



SAFE DESIGN AND USE OF VENT COLLECTION SYSTEMS FOR POTENTIALLY FLAMMABLE MIXTURES

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CONTENTS

[Introduction](#)

[Hazards](#)

[Important Safety Issues for Vent Collection Systems](#)

[Developing a Basis of Safety for a Vent System](#)

[Risk Assessment](#)

[Legal Requirements](#)

[Glossary](#)

[References](#)

INTRODUCTION

Our understanding of the effect that we are having on the Earth's environments continues to improve and expand. We are now much more aware of the damage that can be done if we are not careful and considerate in the way in which we carry out our activities.

Releasing substances into the air that surrounds us can have a very significant impact on both our health and the environment. Consequently, an increasing number of controls are being implemented in the UK by regulatory authorities such as the Health and Safety Executive and the Environment Agencies to minimise and control the impact of process emissions. The uncontrolled release of volatile organic compounds (VOCs) into the workplace or local environment from processing operations is of particular concern.

The need for the collection, containment and abatement of VOCs that arise from workplace activities is widely accepted and the release of VOCs during processing operations is now strictly controlled and regulated. Harmful process emissions should no longer be allowed to escape into the workplace, they should be removed at source by a vent collection system and safely directed to where they can be destroyed or harmlessly discharged. A large variety of equipment is now available that can be attached to the end of vent collection systems to enable this to be achieved.

This document provides general advice on the fire and explosion hazards associated with the operation of vents and vent collection systems. It is aimed at employers and technical staff with responsibility for the design, operation and maintenance of equipment used for the collection and venting of gaseous and volatile flammable emissions. The guidance is expected to be relevant to vent collection projects in many types of industry including; solvent-using sector, petroleum industry, organic chemical industry, printing industry etc.

Advice is given on the important safety issues that you should consider when designing a VOC collection system. The use of risk assessments to identify and prioritise those areas of significant risk is described and the opportunities available to reduce and manage those risks are discussed.

A brief review of some of the important the health and safety legislation that regulates activities involving flammable atmospheres is also included together with a list of useful reference documents.

Pressure relief venting systems that are used to provide the rapid release of unwanted excess pressure in reactors, vessels etc as a result of fire or vigorous reaction are outside the scope of this guide.

This guidance does not specifically address the risks arising from the use of end-of-pipe abatement equipment although many of the principles discussed below are directly relevant. Specific guidance will be published shortly to provide advice on the operation of thermal oxidisers, items of VOC abatement equipment frequently used in association with vent collection systems, and solvent evaporating ovens.

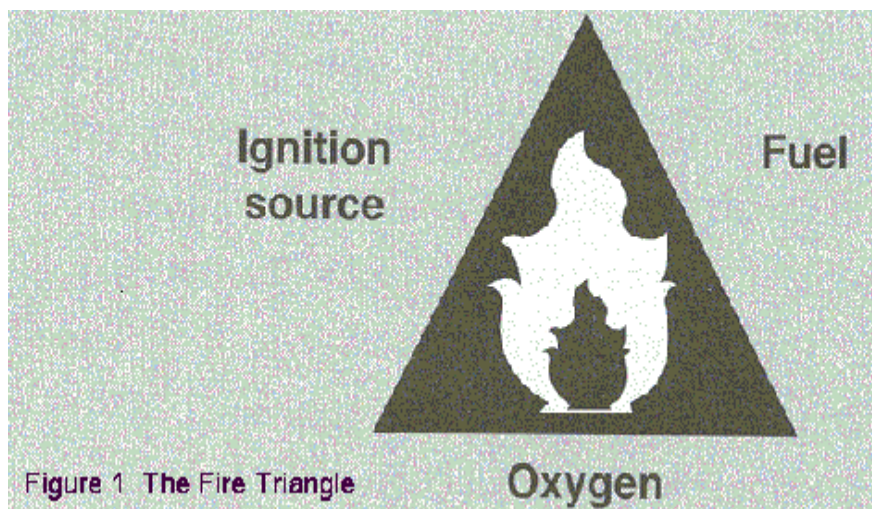
HAZARDS

Mixtures of flammable substances with air and ignition sources are two of the principal hazards associated with the operation of vent collection systems. Risks to safety are created when these hazards are not kept apart. This can occur within the vent system and in the upstream or down stream equipment connected to it. A fundamental principle of the appropriate design and operation of a suitable vent collection system should be that flammable mixtures and sufficiently energetic sources of ignition are not allowed to be present together.

When assessing fire and explosion hazards you should consider the venting arrangements as part of a fully integrated system in conjunction with the upstream and downstream plants and processes and not in isolation.

The fire triangle (Fig. 1) provides a useful starting point when considering the fire and explosion hazards associated with the design and use of vent systems for the collection and containment of flammable vapours. In order for burning (**combustion**) to occur the fire triangle must be complete; fuel and oxygen or an oxidising agent must be present in the correct amounts together with an effective ignition source. If any one of these conditions is missing or removed then a fire will not start or it will go out.¹

The basis of the safe operation of the vent system relies heavily on preventing the requirements for combustion; fuel, oxygen and ignition source, from occurring together at inappropriate times or places within the equipment.



A sound understanding of the principles of combustion will help you to assess the risks associated with the operation of vent systems and the associated plant. The important features of the three essentials for fire to occur and the different forms it can take are discussed below.

Fuel

Many of the substances used in the process industry can be made to catch fire and burn; they are **combustible**. Some are much easier to set alight than others. The more readily a substance catches fire the more **flammable** it is. The temperature of a solid or a liquid can greatly affect how easily combustible solids and liquids catch fire;

this is particularly true for liquids. It is usually the vapour above a liquid that ignites first and carries the flame to the liquid. The warmer the liquid is, the more vapour is given off at the surface and so the more likely the vapour is to catch fire.

If a flame is held close to the surface of a flammable liquid that is being heated a temperature will be reached at which the vapour given off by the liquid catches fire. The lowest temperature at which this occurs is the **flashpoint** of the liquid. When this test is carried out under controlled conditions it is used to classify how **flammable** the liquid is. The lower the flashpoint, the more flammable it is.

When the flashpoint is below 55 °C the substance is classified as **flammable** under The Chemicals (Hazard Information and Packaging for Supply) Regulations 2002, often referred to as the CHIP Regulations.² Chemicals with flashpoints below 55°C are among those classes of materials called **dangerous substances** under The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR). These Regulations describe the legal requirements associated with the storage and use of dangerous substances.³

Substances with a flashpoint below 21 °C are more hazardous and these are classified as **highly flammable**. The lower the flashpoint of a substance the more hazardous it is likely to be. Chemicals with a flashpoint lower than the ambient temperature are more likely to produce a flammable vapour when released or spilled than those with a flashpoint higher than the ambient temperature.

