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Grade 5 Thesis

Variable Air Volume Systems on Fume Cupboard Extracts

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VARIABLE AIR VOLUME OF FUME CUPBOARD EXTRACTS

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1. Introduction to Laboratory Ventilation

Laboratory ventilation predominantly consist of a supply and extract system which works in the same principle as a conventional office block system , but in the laboratory system the pressure regime are different to that of an office. To prevent gases, smells and toxics from escaping from the laboratory area, the pressure in the laboratory is negative to its external area. This is achieved by the supply air being less than the extracted air.

A generic ventilation system for a laboratory consists of a supply air system which is commonly achieved by an air handling unit which disperses treated air via a duct system. The Duct system transports the air to the required area and is usually dispersed using grilles. (see schematic)

The extract side of the system is usually through the face of a fume cupboard. The fume cupboards are connected to an extract system which consists of a chemical resistant ductwork (either uPVC or Fire Retardant Polypropylene) and a centrifugal fan made from the same materials as mentioned. On the discharge side of the fan would be a stack made from the materials mentioned which would raise vertically and at the very end of the stack an efflux cone. The required height of the point of discharge is therefore peculiar to each project, but for an isolated rectangular building of low plan ratio in flat open territory, a height above ground of 1.25 multiplied by the highest point of the building, or 3 m above the highest point, whichever is the greater? To help this further the efflux cone which is fitted at the end of the stack tapers to create velocities of around 10 to 15m/s, what this does is speed the air up considerably and dispersing away from the building and giving it time to be diluted.

As previously mentioned to prevent ingress of contaminated air into surrounding areas of the laboratory the pressures in the laboratory are negative to the outside to prevent this. This is achieved by the volume of the extract being greater than the supply, usually by 10% maximum. It has been know on single fume cupboard systems not to have any supply but on large banks of fume cupboards this is essential, as the pressures in the laboratory become too high. The effects of too higher pressure can make the opening doors difficult, but more importantly on the even flow of air through the fume cupboards face to give good containment characteristics to protect the user.

Over the years many ideas have arisen on saving energy. One that I have worked with closely is Variable Air Volume systems on fume cupboard installations. The idea of a Variable Air Volume on fume cupboards is to reduce plant size and giving the fume cupboards a greater containment and the users less concern that the substance they are using could enter the space they are working in.

2. The Basis of Fume Cupboard Design

The purpose of a fume cupboard is to allow a chemist to mix chemical compounds in a safe manner. A fume cupboard is crudely saying a box with a glass sashed front which in turn is connected to an extracted ventilation system. The glass sashed front is to allow the user to pull down giving them enough space to work but in turn protecting them from any spillages or splashed that may occur. The ventilation system extracts away any harmful fumes that may either be from the chemicals or created from the chemicals being mixed. The ventilation system is made up of ductwork, an extract fan and a discharge stack including a high velocity efflux cone. A fume cupboard is designed to give the greatest containment of fumes or gases with minimum air turbulence thus trying to prevent ingress of the chemicals used back into the working area. Usually a fume cupboard has a face velocity of 0.5m/s with a maximum sash height of 500mm from the work top. When a chemist has finished they would usually pull down the sash which should stop just above the worktop giving a minimal opening. The gap is to allow air from the room to be pulled into fume cupboard chamber to allow the harmful gases to be extracted. With this minimal opening the face velocity of the fume cupboard increasing massively to in excess of 1m/s and creates turbulence within the fume cupboard. This action does not disperse the gases at the rate required.

As years have progress a massive amount of research has gone into the aerodynamics of fume cupboards to create the ultimate containment and there has also been a large amount of development on the air systems that serve fume cupboards.

Most common research and development establishment have laboratories that do not just have 1 No fume cupboard with 1 No extract system, but banks of fume cupboards with one large ventilation system. The problem occurring with a system of this kind is when all fume cupboards have the sashes closed the velocity at which air passes through the extract gaps exceeds more that 1m/s and creates very turbulent air patterns. These high velocities effects the containment of the chamber. This can result in gases escaping which is not acceptable... The easiest way to get round this would to have dedicated extract systems to each cupboard but this would be very costly, so development of Variable Air Volume systems for fume cupboards was developed.

