FUME CUPBOARD PROBLEMS, TESTING AND SOLUTIONS

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The primary purpose of a fume cupboard is to provide safe working conditions in the laboratory for the operator and other personnel, by capturing, diluting and exhausting all fume generated from operations carried out in the fume cupboard.

The efficiency and safety of a fume cupboard depends upon the smooth entry of air into the cupboard for effective containment of fume, scavenging of fumes from the chamber and the trapping or safe dispersal of fume to the atmosphere.

1. AIR TURBULENCE AND CONTAINMENT

Perfect containment would be obtained, if there were no transient reversals in the flow of air passing through the fume cupboard. However, perfection cannot be achieved with a fume cupboard in practice. As soon as equipment is placed in the chamber, or an operator stands in front of the working aperture, some turbulence will be generated in the airstream, even in the most modern aerodynamic fume cupboard.

The critical region for the fume cupboard is at the face of the sash window. Turbulence in the airstream may cause the speed of the air entering the aperture to fluctuate, but it should always flow inwards in a fume cupboard of adequate performance.

Unavoidable eddies within the fume cupboard bring potentially contaminated air close to the critical region at the sash face, by mixing the air within the fume cupboard chamber. In properly designed fume cupboards, internal eddies cannot penetrate this critical region. Escape of fume can only occur when an external eddy is carried into the critical region, and then only if the maximum airspeed in the rotating eddy exceeds the average inward face velocity, so that a transient reversal of flow occurs.

Strong external eddies may be generated by vigorous operator movement, passing pedestrian traffic, air conditioning equipment, fans, heaters, doors, windows, and badly placed inlet air registers. All sources of major air turbulence should be sited remotely from the fume cupboard and checks made that draughts and air jets do not impinge upon the working aperture.

1.1 Face Velocity

A high face velocity through the sash window generally reduces the escape of fume, by overcoming all but the most energetic eddies. However, if the turbulence is being primarily caused by poor entry conditions of the make-up air, the room turbulence will become worse with increasing exhaust flow. Increasing the face velocity above a critical value usually pays decreasing dividends in improving containment.

Furthermore, high velocities, say over 1 m/s, have undesirable effects on experimental work, such as extinguishing Bunsen flames, affecting the temperature control of apparatus, interfering with weighing, and sometimes dispersing valuable sample materials. A high face velocity in a fume cupboard also wastes energy by extracting more conditioned or tempered air from a laboratory than is necessary.

The optimum face velocity for a fully open fume cupboard is usually around 0.5 m/s. This velocity is high enough to overcome all but the most energetic eddies reaching the critical region at the face of a fume cupboard. Steps should be taken to eradicate any violent eddies or draughts that would overcome a face velocity of 0.5 m/s. Under good conditions of low turbulence, satisfactory containment on a fully opened fume cupboard can often be obtained with a face velocity as low as 0.3 m/s. However, even when these conditions pertain, the sash window should be lowered to the halfway position for normal operations. This usually has the effect of increasing the face velocity into the desired range of 0.5-1 m/s.

1.2 Smoke Testing

The most obvious way to check on the turbulence within the fume cupboard and in the room, as well as the containment of fume within the cupboard, is to make the air flow patterns visible by smoke testing. A little common sense is required to interpret the patterns, but it is relatively simple to make a judgement on the effectiveness of the fume cupboard and, with a little experience, it is often possible that the smoke testing will suggest some simple modifications, which will make a marked improvement in the containment of a poor cupboard.

The Australian Standard, AS 2243.8, calls for regular smoke testing of fume cupboards, even though some of the overseas standards are lukewarm about smoke testing. There is a mistaken belief in some scientific circles that there is no place in science for "subjective" tests, such the smoke testing of fume cupboards. However, the suggested "objective" containment tests, e.g. the sulphur hexafluoride BS test, are much more expensive to perform and provide far less information, than smoke testing, so are not an adequate alternative.

The simplest way to generate sufficient smoke to test several fume cupboards is with a commercial smoke kit, such as the Drager Air Current Tube. Each sealed tube contains a small quantity of sulphur trioxide, absorbed on brick granules. When air is puffed through the unsealed tube, sulphur trioxide vapour is released, which reacts with water vapour in the air to form sulphuric acid vapour. This immediately gathers more water vapour to form highly visible droplets, a few microns in diameter. The resulting aerosol, while unpleasant to breathe, is not particularly toxic and is easily avoided in fume cupboard tests.

For making the air flow patterns in a room visible, it is sometimes necessary to generate more smoke than an Air Current Tube can provide. Theatrical fog and smoke machines, such as the ROSCO 1500, can supply short bursts of smoke for testing a room, or copious quantities suitable for testing atmospheric dispersion from a stack. Although the smoke is of low toxicity, respiratory protection should be worn, if the exposure to the smoke is prolonged, as in the leak testing of Clean Rooms. Such machines may be hired from theatrical suppliers, if purchase of such a machine cannot be justified.