Not all possible mixtures of a flammable substance with air will ignite or explode. The lowest concentration that will ignite is called its **lower explosion limit (LEL)**; the highest concentration is the **upper explosion limit (UEL)**. The range of concentrations between the LEL and the UEL that will ignite and burn is called the **flammable range** and this varies greatly between different flammable substances. Some have very narrow ranges while others have wide ranges.

The values of LEL and UEL quoted in material safety data sheets (MSDSs) are usually the values measured at 20 °C. The flammable range of most substances gets wider as the temperature is increased above 20 °C. It is particularly important to note that the LEL of many substances decreases as the temperature of the mixture increases. This may mean that a mixture that is below the LEL at ambient temperatures becomes flammable at the operating temperature of the vent system.

Mixtures with concentrations below the LEL or above the UEL will not ignite and support (propagate) a flame. This principle is an important basis for the design and safe operation of vent collection systems.

Ignition Sources

A sufficiently powerful source of ignition is the second essential part of the fire triangle. Without a suitable ignition source there will be no fire or explosion.

There are a number of potential ignition sources that may be present in a vent collection system.¹ The more important ones are listed below:

- Electrostatic sparks
- Hot work; e.g. welding and burning

- Electrical equipment; e.g. electric motors
- Hot surfaces; e.g. bearings
- Mechanical friction; e.g. impellor impact
- Auto-ignition
- Thermal decomposition
- Chemical reaction; e.g. from catalyst carry-over

Oxygen or Oxidising Agents

Oxygen or an oxidising agent is the third part of the fire triangle. It is the chemical reaction between the fuel and oxygen, usually from the air, which produces the heat and flames that we associate with fire. If there is too little oxygen present then a fire or an explosion will not occur. The minimum amount of oxygen necessary to maintain combustion of a particular fuel is called the **minimum oxygen concentration (MOC)**.

Oxygen from the air is by far the most common oxidising agent involved in fires and explosions. Other substances such as chlorine, ozone, the oxides of nitrogen and oxygen-rich salts such as nitrates, peroxides and chlorates etc can also promote fire and explosions. If oxidising agents other than oxygen are likely to be present or produced in the upstream processes then you should ensure that the risks associated with them are be adequately assessed.

Explosion

The ignition of a fuel/air mixture in a confined space, such as inside a vent or duct, is very different to when a fuel burns in the open air. When a flammable mixture contained within a duct is ignited, combustion takes place rapidly and the pressure rises sharply. We would say that an explosion had occurred.

Explosions can be grouped into main two categories, **deflagrations** and **detonations**. The more common of these are **deflagrations**. Here the flame moves through the flammable mixture at less than the speed of sound. A deflagration is the more common result when a flammable mixture ignites inside a duct. The pressure produced inside the vent system can be up to 10 times greater than the pressure before ignition.⁴

Detonations are much less likely to occur but the consequences can be more severe. In this type of explosion the flame travels through the flammable mixture at supersonic speed. The pressure produced by a detonation can be several times greater than that produced by a deflagration.

Most explosions in vent systems start as deflagrations and remain as such. In some cases, however, the deflagration may develop into a detonation as the flame travels along the duct. This is known as **deflagration to detonation transition**. It results from the flame accelerating as it travels through the flammable mixture. If the rate of acceleration is sufficient the speed of the flame will become supersonic and the deflagration will become a detonation. Bends, changes in diameter, obstacles in the

duct etc. will all increase turbulence and cause the flame to accelerate more quickly, increasing the likelihood of deflagration to detonation transition.

The acceleration of the flame front during deflagration to detonation transition can produce very high peak pressures indeed; up to 100 times the initial pressure. ⁴ Events of this type are likely to have devastating effects on unprotected systems. The consequences of an explosion occurring in a vent collection system should be considered very carefully, particularly the likelihood of injury or damage to hazardous adjacent plant from missiles.

IMPORTANT SAFETY ISSUES FOR VENT SYSTEMS

Flammable Mixtures

All pipelines carrying flammable atmospheres present a risk of fire or explosion. You should control the volume and composition of your vent streams so that a flammable atmosphere is never present within the system. It is particularly important to recognise that the flammable range of a mixture may be considerably wider than those of its individual components. It is very difficult to completely eliminate ignition sources and so your top priority should be to avoid flammable mixtures.

During the initial design phase three broad approaches are often considered; fuel-rich, fuel-lean and inerted operation. In many collection systems several branches will feed into each vent header at the process plant end. Consequently, it is important to have a full understanding of the potential variability of the process streams that may be combined together in each header. Great care should be taken to ensure that a flammable mixture is not inadvertently produced by mixing of a fuel-rich vent stream from one branch with a fuel-lean stream from another.

Carry Over of Solids

You should prevent the carry over of solid particles or other materials from the process that may form hazardous deposits in the vent system. If combustible materials are allowed to accumulate within the vent system they will increase the likelihood of blockages, excessive backpressure and unforeseen exothermic reactions. Where deposits are present the likelihood of a fire occurring and its severity are much greater.

Where a process uses or creates a flammable dust and there is a possibility of carry over, the potential for a dust or dust/vapour explosion in the vent system should be considered. If there is insufficient carry-over to cause a dust explosion then the possibility of a dust/vapour hybrid explosion should be assessed. Note that the LEL of a flammable liquid may be lowered when a dust is present. It is also important to recognise that the auto-ignition temperature of many materials is reduced when they are present as a thick dust layer on a heated surface.

In a system that is being rendered fuel lean by the addition of secondary dilution air, the accumulation of solids may produce a partial blockage causing a decrease in the dilution airflow. This may lead to an increase in the concentration of the flammable substance taking the mixture into the flammable range.

In situations where a flame arrester is considered necessary but fouling, due to dusts or materials liable to polymerisation, is possible a parallel arrester may be required together with arrangements, e.g. differential pressure measurement, to identify when fouling has occurred.⁶ In this way a clean arrester can be brought safely in to service while the fouled one is renewed. An interlocked valve system should be used to ensure that the header cannot be isolated during the swap-over procedure, which could result in over-pressurisation of the plant.

If accumulation of solids within the system is possible it should be considered as a foreseeable deviation when developing the **basis of safety** and the risks associated should be assessed.

Condensation or Freezing of Liquids

You should prevent liquids condensing inside the vent system. Condensation may cause liquid logging, increase the weight of the system beyond its design specification or may block or rupture the duct if freezing takes place. When condensed flammable liquids vaporise as the system warms up a flammable atmosphere may form. Vents and ducting that could be exposed to low temperatures may need to be lagged or trace-heated to prevent condensation or icing occurring. The integrity of carbon steel headers may be challenged through embrittlement if they are exposed to sub-zero temperatures produced by the cooling effect of evaporating condensate.