3. How a Fume Cupboard Extract System is Designed

3.1. Extract

The system works as follows, you have a number of fume cupboards let's say 10 for this example and let's say that the fume cupboards are 1500mm wide which gives a working area of 1200mm. All have the same working face velocity of 0.5m/s at a working sash height of 500mm. This will mean that the fume cupboard will require $0.3m^3/s$. The full system will be designed to have a total volume of $3.0m^3/s$ and the fan will be sized accordingly when the pressure drop of the ductwork system has been designed. A common pressure drop for a system of this type would be between 400 to 800 Pascals, with the efflux cone usually being the highest drop.

The calculation below work as follows,

Fume cupboard working area

1.2meters x 0.5 meters = **$0.6m^2$**

The face velocity is set as British Standard **0.5m/s**

Therefore the volume will be

$0.6m^2$ x 0.5m/s = **$0.3m^3/s$**

If there are **10** No fume cupboards then the total volume will be

10 x $0.3m^3/s$ = **$3.0m^3/s$**

3.2. Fresh Air Bleed

If a Variable Air Volume system is being used on a fume cupboard extract then a fresh air bleed is essential. The bleed is used to keep the volume and pressure constant which means the efflux velocity will also stay constant.

The duct velocity in an extract system of this kind is usually 5m/s, but due to the nature of the air being transported the discharge velocity requires to be higher. The reason for the higher discharge velocity (efflux velocity) is to disperse the contaminated air as far away from source as possible. The reasoning for this is

- To allow the contaminated air to dilute with fresh air
- To keep the contaminated air away from any fresh air intakes that could re circulate this back into the building

To achieve the desired efflux velocity at discharge the ductwork diameter is reduced dramatically to create a velocity in the region of 10m/s but should be no less than 7m/s according to BS 7258. The fresh air bleed allows this to happen. When a Chemist has set up an experiment and left it to run they would usually close the sash on a fume cupboard in the case of any spillage or explosion. In doing this the actuator on the fume cupboard would close reducing the volume to the fume cupboard but increasing the pressure in the system. If this is the case on a number of the fume cupboards then system pressure would increase the volume would reduce and this would also reduce the duct velocity. If the duct velocity reduced then the efflux velocity would also be affected and not achieve the desired rate. What the fresh air bleed does is compensate for a fume cupboard sash closing and allow fresh air be sucked into the system and keeping the system constant.

The bleed is a duct which is usually connected to the main header duct and sized the same diameter. It is not connected to any fume cupboard or hood but just as an open end to atmosphere. Part of the duct is an actuated multi blade damper which is controlled by a sensor in the duct. This part of the system works on pressure. As explained before if a fume cupboard sash is closed the system pressure will rise. A duct pressure sensor will measure this and if the system pressure rises above the sensors set point then a signal will be sent to the bleed air actuated damper requesting it to open. The damper will then open until the sensor asks it to stop as the systems design pressure has been restored. This will continue to happen as the system demands it to.

With the bleed air monitoring the system pressure and maintaining a constant then the efflux velocity will also remain constant and ensure that there is no fear of contaminating any surrounding areas.

3.3. Supply System

On a system with a large amount of fume cupboards a supply air system is necessary. The reason for this is to keep a manageable negative pressure in the laboratory and giving the fume cupboard an even flow through it working area.

The supply system does not usually have to be sized the same size as the extract. What is common is the supply will only be 90% of the extract volume.

Total System volume of 3.0m³/s for extract system

Total System volume of 2.7m³/s for the supply system (90% of extract volume)

The system usually comprises of a dedicated AHU with heaters, filtration and a fan which transports tempered fresh air into the working area via a galvanised duct system. The air is disperses into the area through ceiling mounted grilles. The supply air in a Variable Air System of this type is commonly fitted with a Variable Air Volume damper which modulates to achieve the desired volume required, dependant on the fume cupboard states. The desired volume is determined by the fume cupboard system and controlled via room differential pressure sensors which measure the negative pressure between the laboratory and the area’s outside. These then determine the supply Variable Air Volume dampers position.