2. AUXILIARY AIR SUPPLIES TO AIR CONDITIONED LABORATORIES

Auxiliary air supply is unconditioned air delivered into, or adjacent to, a laboratory fume cupboard, in order to reduce consumption of conditioned air in an air conditioned laboratory. It should not be confused with the ordinary make-up air supply, which (if fitted) is delivered remote from the fume cupboard to replace the air taken by laboratory fume cupboards. In an air conditioned laboratory, ordinary make-up air does not reduce the load on the air conditioning system.

It is often claimed to be desirable, on economic grounds, to supply at least half the make-up air to the immediate vicinity of the fume cupboards from an auxiliary system independent of the air conditioning system.

Auxiliary air supply systems, where fitted, deliver a cross-flow of air across the entire width of the working aperture, immediately above the sash window, either inside or outside the fume cupboard chamber.

When the auxiliary air system is fitted inside the fume cupboard, it almost always reduces the face velocity of the air, entering the fume cupboard from the laboratory, below that specified in any of the fume cupboard standards. However, this vexatious fact has never seemed to worry the advocates of auxiliary systems.

Fan assistance of an internal auxiliary air supply creates an unacceptable risk of reverse flow into the laboratory, especially if the performance of the extract fan deteriorates, due to corrosion, build-up of debris, or some other reason. Some of the fan assisted internal auxiliary air supplies are no more than high speed air curtains; when the jet of air strikes the working surface, the air divides, with part going forward into the cupboard and part coming back out of the cupboard. The positioning of apparatus in such a cupboard is therefore very critical.

Where the internal auxiliary air supply is not fan assisted, either wind-blown dirt is introduced directly into the cupboard, or the auxiliary supply soon ceases to operate due to filter blockage.

If the air flow from an external auxiliary air supply register is not laminar, or the outlet velocity is above 0.5 m/s, fume may be drawn into the laboratory from the cupboard by an induced Venturi effect. Unfortunately, in situations where this stringent velocity requirement is met, buoyancy effects in warm weather usually prevent the hot unconditioned auxiliary air from reaching the working aperture of the fume cupboard, when the sash is not in the fully open position. So that, in a safe system, the economic benefits are usually lost when most needed. Thus the claims for auxiliary supply systems have never been substantiated in practice. An auxiliary system delivering unconditioned air with sufficient velocity to overcome the buoyancy effects on a hot day creates a dangerous cross-flow across the face of the cupboard in colder weather.

Auxiliary air systems have been the primary cause of a number of fume containment problems, including pressurisation and reverse flow out of the fume chamber, as well as providing uncomfortable working conditions for the operator, without demonstrating any worthwhile savings in operating costs. Accordingly AS 2243.8 recommends that auxiliary air supply systems no longer be fitted to fume cupboards.

2.1 Alternative Solutions

Alternative solutions to the problem of air conditioner load are:

2.1.1 Variable exhaust controlled by sash

Use a variable exhaust flow linked to the sash opening of each fume cupboard, together with a variable speed make-up air supply fan, separate from the air conditioner (which should only recirculate air from a single laboratory). The variable speed supply fan should be automatically controlled to maintain a constant air pressure within the laboratory about 10 Pa below atmospheric pressure. If the laboratory is a Clean Room, the chosen pressure should be 15 Pa above the pressure of the surrounding rooms.

2.1.2 Reduce room turbulence

Minimise the turbulence within the room so that the face velocity with the sash fully raised may be reduced into the 0.5 to 0.3 m/s region.

2.1.3 Ventilated enclosures

Use tailor-made ventilated enclosures with smaller openings than fume cupboards.

2.1.4 Separate room

House the fume cupboards in a separate unconditioned room off the laboratory.

3. SOME CAUSES OF POOR PERFORMANCE

3.1 Recirculation of Fume within the Fume Cupboard Chamber

Eddy generation, within the chamber of a poorly designed fume cupboard, may cause most of the fumes to recirculate several times, before they are drawn off by the extractor fan. In one design, the eddies were created by sharp edges on the entry fascia of the fume cupboard, because of the use of extruded aluminium sections to simplify manufacture. In another, the eddies were generated by "rogue air" flowing from wall cavities down the rear of the unsealed sash windows of built-in fume cupboards. Such fume cupboards are not suitable for work with highly toxic material as they are unable to reach the highest degrees of containment. Smoke testing will easily pick out this fault and may suggest means of rectification.

3.2 Instability of Air Flow through Critical Region

In a few designs, notably ones in which a large proportion of the flow is taken from a sump beneath the working surface, the airflow through the critical region may be so unstable that momentary reversals of flow occur every few minutes, even though the air in front of the cupboard contains no eddies. Such a cupboard must not be placed in service until the instability has been completely eradicated. These problems can be found, and possible solutions tested, with the aid of smoke testing.