Condensation is particularly likely to occur at start up, after non-routine shutdowns and in situations where the vent pipe work is outside or runs through unheated ceiling voids. Lagging and/or effective trace heating may be required to prevent condensation. If condensation or liquid carry over is unavoidable then suitable knock-out pots and drain points should be incorporated into the system. The design and installation of these should ensure that their location and the “fall” of the associated pipe/duct work are appropriate and compatible. The hazards associated with the use of the drain points for the recovery and handling of any condensed flammable liquids should be evaluated and appropriate arrangements provided.¹

Temperature and Pressure

You should give careful consideration at the design stage to the arrangements when high and low pressure streams are collected into a common header. The possibility of high pressure vents causing back flow, over pressurisation or the contamination of low-pressure sources (e.g. stock tanks) should be fully assessed.

You should ensure that the risks associated with the inclusion of high temperature streams are fully assessed. These may cause damage to unsuitable headers or may take the combined vent stream mixture above its auto-ignition temperature. Elevated temperature and/or pressure may also widen the flammable range of the components of the vent stream.

Materials of Construction

You should ensure that the vent system is made from materials that are suitable for the range of process chemicals and operating conditions that are foreseeable, including those resulting from process deviations. The suitability of the materials used for the fabrication of the vent system depends on several factors including:

- Operating temperature range
- Appropriate corrosion and erosion resistance
- Operating pressure range
- Electrical conductivity (to prevent the accumulation of static)
- Fire resistance
- Whether design for explosion containment is required

You should ensure the likelihood of water vapour entering the system should be considered together with the corrosion that it might cause in combination with traces of other substances such as hydrogen chloride.

Explosion Mitigation

Risk is the product of the likelihood and the consequences of an unwanted event. The likelihood of a sufficiently energetic ignition source occurring within the vent system can be minimised but it cannot be assumed to be zero. Consequently, even the transitory presence of a flammable atmosphere inside the system will give rise to a significant risk from fire and explosion. The consequences of a deflagration or detonation can be very severe, resulting in catastrophic rupture of equipment and possible domino effects. For these reasons it may be difficult to design and operate a vent system that handles particularly hazardous streams that has a sufficiently low frequency of explosion to result in an acceptable risk. In these situations some form of explosion prevention, suppression, protection or mitigation measures will be necessary to achieve an acceptable risk.

You should consider whether separate dedicated headers are required to effectively address the risks in systems handling highly incompatible vent streams.

Operation and Maintenance

Vent collection systems should be treated in the same manner as production units. They should not be seen as service units of secondary importance. Their operation and maintenance should be integrated into the safety management system for the production units they serve.⁵ Where a vent collection system handles gaseous effluent streams from a number of units under the control of different work teams, special arrangements should be made to ensure that effective communication takes place between everyone involved. Each work team should ensure that the others have an awareness of the status of their plant, especially with regard to unusual or unexpected situations or proposed actions.

Whenever reasonably practicable, the maintenance on a vent collection system should be planned to coincide with downtime on the associated production plants and vice versa. Where a number of upstream plants are connected via a complex vent system, robust management procedures should be in place to ensure that maintenance activities are effectively controlled and coordinated.

You should ensure that a single suitable person is recognised to be in overall control of any significant maintenance work that involves or may affect the integrity of the

vent system. This person should have a full understanding of the scope of the proposed work and the potential for it to affect, or be affected by, the conditions in the upstream plants, the vent collection system or any abatement equipment. You should ensure that a suitable and sufficient risk assessment is always produced before starting any significant work on the system or associated equipment.

You should formally document and manage any changes made to the vent equipment layout, specifications or operating to prevent the inadvertent introduction of new hazards. It is important that all appropriate personnel are aware that the vent collection system comes within the scope of the plant modification system.

New or modified processes are frequently introduced on to general purpose production units. You should ensure that appropriate procedures are in place to review the implications of any proposed changes on the safety and integrity of the vent system before they are introduced. The assessment should consider any new flammability and chemical reaction hazards and the compatibility of any new substances with the materials of construction of the vent collection system. The hazard analysis, risk assessment and the changes made to the system should be formally documented.

Divert to Stack

Vent collection systems connected to abatement plant, such as thermal oxidisers, typically incorporate arrangements to divert the vent stream directly to atmosphere through a stack when the vent stream may be in the flammable range. This may occur during start-up/shutdown conditions, during fault conditions or in cases of abatement plant malfunction. You should ensure that the hazards associated with this operation, e.g. discharge of untreated flammable mixtures into the local environment, are fully appreciated and the risk from fire or explosion fully evaluated.

DEVELOPING A BASIS OF SAFETY FOR A VENT SYSTEM

A critical point in the design of a new or modified vent collection system is the decision on what will be the **basis of safety**. The basis of safety is an explanation of the fundamental principles that have been used as the foundation for the design of a safe vent system together with a description of the precautions taken and the protection devices installed to further reduce the risk of injury.

When considering the basis of safety you should consider how the three key factors necessary for combustion would be controlled in order to prevent a fire or explosion occurring. Techniques frequently used as the basis of safety include; operation with very low oxygen concentrations (inerting), operation below the LEL and the elimination of ignition sources.

Selecting an effective and robust basis of safety for a vent system is heavily reliant upon the collection and intelligent evaluation of accurate, reliable and appropriate plant, process and emission information. Without this factual information it will not be possible to arrive at an appropriate conclusion or be able to demonstrate that the proposals put forward are suitable. A structured approach will minimise the work involved and will also reduce the likelihood of errors and omissions occurring. It will also ensure that all the necessary information is collected. [Figure 2 below](#) shows a suitable manner in which the preparation of a basis of safety may be developed.

Once the type, quantity and concentrations of the flammable materials, the temperatures and pressures etc. likely to occur within the vent collection system has been determined, a basis of safety can be put forward for closer examination and HAZOP. The most appropriate technique for the basis of safety is usually apparent from the range of operating conditions that the system routinely experiences.

When the basis of safety has been decided you should carry out a risk assessment. This should establish the risk of injury resulting from a VOC collection system designed against this basis of safety and whether that risk is acceptable. During the risk assessment process the effect of foreseeable deviations from normal operating conditions should be examined and the risk to personnel that these events generate determined. This exercise is described in some detail in the next section.

The final outcome of the entire process is the preparation of the finalized basis of safety document and the risk assessment. These should be supported by a fully documented design, mass balance and operating instructions.

The steps involved in a suitable approach to developing the basis of safety are described below and are summarized in [Figure 2](#).

Collection of Data on the Vent System.

