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Safety Manual

Vacuum Pump and Vacuum Systems

Original Instructions

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Contents

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Contents

1 Introduction

1.1 Scope of this publication

This document contains safety information associated with the specification, design, operation and maintenance of vacuum pumps and vacuum systems.

The document identifies some of the potential hazards which can arise and provides guidelines intended to help minimise the probability of safety hazards and to ensure that, if a hazard arises, it is suitably dealt with.

This document is intended to be read by anyone who specifies, designs, installs, operates or maintains vacuum pumps and vacuum systems. We recommend that this is read in conjunction with:

- The Instruction Manuals supplied with your equipment
- Information provided by the suppliers of your process gases and chemicals
- Information supplied by your safety department.

WARNING

Failure to obey the safety instructions given in this manual and the relevant pump instruction manual can cause serious harm or death.

If you require any further information on the suitability of Edwards products for your process application, or on safety aspects of your vacuum pumps or vacuum systems, please contact your supplier or Edwards.

1.2 Explosion risks

Note: *Edwards pumps are available that meet the European ATEX directive for equipment used in potentially explosive atmospheres.*

Unexpected explosions are invariably caused by deviation from safety guidelines. Nevertheless, some of the incidents of explosions have been extremely violent and could have caused serious injury or death.

Common causes of violent rupture of a vacuum system component are ignition of flammable materials, or the blockage or restriction of the pump exhaust. To avoid hazards, you should pay attention to the following to help ensure the safe operation of your vacuum pumps and systems.

- Unless your system has been designed for pumping material at concentrations where it could be ignited in the vacuum pump, you must ensure that mixtures of flammables and oxidants are kept outside the flammable range. The use of inert purge is one way of achieving this. See Section 6.5 (Avoiding the flammable zone).
- Ensure that exhaust blockages cannot occur during operation, either because of mechanical components (for example, valves or blanks) or because of process materials or by-products depositing in pipelines, filters, and other exhaust components, unless your system has been designed to cope with it.
- Use only PFPE (perfluoropolyether) oils in places of the pump mechanisms which are exposed to high concentrations of oxygen or other oxidants. Other types of oils sold as "non-flammable" may only be suitable for use with concentrations of oxidants up to 30 % v/v.
- Ensure that the accidental over pressure of a deliberately closed and isolated vacuum system cannot occur; for example, as a result of a fault in a pressure regulator or purge control system.
- Where the pumped product can react violently with water, it is recommended that a cooling material other than water (for example, heat transfer fluid) be used in the cooling circuit. Please consult Edwards for advice.

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2 When hazards arise

Hazards can arise during all phases of a system's life. These phases are:

- Design
- Construction
- Operation / Commissioning
- Maintenance / Decommissioning.

The types of problem which arise in each phase are summarised below. In all cases, you must be aware that you can minimise the hazards in your system only when you have a thorough understanding of the equipment and process / application in the system. If you are in doubt, you must ask your suppliers for more information or advice.

2.1 Design

When you design your system, you must choose the correct type of equipment for your application. You must consider:

- the technical specification of the equipment
- the materials used in the construction of the equipment
- the operating consumables used with the equipment (such as lubricants and operating fluids)
- the process conditions and materials.

You must also think about the general suitability of the equipment for your application and ensure that it will always be used within its specified operating conditions.

You must establish design procedures to ensure that errors in the design are reduced to a minimum. Such procedures should include an independent check of design calculations, as well as consultation on design parameters.

Hazard analysis must always form part of your design review. You can eliminate many potential hazards by careful consideration of the use of equipment in your system.

2.2 Construction

Reduce the probability of the occurrence of a hazard during construction by the use of skilled and qualified personnel and quality assurance procedures. Skilled personnel are able to identify the correct components that are required during assembly and are also able to identify faulty or poorly manufactured components and equipment. Quality assurance procedures will help to identify and rectify poor workmanship and will ensure that the design specification is strictly followed.

Personnel must take special care and observe all safety precautions when installing new equipment in a system in which toxic, corrosive, flammable, asphyxiant, pyrophorics or other hazardous substances have been pumped, produced or may still be present.