The purpose of the supply system is to give a good even flow through the face of the fume cupboard and preventing any harmful toxics getting back into the laboratory because of turbulence within the chamber. The grilles that supply the area are usually about 1.2 meters from the front of the fume cupboard (2 No ceiling tiles) to allow the air to be draw across the fume cupboard face evenly. In the case of a perforated plenum ceiling, insulated bags are place in the tiles directly in front of the fume cupboards. Another design which works very well also giving an even flow if the ductwork is on show with no ceilings is air socks. These are long tube like cloth bags which fit to the end of the duct and when pressurized blow up (please look at the front cover and see the light blue socks).

A negative pressure is required at all times in a laboratory and is achieved by the extract rate being greater than the supply air rate. Through experience -10 Pa is maximum and comfortable, if this is exceeded problems of too high pressures occurs. Simple things like opening doors are difficult, and wind noise can be created through cracks etc. Most of all the laminar flow of the fume cupboards can be effected and the containment levels reduced.

4. Fume Cupboard Commissioning

The VAV side of the installation has 2 No dampers as standard for each fume cupboard 1 No VCD for proportional balancing and an actuated damper which will be used as the varying damper. Each fume cupboard is fitted with a diode air flow sensor which is usually situated in the top of the fume cupboard chamber and is wired back to a digital display controller which is situated on the front of the fume cupboard (see picture 2). The airflow sensor works similar to a hot wire anemometer with 2 No diodes one which feels the cold air and one that feels warm air. The 2 send back a signal to the controller on the front of the fume cupboard. The digital (or in the old days analogue) controller is where all the electronic wizardry happens, but also has a display and controls for the user of the cupboard . Firstly there is a digital read out showing the exact face velocity through the fume cupboard face. There is a low flow alarm including a mute button which is used to mute if the flow drops below the set parameters. In addition there is sash high alarm including a mute button this will only happen if the sash is raised above 500mm and is activated by a micro switch which is positioned on top of the fume cupboard. There are also indicator lights one indicating safe air and one for low air.

The system air flows are set up as buy using the VCD to ensure that the modulating damper regulates through its full travel and achieves the 0.5m/s face velocity regardless of sash position. All fume cupboards are rechecked to see what the face velocities are, now that the actuating dampers are in control. The face velocity is checked using a hot wire anemometer (Airflow Developments TA 5 see picture 1) by scanning across and down and looking for an average of 0.5m/s. In most cases there is an amount of calibration to be carried out. Firstly the airflow sensor requires calibrating to the digital read out. This is done by comparing the hotwire anemometer reading to the digital display. If they are not synonymous with each other then the sensor requires calibrating.

The Calibration of the sensor is carried out by adjusting 2 No potentiometers which are part of the control unit. One of the potentiometers is for working height calibration and the other for closed sash calibration. The working height potentiometer is adjusted to read the same as the anemometer, this could take a number of attempts as the potentiometers are very sensitive. When this is achieved the sash on the fume cupboard is closed, reducing the height from 500mm to 50mm. With this the face velocity increases to a flow rate exceeding 1m/s. The purpose of the VAV system is to achieve the same velocity as when at full working height.

The same process is applied when setting up the velocity at low sash height. When the face velocity is checked and it will exceed what is required, the remaining potentiometer is adjusted to set the actuating damper to achieve the desired airflow of 0.5m/s. In setting this the digital read out should also read 0.5m/s. Once this is achieved the sash is set back to its working height to establish if the setting of the low sash volume has had an effect on the previous settings. As you can imagine this is quite repetitive and checks on already set up fume cupboards need to be re-checked to ensure no adverse effect have taken place to its calibration while continuing the process on unset up cupboards.

5. Problems associated with the system

Basically this is a fantastic system which in principle should enable the containment of the fume cupboards to be achieved with very little effort, but experience shows there needs to be more effort given in setting up the system in the first stage. Many systems do not work correctly due to the fact of this matter, and this causes the users to lose confidence in its working capabilities. The fundamental flaws are

1. Understanding of how the system works and what it is trying to achieve
2. Ensuring that when calibrating the system and its components, it is carried out thoroughly and re-checked before declaring that the system works.

One of the biggest instances that could be avoided is to check that the bleed air is set up and works correctly. All the works on the fume cupboard side could be set up, calibrated and proven to be working correctly. The face velocities have been proven to the end user and they seem happy with what they are provided with. What is unbeknown to them that due to the bleed air not operating correctly they and other could be at harm as the efflux velocity is not being achieved. This is obviously a very unacceptable occurrence which could endorse prosecution for malpractice in today's Health and Safety laws.