All the emission sources likely to be handled by the vent collection system should be identified before starting the design of a new system or making changes to the emission loadings of existing system. The number, type and location of the vents will have a major impact on the size and complexity of the collection system. Typical vent systems are likely to include many of the following sources of emissions:

- Tank breathing vents
- Breather valves
- Reactor vents
- Mixing and process vessel vents
- Sample points
- Charging/filling points
- Laminar flow booths
- Vacuum pump exhausts
- Lute pots and siphon breakers
- IBCs used in processes
- Coating and drying process emissions
- Solvent cleaning operations

During the exercise you may identify a number of emission sources that could be eliminated, recycled or minimised by other means. Any existing vent or flare header systems should also be noted and a plan for dealing with these included.

Much of the information required during the design stage of the project may have been collected previously during the preparation of submissions to the Environment Agency under Integrated Pollution Prevention and Control (IPPC) requirements. Where new information comes to light the plant engineering line diagrams (ELDs) and process and instrumentation diagrams (P&I Ds) should be updated for the existing plants and any new vent sources clearly marked. You should carry this information over onto site plot plans and general arrangement drawings to aid both the estimation of project costs and the mechanical design of the vent system. Up to date accurate plant drawings will prove invaluable when HAZOP studies are carried out.

When all the relevant vents and emission sources have been identified the work to analyse and quantify these emissions can commence. It is essential that the information gathered covers the full range of anticipated operating conditions, especially foreseeable but atypical ones. The importance of gathering accurate information on **all** the foreseeable processing situations cannot be overstated.

Collection of Component Flammability Data.

Flammability data, particularly LEL, UEL and MOC, are required for each of the significant components in the emission streams that the vent system will collect. This will enable a determination to be made about if, when and where flammable atmospheres are likely to be present within the vent system.

You should ensure that the flammability data used as the basis of decisions are relevant to the conditions that will be present in the system, i.e. appropriate for the foreseeable temperature, pressure, nature of inert etc. If possible, experimentally determined flammability diagrams should be used. If these are not available then they should be constructed for each of the worst-case compositions for each of the vents.

In some instances there may be synergy between components in the emission stream that may increase the risk. For example, the presence of a relatively small amount of hydrogen can have a large effect on the flammable range and flash point of a mixture. If there are multiple components or significant quantities of reactive gases present then experimental determination of the flammability characteristics of the mixture should be considered.

Flammability diagrams can also be used to assess the possible consequences of air ingress into fuel-rich systems. Critical flammability estimates should be backed up with experimental data. If the expertise to determine this information is not available "in-house" then a suitable contractor should be engaged.

Identification of Operating Scenarios.

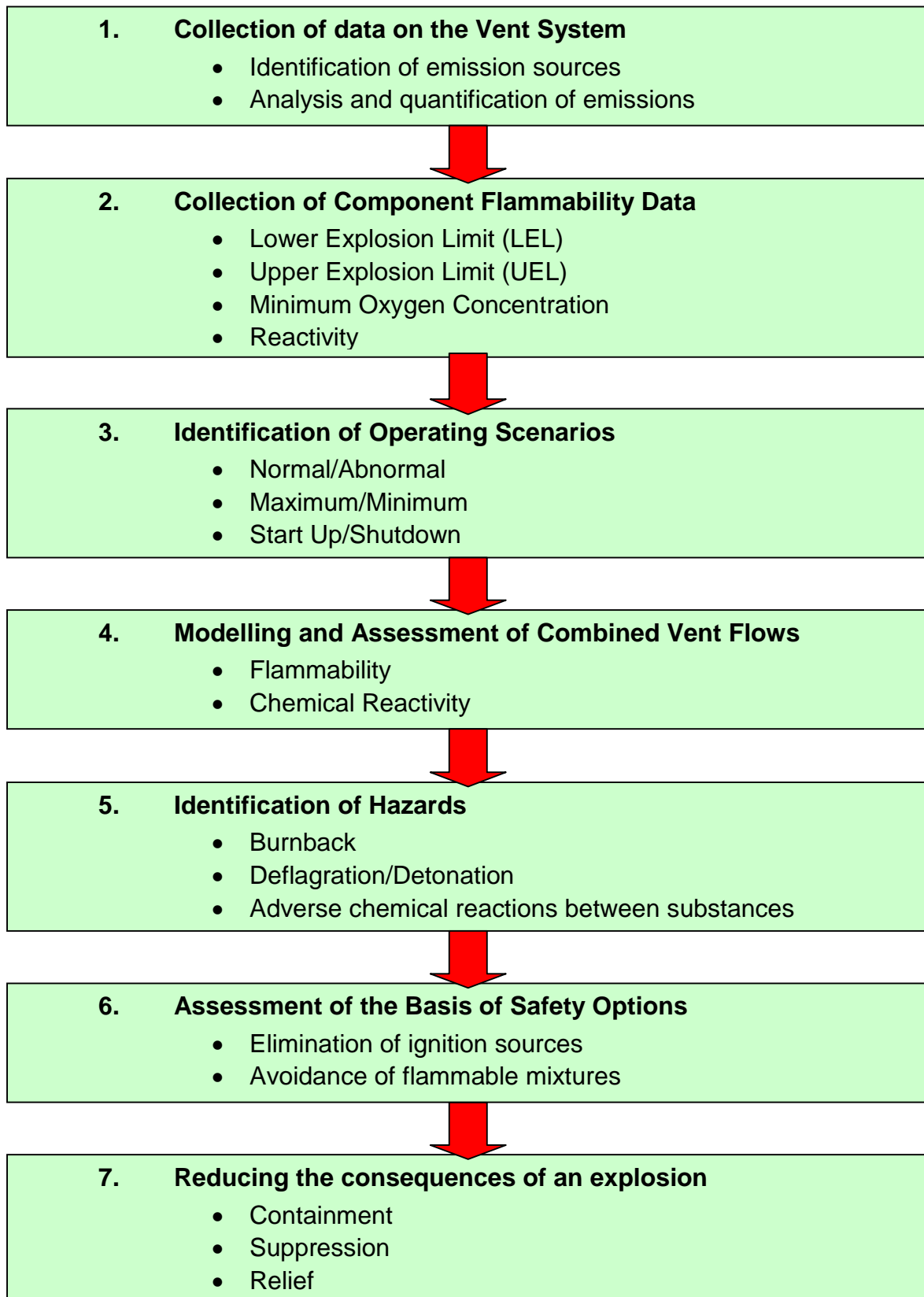
The range of operating scenarios that are appropriate to the individual process sources should be identified and process information gathered on them. Scenarios to be considered may include:

- Start-up from cold
- Re-start after trip
- Routine shut-down
- Emergency shut-down
- Stand-by
- Normal operation
- Low rate operation
- VOC/fuel excess
- Air/oxygen/oxidant excess or generation
- Inerting agent shortfall or failure
- Maintenance
- Depressurisation or venting down
- Vacuum development
- Purging
- Liquid in vent system

Other significant and foreseeable scenarios should also be identified as part of this work, which is intended to detail the full envelope of operating conditions for the system. The list produced should also include those scenarios that would arise through the failure of trips or controls. An in-depth knowledge of the plant and its associated control systems and safety trips will be required to identify and assess all the foreseeable scenarios.

