store energy, and therefore any mechanical switches associated with such components may well generate incendive sparks even though the circuit voltages and currents are low. Inductances can be identified by the core material, commonly steel laminations and ferrite pot cores. Capacitors can be identified by their physical size.

OTHER EQUIPMENT

This includes equipment not normally considered laboratory equipment. Typical examples include pocket calculators, personal data assistants (PDAs), MP3 players and other entertainment devices. Although such personal entertainment devices should not be present, many do find their way into laboratories, but the risk of ignition is low from solid state devices. However, motor driven CD players and cassette tape players may present a risk of ignition and appropriate controls should be put in place to prevent their use in and around fume cupboards.

EXAMPLE ASSESSMENTS OF EQUIPMENT

LABORATORY STIRRER MOTOR

A stirrer motor is shown in Figure 3, and this has been opened to reveal the type of motor. The speed variation is mechanical, and the motor has six leads, two for the main winding, two for the auxiliary winding, and the remaining two are for a thermistor sensor embedded in the windings for overload protection. Inspection of the printed circuit shows a large capacitor and a triac, so the motor is a permanent capacitor type and therefore non-sparking. The thermistor is wired to the triac in series with the supply, so that if the thermistor becomes hot, it inhibits firing of the triac and so cuts off the supply. Again, this is non-sparking so can be deemed acceptable for use in a fume cupboard.

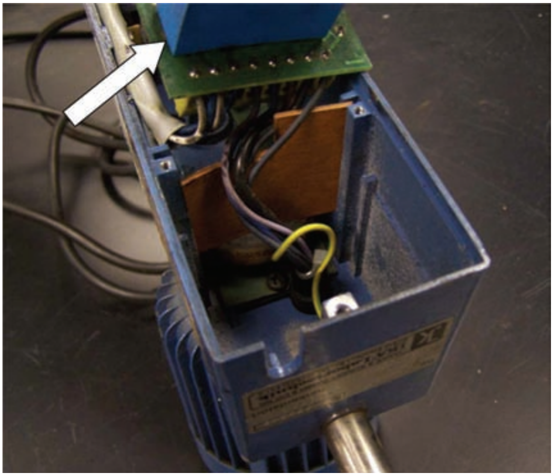

Figure 3. Internal view of stirrer motor showing six motor leads and capacitor (arrowed)

LABORATORY HOTPLATE

This is shown in Figure 4. Examination of the heating element shows that it is embedded in the metal plate, and therefore in good thermal contact, so there is little risk of hotspots occurring. The main temperature control is by thermocouple used to fire a triac to control the temperature. This control system does not have any sparking contacts, so it acceptable.

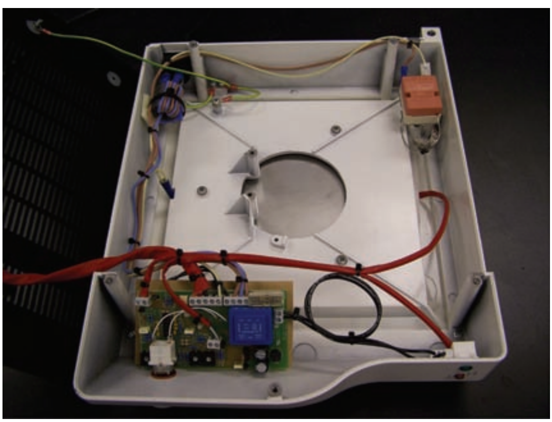

Figure 4. Hotplate showing thermal cut-out (arrowed)

However, the hotplate is fitted with a thermostatic "policeman" (arrowed) to cut off the supply if the thermocouple or triac controller fails. This type is an open snap type thermostat and will spark if it operates. Therefore this type of hotplate is probably unsuitable for use in the fume cupboard, particularly if located at the base of the cupboard where an explosive atmosphere could be anticipated.

ROTARY EVAPORATOR

In this piece of equipment, there is not only the heated water bath to consider, but also the variable speed motor. The hot water bath is similar to the hotplate above, but since there is no open-frame thermostat, this is acceptable. Removal of the cover as in Figure 5 shows that this is an induction motor, with a computer-style cooling fan. The cooling fan is powered by a solid-state switched three-phase motor with all the electronics encapsulated, so this will not give rise to sparks. Similarly, the main drive induction motor has no sparking contacts. Since there are only three wires to the main motor windings, it is a permanent capacitor two-phase motor, and is driven from a variable frequency supply with feedback from a speed sensor (arrowed). As the cooling fan operates at full speed all the time, the main motor has adequate cooling at low speeds.

AUTOMATIC CUT-OFF CONSIDERATIONS

Where loss of ventilation could result in the accumulation of flammable vapours, consideration should be given to the use of automatic cut-outs, mounted externally to the fume cupboard, to shut down the experiment safely. Typical shut-offs would include solenoid

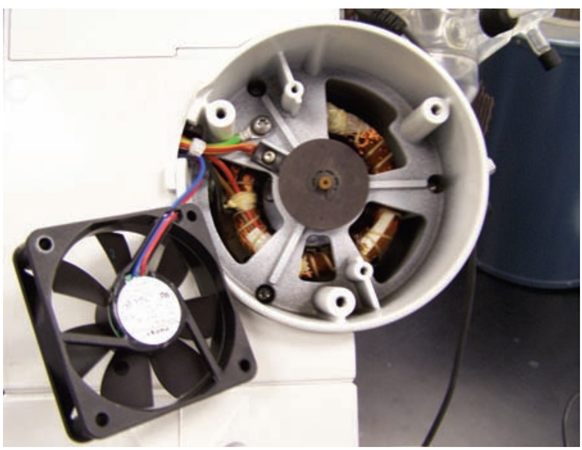

Figure 5. Rotary evaporator motor and cooling fan, showing speed sensor (arrowed)

valves to shut off gas feeds, stopping feed pumps adding reagents and shutting off heater supplies. However, care should be taken to ensure that the cut-off does not revert to a hazardous condition. For example, shutting off a chiller unit used to cool an exothermic reaction would result in loss of cooling and a potential reaction runaway.

CONCLUSIONS

- The Area Classification Standards are not directly applicable to laboratory fume cupboards.
- Laboratory fume cupboards are should not be classified as non-hazardous.
- The most appropriate zoning for heavier-than-air vapours and gases would be that the bottom 100 mm of a fume cupboard should be classed as Zone 1 or Zone 2, with the remainder either Zone 2 or non-hazardous, depending on the inventory and equipment in use.
- The most appropriate zoning for lighter-than-air vapours and gases would be that the top 100 mm of a fume cupboard should be classed as Zone 1 or Zone 2, with the remainder either Zone 2 or non-hazardous, depending on the inventory and equipment in use.
- Where suitably certified electrical equipment is available, it should be used.
- Where no certified equipment is available, any electrical equipment to be used in fume cupboards should be examined to determine whether there is a risk of the equipment becoming a source of ignition.
- Minor modifications to equipment can be made to reduce the risk of ignition occurring.
- Equipment should not be located in positions where the occurrence of explosive atmospheres is foreseeable.

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