Another flaw with this system is the users are not trained in how to use the fume cupboards correctly. Due to lack of training and understanding by the operatives the system is not operated correctly and complaint by them, and return visits with no faults found are frivolous. Correct training which is not difficult to carry out and is now an integral part of the hand over procedure.

6. The Way Forward

The Variable Air Volume system for fume cupboards when it was first developed around 20 years ago was going to be the new revolutionary, had to have system which everybody in the PharmaChem industry was getting excited about. Unfortunately the technology has not been developed as advanced as it should have been. More time and effort should be set aside to develop this system further. Many people have tried and some of the leading fume cupboard experts have developed an excellent product but still the operation is not quite right. One of the big pluses which have been developed is that these types of systems now have their own BMS style control where it can be monitored remotely. This includes room pressure controllers which are situated outside the laboratory area and give a good visual indication of the lab area.

The new British Standard for Fume cupboards (BS EN 14175) which is looking to reduce the airflow on fume cupboards as long as it still achieves the desired containment levels could see the end Variable Air System being used. They are looking for greater aerodynamics on fume cupboards which would reduce turbulence in the airflow patterns. In this the fume cupboards face velocity could reduce to as low as 0.3m/s. If this could be achieved it would result in when the fume cupboards sash is closed then the face velocity would only increase to around 0.6m/s and still giving an acceptable containment level. If this is the case why would you need a VAV system?

7. References

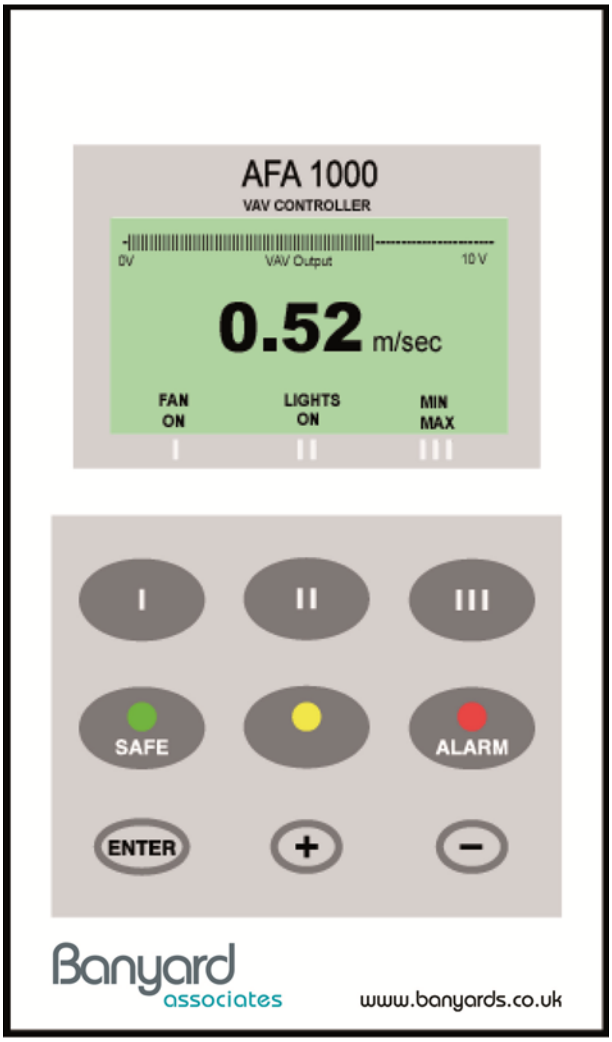
- BS 7258 Parts 1 to 4
- BS EN 14175 Part 4 On site testing
- TYPICAL FUME CUPBOARD VENTILATION SCHEMATIC 1

<u>Picture 1</u>
<u>Airflow measurements TA5 Hot wire Anemometer</u>

Typically used when setting up systems and annual recheck

PICTURE 2

TYPICAL EXAMPLE OF THE FRONT FACIA OF A VAV CONTROLLER ON A FUME CUPBOARD



TYPICAL FUME CUPBOARD VENTILATION SCHEMATIC 1