A team of experienced personnel should be used for this task rather than a single individual. The maintenance of records on the system, however, should be the responsibility of a named individual. An important outcome of this work is to identify any differences in the way in which the system performs or in the conditions of each vent under the different operating scenarios and to appreciate if these lead to changes in the flow rate or composition of the vent.

Fig 2. Developing a basis of safety for a vent system



Modelling and Assessment of Combined Vent Flows.

The flammability characteristics of the emissions for all possible combinations of vent sources under each of the foreseeable operating scenarios should now have been determined. With this completed, it should be possible to place the composition of each of the possible vent streams into one of the following categories:

- Fuel-lean
- Fuel-rich
- Inerted
- Flammable

Fuel-lean vents, those with fuel concentrations below the LEL are safe under all situations where additional air ingress may occur. A loss or reduction of airflow through the system, however, may increase the concentration of flammable materials above the LEL for the mixture.

Fuel-rich vents have compositions above the UEL and so the ingress of air could bring the mixture into the flammable region by dilution or by the production of the flammable substance(s).

Inerted streams are those in which the oxygen concentration present is below the minimum oxygen concentration (MOC) necessary for combustion to take place. The ingress of air into systems of this type, for example by the venturi effect or through loss of over-pressure, may cause a localised increase in the oxygen content to above the MOC and produce a flammable mixture.

Flammable emissions are those with concentrations of flammable substances within the flammable range.

You should take particular note of processing scenarios that could move the composition within the vent system from “safe” into the flammable range. Flammable vent compositions should be avoided or treated to take them out of the flammable region (e.g. by inerting or dilution).

Although oxygen in air is by far the commonest oxidant, it is not the only one that may be encountered. Chlorine, in particular, and the oxides of nitrogen commonly act as powerful oxidising agents. The possibility of the presence or generation of other oxidants should be considered as part of the hazard identification process

Identification of Hazards.

When the individual and combined vent flows have been fully assessed and categorized it should then be possible to identify the hazards that these mixtures present. Potential hazards from flammable vent streams may include burnback and propagation to other vulnerable equipment, deflagration, detonation and unwanted chemical reactions between substances present in the streams.

Assessment of the Basis of Safety Options for the Vent System.

The work described above should have produced an in-depth understanding of the operating conditions that may occur within the vent system. You should now consider what an appropriate basis of safety for the system may be. Options may include:

Avoidance of ignition sources

This is an important technique that should be included in the design of the system whenever practicable. It will significantly reduce the likelihood of an explosion and is required under DSEAR. It is, however, very difficult to ensure the complete elimination of ignition sources. Consequently, this is not usually a suitable basis of safety for systems.

Avoidance of flammable mixtures

Ensuring that flammable mixtures are not present in the vent system can often be an attractive option for further consideration. In many circumstances this approach can generate acceptable levels of risk at reasonable cost. There are three general approaches through which the presence of flammable atmospheres can be avoided and the important aspects of each of these are summarized below.

Fuel-lean operation

Vent systems handling fuel-lean mixtures will remain safe should additional air enter the system unexpectedly. They can be operated above or below atmospheric pressure without increasing the risk of generating a flammable mixture through air ingress. If the vent stream is toxic then consideration should be given to operating at sub-atmospheric pressure in order to reduce the likelihood of releases into the local environment.

A substantial safety margin should be incorporated into the design to ensure effective dilution of flammable materials so that the concentration of flammable substances is always maintained well below the LEL in **all** sections of the system. The concentration of flammable substances should be controlled below 25% LEL **at the temperature of the mixture?**

Fuel rich (oxidant lean) operation

The concentration of flammable substances in fuel-rich vent streams is above the UEL. These mixtures are safe and will not ignite but this method of operation is much less robust and much more prone to failure than fuel-lean.

Fuel-rich systems can be considered to fail-to-danger. In the event of an unexpected leak of air into the system or a reduction in the amount of flammable material entering the vent stream the concentration of the flammable substances will fall. The reduction may be sufficient to drop the concentration of flammable substances below the UEL. In these situations there would be a flammable atmosphere within the system and the risk from explosion would be high.

Wherever practicable, the system should be operated at greater than ambient pressure when fuel-rich operation is considered as the basis of safety. Under these conditions the likelihood of leaks of air into the system will be significantly reduced. In

many situations a leak from the vent system to the atmosphere will be less hazardous than ingress of air that could result in the mixture becoming flammable.

The consequence of a leak from a fuel-rich header operating under significant positive pressure could be a jet fire that may impinge on adjacent equipment. The possibility of consequential ignition or damage to other equipment in this event should be considered.

Where the material in the gas stream is not only flammable but also toxic or highly damaging to the environment, the implications of operation at positive pressure requires further consideration. The consequences of a release of toxic material into the local environment should be carefully assessed against those from air ingress.

The low operating pressure of most vent systems means it is unlikely that leaks will release sufficient gas to cause a significant fireball or flash fire. If, however, the release were to occur into a confined area then the risk from a vapour cloud explosion should be assessed. Consequently, the implications arising from the routing of the vent system pipework and ducts should be given appropriate consideration at the design stage.

From the information above it should be readily apparent that fuel rich headers are always inherently less safe and generate a higher risk from fire and explosion than fuel lean headers.

Inert Operation

Inerted vent streams are those in which the oxygen concentration is maintained below the minimum oxygen concentration (MOC) necessary for combustion to take place. Under these conditions mixtures of flammable substances will not ignite. If, however, there is a leak of air into the system and the MOC is exceeded then a flammable mixture may be formed. Where this may be the case consideration should be given to operating the system at greater than atmospheric pressure.

The oxygen level within the system should be controlled at a level considerably lower than the MOC to compensate for uncertainties in concentration estimates, process fluctuations and the uncertainty in estimating the MOC of mixtures. The maximum concentration of oxygen during operation should be at least 2% below the lowest experimentally determined MOC for any foreseeable vent stream mixture. When determining the size of an appropriate "safety margin" due consideration should be given to the accuracy with which the oxygen concentration within the vent system can be monitored and controlled during operation.

Where inerting is the basis of safety, the accuracy and reliability of the monitoring system are of fundamental importance. It is likely that auto-calibrating or duplicate systems, supported by appropriate maintenance arrangements will be necessary to demonstrate that the hazards have been effectively managed.