In other designs, insufficient flow may be taken from the sump, allowing vapours to be drawn out of the sump into the eddy created by the body of the operator at the face of the fume cupboard. It is important that the flow from the sump to be optimised to avoid these problems.

3.3 Fume Cupboard Placed in Too Confined a Space

Sometimes the fume cupboard is placed in a small room or in a small alcove off a larger laboratory. The difficulty in this case is to bring in the required make-up air in a satisfactory manner in order to keep air turbulence within the room to a minimum. Outlet velocity from the supply register must be kept below 0.5 m/s, if the room is small, and the inlet air should not directly impinge on the working aperture.

3.4 Fume Cupboards Built into Laboratory Walls

A problem may exist in buildings in which the fume cupboards are built directly into the walls of the laboratory. In this case, the fume cupboard is likely to be surrounded on three sides with air at atmospheric pressure from the wall cavity or ceiling space. Since the ventilation is usually balanced to give an air pressure in the laboratory below atmospheric pressure, this can give rise to leaks of air into the fume cupboard through any service penetrations, which may cause reverse flow out of the fume cupboard into the laboratory. Careful sealing of all possible leak routes is required and the problem is best avoided in the design stage by specifying free-standing fume cupboards.

3.5 Bulky Apparatus Inside the Fume Cupboard

Bulky apparatus in the fume cupboard tends to interfere with the flow, especially if it is placed along one of the side walls. This can make for dead spots in the cupboard as well as creating large eddies and poor containment. Apparatus, especially if generating fume, should be placed centrally in the chamber and, if bulky, the sash window lowered until uniform flow is established through the working aperture.

3.6 Bulky Apparatus and Furniture In Front of the Fume Cupboard

Any apparatus or laboratory furniture should not be located where it will interfere with the airflow into the fume cupboard. Tall bulky apparatus should not be located within 1.8 m of the front of the sash window or within 1 m to either side and must never project into the working area in front of the cupboard within 1 m of the sash window. Unfortunately in some laboratories halon fire suppression systems project, at head height, into precisely this area from the side wall of the laboratory.

Laboratory benches should not intrude into the working area in front of the cupboard, since it is too tempting for the unwary to place apparatus on the bench just outside the cupboard, where eddies will be created to draw fume out of the cupboard.

Any retaining lip on the fume cupboard base should be wholly within the fume cupboard chamber, since projections outside the face of the sash will generate eddies to draw fume through the critical region.

4. METHODS OF IMPROVING THE CONTAINMENT OF A FUME CUPBOARD

Containment of fume within a fume cupboard may be improved in the following ways:

4.1 Increase Exhaust Flow

Increase the face velocity into the cupboard at all sash openings by increasing the total exhaust. This has only a limited effect since it increases turbulence, both in the cupboard and the room, as well as increasing the energy consumption for heating and cooling the laboratory.

4.2 Reduce the turbulence inside the cupboard

Eliminate any flow instabilities that cause flow reversals in the working aperture. Aerodynamic fume cupboards use tapered leading edges and aerofoils to reduce the concentration of the aerosol or vapour returning to the critical region behind the face of the fume cupboard. It is preferable that service controls not be located on the surface of the inlet, where they may disturb the airflow. However, weak eddies are still created behind the sash window and any bulky apparatus in the cupboard.

4.3 Reduce the turbulence in the room

Eliminate any impinging air jets (these are a frequent cause of a dangerous fume cupboard's poor performance) and re-direct draughts away from the fume cupboard. Reduce the velocity of cross-draughts below 0.5 m/s, preferably below 0.2 m/s. Air conditioners, fans and auxiliary supply registers are frequently the cause of the offending airflow. Turbulent eddies are also caused by pedestrian traffic movement, which should be kept clear of the working area in front of the cupboard.

4.4 Improve Scavenging

Adjust the baffles of a poorly scavenged fume cupboard to increase the scavenging over the base and sump of the cupboard. Care must be taken that the flow increase from any sump below the work surface does not cause flow reversals and instabilities over the work surface.

4.5 Adjust Air Pressure

Balance the exhaust/supply airflow ratio to achieve an air pressure in the laboratory which is only just below atmospheric, preferably within 10 Pa. If the laboratory is not supplied with make-up air, then ensure that the make-up air drawn into the laboratory has an easy draught-proof path, via adequately sized grills or louvres, to keep the laboratory air pressure within 20 Pa of atmospheric. This reduces the velocity of uncontrolled "rogue air" leaking into the laboratory, since this may be the source of excessive air turbulence and air jets. Ingress of air in sensitive regions, in and around the fume cupboard, should be prevented by sealing any leaks in these areas.

4.6 Lower Sash

Reduce the working aperture by lowering the sash window. This prevents the largest eddies from penetrating the aperture and increases the effective face velocity, even in a by-pass cupboard, without increasing turbulence within the room. The sash window also acts as a splash shield and prevents careless individuals inserting their heads into the fume cupboard, which would completely negate the containment principle.