Reducing the Consequences of an Explosion

The following techniques should be considered as ways in which the consequences of an explosion can be managed. In this way the risk to safety can often be greatly reduced.

Containment.

Here the system is designed and constructed to safely withstand and contain any foreseeable explosion. The equipment may be damaged as a result of the explosion but there will be little risk to safety. This approach is often possible but can prove to be very expensive to implement.

Explosion suppression.

This technique detects the initial stages of the explosion and stops its development, usually through the injection of a specialised suppressant chemical. This system works well with dust explosions but is often not effective with gaseous explosions.

Explosion relief/mitigation.

Here the over-pressure produced as a result of the explosion is relieved quickly and efficiently to prevent the vent system from failing in a dangerous manner. It is important to ensure that the energy and products of the explosion are vented to a safe place and not into a workroom. Explosion relief may frequently be used effectively to reduce the consequences of deflagrations but not detonations.

RISK ASSESSMENT

Once the basis of safety for the vent system has been established you should assess the implications of all foreseeable conditions on the safety of the system. The likelihood and probable consequences of a fire or explosion in the system should be determined in order to identify the total package of control and mitigation measures necessary to ensure that the level of risk is acceptable **and** has been reduced as low as is reasonably practicable.

Employers are required under the Management of Health and Safety at Work Regulations 1999 and, when flammable substances are involved, the Dangerous Substances and Explosive Atmospheres Regulations 2002, to carry out suitable and sufficient risk assessments in order to ensure that the risks to people are tolerable and as low as reasonably practicable.^{3.5} Published guidance on risk assessment is available from HSE publications INDG 163 (Rev 1) and L21 and also from BS EN 1050:1997; Safety of Machinery – Principles for risk assessment.

The work necessary to assess the risk resulting from a vent collection system should be undertaken in a structured, logical manner. An approach of the type outlined in [Figure 3](#) should enable the effects of plant activities, faults and process deviations on conditions within the proposed system to be determined. The work should show whether the proposed basis of safety is suitable or if unacceptable situations, e.g. flammable mixtures, are foreseeable. The safety measures in place to prevent such events occurring or to mitigate their effects should be determined. The effects and likely consequences resulting from a deflagration or detonation within the system should also be identified.

The hazards, the effects of an unwanted event and the likelihood of occurrence provide the basis for an assessment of the risk of injury arising from the operation of the vent system. A decision on the acceptability of the safety of the system will need to be made once this has been done. In circumstances where the risk is considered

to be unacceptable and cannot be reduced to an acceptable level through improved design or operation then secondary protection, i.e. explosion suppression or relief etc., will be necessary.

When the effect of secondary protection has been determined a further risk assessment for the vent system should be carried out. If the design and operating controls are appropriate and suitable secondary protection measures have been specified it is likely that the vent system will now present an acceptable level of risk. At this point the basis of safety document can be finalised.

The following subsections together with [Figure 3](#) may be helpful when developing the basis of safety proposal into a risk assessment and in finalizing the basis of safety document.

Identification of the Potential for Flammable Mixtures in the System

All the foreseeable scenarios that may still result in a flammable mixture in the vent system now need to be identified. The likelihood of these scenarios occurring should be assessed following the incorporation of the design and operational changes dictated by the proposed basis of safety. Much of the work carried out during the preparation of the basis of safety will be of assistance in this part of the study.

Estimation of the Likelihood of a Flammable Atmosphere in the System

The frequency with which the flammable atmosphere scenarios identified in the previous sub paragraph above will occur should be estimated. A thorough knowledge of the plant operation, layout and maintenance procedures is required to make a judgement on whether the likelihood of a flammable mixture being present within the system is high, medium or remote etc.

Estimation of the Likelihood of an Incendive Ignition Source

The likelihood of a sufficiently energetic source of ignition occurring in the vent system should now be assessed. The brief review of potential ignition sources given in the chapter on hazards should provide useful information to assist in this task.

Widespread experience has consistently shown that it is extremely difficult to completely eliminate ignition sources from workplace equipment. Consequently, it is always prudent to consider that there will always be a finite risk of an ignition source being present. Nevertheless, the avoidance of ignition sources is still a necessary and useful measure in reducing the likelihood of a fire or explosion. It is also an explicit requirement under DSEAR.³

Identifying the Consequences of Fire/Explosion in the Vent System.

The consequences of a deflagration or detonation in the vent system are largely determined by the characteristics of the flammable atmosphere and the vent system. The earlier section on explosions described how their properties vary considerably. The size and shape of the vent system and the chemicals present in the vent stream can make a great difference to how violently it may explode. In order to identify the likely effects of an explosion it is necessary to understand the characteristics of the explosible mixtures likely to be present.

The location of the vent system, e.g. its proximity to frequently occupied areas or flammable liquid/gas storage, will significantly affect the likelihood and severity of the injuries that may occur as a consequence of an explosion. The damage caused by the production of missiles and the potential for these to cause the rupture of neighbouring stock tanks or pressurised vessels should be considered. These “domino effects” can have a major impact on the risk that results from the vent system and should be adequately assessed and controlled.

Assessment of Risk.

A qualitative estimate of how frequently a flammable atmosphere and a sufficiently powerful ignition source are each likely to occur should now be determined. The likelihood of these two events occurring can be combined to provide an estimate of the likelihood that a flammable atmosphere will form within the system, be ignited and produce an explosion.

The likelihood of an explosion occurring should be combined with an estimate of the foreseeable consequences to arrive at an assessment of the overall risk of injury from the system. This should be reviewed and used as a basis upon which to make decisions on possible next steps.

If the degree of risk is considered to be unacceptable then further risk reduction work will be necessary. This may involve improved hazard prevention and control measures and/or secondary protection or mitigation against deflagration/detonation. If it is decided to improve the prevention and control measures, then fault trees can be very useful for identifying which events contribute most to likelihood of an explosion. This approach often enables better targeting on where to focus the risk reduction effort. Should it not be possible to further reduce risk in this way, secondary protection will need to be employed in order to enable a tolerable risk to be obtained.

The Health and Safety at Work etc. Act (1974), the Management of Health and Safety at Work Regulations 1999 and DSEAR require that risks to people should be reduced as low as is reasonably practicable (ALARP). Therefore, if even when the level of risk, in absolute terms, is considered to be tolerable, additional investment on risk reduction techniques should be applied up to the point where the level of risk is tolerable and any further reduction would involve a grossly disproportionate level of expenditure.

Identify Suitable Secondary Explosion Prevention/Mitigation.

The use of techniques to halt the progress or lessen the effect of an explosion is often necessary to fulfil the requirement to reduce risk to ALARP. Explosion relief, explosion suppression and flame arrestors are identified as **autonomous protective systems** under the “Equipment and protective systems intended for use in potentially explosive atmospheres Regulations 1996” and as such the appropriateness of their design now requires certification by a Notified Body. Some of the options available for the prevention or mitigation of deflagrations and detonations are given below.

Flame Arrestors

Flame arrestors are usually made in the form of a fine metal mesh pad and are designed to halt the progress of a flame front.⁶ The presence of a flame arrester in a pipeline or duct can often hold back a flame front and provide a short period of time

during which the plant may be shut down or the fault condition rectified before an incident occurs. Appropriate flame arresters are available for deflagrations and detonations. The main disadvantage of flame arrestors is the backpressure that they may produce, their potential for blockage and the subsequent alteration to designed flow rates. Metal element flame arrestors are probably inappropriate where solids or liquids capable of solidification or polymerisation are present within the vent stream. Guidance on the selection and use of flame arresters is contained in HSE guidance booklet HSG158, "Flame Arresters".

Explosion relief

Explosion relief is designed to open at a relatively low overpressure to allow an explosion to be safely discharged before a damaging pressure has built up inside the vent or pipe. Relief may be provided in the form of a weak membrane designed to burst, a light panel that blows out or hinged door that swings open at a low predetermined pressure.⁷

The design and installation of suitable explosion venting is a highly technical topic and should only be carried out by competent people. The work cannot be carried out successfully without a thorough knowledge of the explosion characteristics of the flammable materials present.

Very large flames are known to emerge when relief of an explosion takes place. The thermal radiation effects from these vented flame jets and fireballs can be very significant. Consequently, the location of discharge points for explosion relief devices should be selected with great care and should be an outdoor safe place, not into a workroom.

Well-designed and maintained explosion relief is a reliable method of mitigating deflagrations. It should be noted that explosion relief can only be used to protect against deflagration and prevent transition to detonation. It is generally not possible to adequately relieve stable detonations.

Explosion isolation and suppression

Explosion isolation involves detecting the early stages of an explosion using pressure or infrared etc. detectors. These trigger the activation of mechanical "slam-shut" valves or the injection of a chemical barrier ahead of the propagating flame front to arrest its progress through the vent system. Appropriate designs are available for deflagrations and detonations.

Systems in which the rapid closure of valves is fundamental to their effective operation cannot tolerate high levels of solids or streams where condensation or polymerisation of components in the vent stream is foreseeable.

Explosion suppression is a similar, active protection method and involves detecting and extinguishing the flame in the early stages of its development by rapidly injecting suppressant materials, such as nitrogen, carbon dioxide, steam and sodium hydrogen carbonate.

The injection of chemical suppressants interferes with the mechanism of the combustion reaction and arrests the propagation of the flame front. With inert suppressants the injected material dilutes the flammable mixture and takes the

composition in the system to below the LEL and the flame goes out. Other suppressants quench the explosion by the removal of heat; lowering the temperature of the mixture to below its auto-ignition temperature.

Explosion suppression systems are relatively expensive to install and need regular testing and maintenance by the manufacturer in order to ensure they will work when required. The design and installation of suppression systems is a highly specialised field and it is recommended that a competent specialist contractor is consulted for advice.

Hydraulic Arrester

Hydraulic arrestors use a liquid seal to act as a flame arrestor. An effective arrestor design is based upon ensuring that the velocity of gas through the sparge pipe allows a sufficient water layer between rising bubbles to prevent ignition transfer and flash back. Flame propagation will therefore be stopped at the water surface. Increasing the gas flow rate above the maximum gas flow will cause ignition transfer between bubbles and allow flash back. This type of arrester is not widely used due to the difficulties of design and their reliance on appropriate maintenance.

Containment

This method would require constructing the whole plant to withstand deflagration, overdriven detonation and stable detonation pressures as defined in the previous section. In situations where detonation is unlikely containment may be a viable approach due to the moderate (<10 bar) overpressures involved. Where detonation is possible this approach is often not practical.

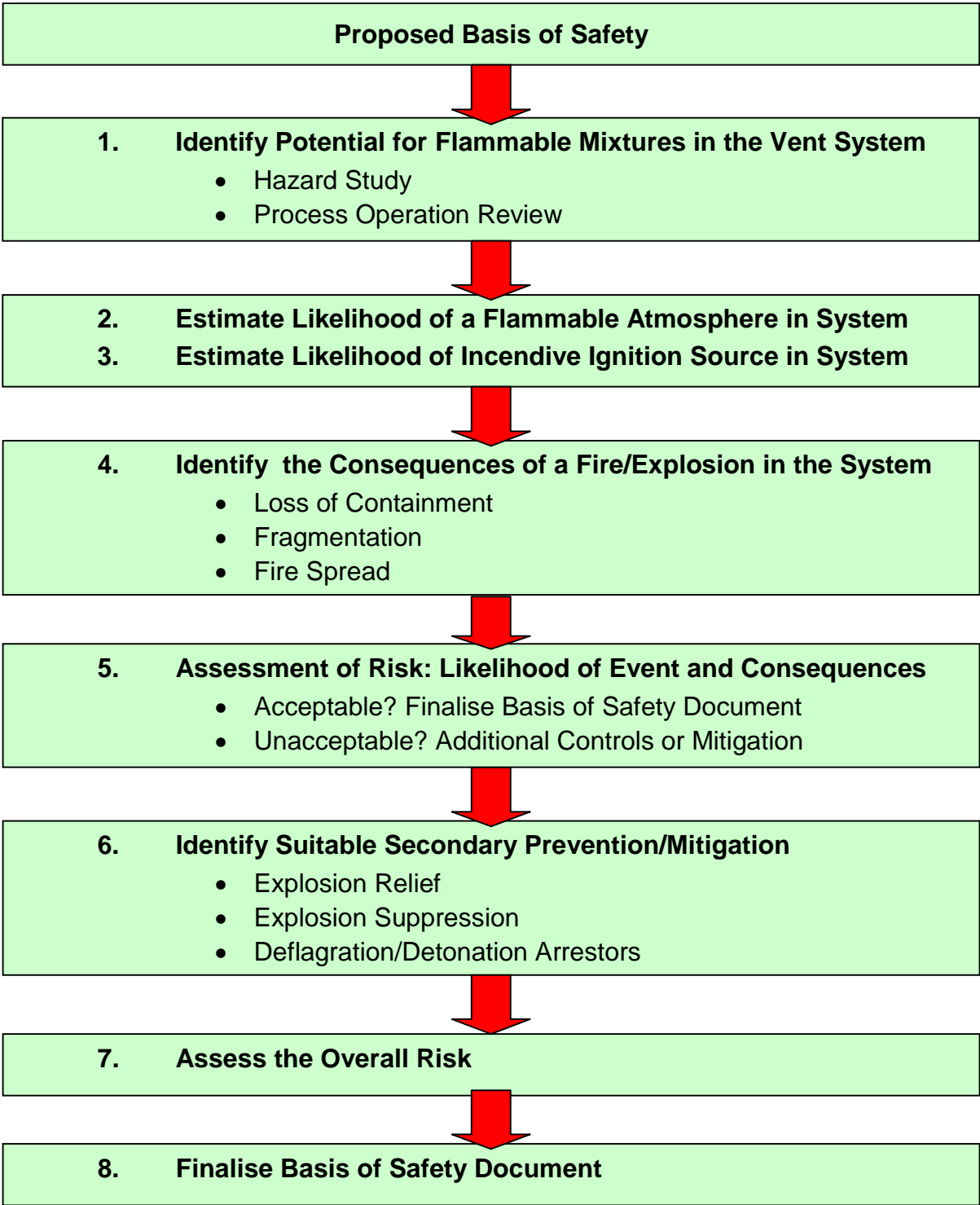
Assess the Overall Risk.

If the level of risk determined at sub paragraph, '[Assessment of Risk](#)' is unacceptable then use of appropriate secondary mitigation or protection techniques should be investigated. In particular, the effect on the areas of unacceptable risk identified in sub paragraph, '[Assessment of Risk](#)' should be assessed in detail. The equipment identified in sub paragraph, '[Identify Suitable Secondary Explosion Prevention / Mitigation](#)' above, should lead to a marked reduction in risk when used effectively.

It should now be possible to arrive at an assessment of the overall risk to people that the vent collection system produces. Provided that a suitable basis of safety has been selected, incorporating appropriate measures to contain and control all the foreseeable hazards, and any remaining significant risks have been mitigated then an acceptable level of risk should result.

All employers and the self-employed must carry out a risk assessment of their undertakings, those with 5 or more employees must record the significant findings. Employers are free to choose the manner in which they do this provided that the assessments are readily retrievable and where appropriate should be linked to other health and safety management information.

Fig. 3 Vent Collection System Risk Assessment



Finalise the Basis of Safety and Risk Assessment Documents.

The basis of safety document should identify the principles and techniques used to ensure that the plant is safe. Operating instructions, maintenance schedules and procedures, engineering drawings, analytical information and material safety data should be provided, where appropriate to support the basis of safety.

The risk assessment document should demonstrate that the design and basis of safety for the vent collection system are appropriate and that the level of risk from the system is acceptable.

LEGAL REQUIREMENTS

Health and Safety at Work etc. Act 1974

This Act is concerned with securing the health, safety and welfare of people at work and with protecting those who are not at work from risks to their health and safety arising from work activities. The Act and its relevant statutory provisions also deal with controlling the storage and use of explosives and highly flammable or otherwise dangerous substances. The general duties in sections 2 to 4 and 6 to 8 of this Act apply to all the work activities, which are the subject of this guidance book. The Act is enforced either by HSE or by local authorities as determined by the Health and Safety (Enforcing Authority) Regulations 1989. Guidance on the Act is contained in an HSE publication entitled **A Guide to the Health and Safety at Work etc. Act 1974**.

Management of Health and Safety at Work Regulations 1999

These Regulations require all employers and self-employed persons to assess the risks to workers and others who may be affected by their undertakings so that they can decide what measures need to be taken to fulfil their statutory obligations. These Regulations also require an assessment to decide on appropriate health and safety arrangements, health surveillance, emergency planning, and the provision of information and training. An Approved Code of Practice gives guidance on the provisions of these Regulations.

Dangerous Substances and Explosive Atmospheres Regulations 2002

DSEAR is a set of regulations specifically concerned with the protection of people against the risks from fire and explosion arising from presence of **dangerous substances** in the workplace. Dangerous substances include those flammable materials, e.g. solvents and VOCs that can produce an explosive atmosphere and are often present in the gaseous streams handled by vent collection systems. Under DSEAR the risks from fire and explosion should be assessed in detail. An appropriate risk assessment is an identification and careful examination of the dangerous substances present or likely to be present in the workplace; the activities involving them; and how these might fail and cause fire, explosion etc. and cause harm to employees or the public. Its purpose is to help determine what needs to be done to eliminate or reduce the safety risks arising from the use of dangerous substances. The risk assessment should take account of the hazards of the dangerous substances used and those hazards discussed earlier.

GLOSSARY

Auto-ignition temperature: The minimum temperature at which a material will ignite spontaneously under specified test conditions. Also referred to as minimum ignition temperature.

Combustible: Capable of burning in air when ignited.

Deflagration: An explosion in which the flame front in moving through the unburnt flammable mixture at a velocity less than the speed of sound.

Detonation: An explosion in which the flame front is moving through the unburnt flammable mixture at a velocity greater than the speed of sound.

Flame arrester: A device consisting of an element, a housing and associated fittings which is constructed and used to prevent the passage of flame.

Flammable: Capable of burning with a flame. When used to denote a hazard category under the CHIP Regulations it signifies a flash point below 55°C.

Flammable range: The concentration of a flammable vapour in air falling between the upper and lower explosion limits.

Flashpoint: The minimum temperature at which a liquid, under specific test conditions, gives off sufficient flammable vapour to ignite momentarily on the application of an ignition source.

Hazard: Something with the potential for causing harm. The harm may be to people, property or the environment, and may result from substances, machines, and methods of work or work organisation.

Header: A section of pipework or duct into which other, often smaller, pipes or ducts feed.

Incendive: Having sufficient energy to ignite a flammable mixture.

Inert: Incapable of supporting combustion; to render incapable of supporting combustion.

Lower explosion limit (LEL): The minimum concentration of vapour in air below which the propagation of a flame will not occur in the presence of an ignition source. Also referred to as the lower flammable limit or the lower explosive limit.

Risk: The likelihood that, should an incident occur, harm from a particular hazard will affect a specified population. Risk reflects both the likelihood that harm will occur and its severity in relation to the numbers of people who might be affected, and the consequences to them.

Risk assessment: The process of identifying the hazards present in any undertaking, the extent of those likely to be affected by them and likelihood of harm occurring and of evaluating the extent of the risks involved, bearing in mind whatever precautions are already being taken.

Upper explosion limit (UEL): The maximum concentration of vapour in air above which the propagation of a flame will not occur. Also referred to as the upper flammable limit or the upper explosive limit.

Vapour: The gaseous phase released by evaporation from a material that is a liquid at normal temperatures and pressure.

Vent collection system: An arrangement of pipework, ducts and other equipment, e.g. instruments, fans etc, used to prevent the uncontrolled escape of gaseous waste streams at the point of their generation by containing and directing them to a suitable location for their release or destruction.

VOC: volatile organic compound, such as a solvent or other low boiling point chemical.

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