Electrical equipment must be installed by skilled / qualified personnel, in accordance with all appropriate local and national electrical regulations.

2.3 Operation / Commissioning

Hazards can be caused during operation by equipment and component failure as a result of age, improper use or poor maintenance. Reduce the probability of such hazards by proper training in the use (and maintenance) of the equipment. Where necessary, refer to the information supplied by Edwards and your other suppliers in the form of Instruction Manuals, training and after sales service.

2.4 Maintenance / Decommissioning

To prevent personnel coming into contact with dangerous substances, special care must be exercised and all safety precautions must be observed during maintenance of a system in which toxic, corrosive, flammable, pyrophoric, asphyxiants or any other substances have been pumped or produced.

Consideration should also be given to a planned maintenance program, and to the safe disposal of components which may be contaminated with dangerous substances. You must follow the maintenance advice given in the instruction manuals for all equipment to ensure safe and reliable operation. Typically ATEX systems have additional requirements.

3 Chemical sources of hazards

3.1 Chemical reactions and explosions

You must carefully consider all possible chemical reactions which in normal use, misuse and failure conditions may occur at any point within your vacuum system. In particular, you must carefully consider reactions which involve gases and vapours which can lead to explosions. Experience has shown that explosions have occurred in which there were materials involved which were not originally considered by the system designer, and in which the failure mode of such equipment had not been taken into account.

3.1.1 Homogeneous reactions

Homogeneous reactions occur in the gas phase between two or more types of gas molecules. Gas combustion reactions are usually of this form. For example, to our knowledge, the reaction between Silane (SiH_4) and oxygen (O_2) is always homogeneous. Therefore, if you have such reactions in a manufacturing process, you must carefully control the process pressure and reactant concentrations to prevent the occurrence of excessive reaction rates.

3.1.2 Heterogeneous reactions

Heterogeneous reactions require a solid surface to occur i.e. some gas molecules only react when they are adsorbed onto a surface, but do not react in the gas phase at low pressures. This type of reaction is ideal for certain processes since it minimises the effects of reactions which occur within the process chamber, reduces the generation of particulate, and reduces the probability of contamination.

Most heterogeneous reactions become homogeneous at higher pressures, commonly well below atmospheric pressure. This means that the way the gases react in process chambers will not necessarily relate to the way that they react when compressed by a vacuum pump.

3.2 Problems with abnormal reactions

Abnormal reactions can occur when chemicals come into contact with gases or materials that the system designer has not anticipated. This can occur, for example, when there is a leak which allows either atmospheric gases to leak into the system, or toxic, flammable, explosive or other hazardous gases to leak out into the atmosphere.

To prevent the occurrence of these reactions, you should maintain a leak tightness of 1×10^{-3} mbar l s^{-1} (1×10^{-1} Pa l s^{-1}), or lower, in your system. High vacuum applications would typically maintain a leak tightness of 1×10^{-5} mbar l s^{-1} (1×10^{-3} Pa l s^{-1}) or lower. You must also ensure that all valves in the system are leak tight across their seats.

Gases which do not normally come into contact with each other during the process cycle may be mixed in the pumping system and exhaust pipelines.

It is possible that water vapour or cleaning solutions may be present in the process chamber after routine maintenance procedures. This could occur after the process chamber has been flushed and cleaned. Water vapour may also enter the system from exhaust ducts and exhaust scrubbers.

Where solvents are used to flush process deposits from the vacuum system, it is important to ensure that the selected solvent is compatible with all the process materials in the vacuum system.

3.3 Explosion hazards

The source of explosion hazards generally falls into one of the following categories:

- Oxidants
- Flammable / Explosive materials
- Pyrophoric materials
- Sodium azide.

Note that, in European Union (and some other) countries, suppliers of process materials are required by law to publish physical and chemical data for materials which they sell (usually in the form of Material Safety Data Sheets). The data for a material must include, where applicable, information about the upper and lower explosive limits, the physical and thermodynamic properties of the material, and any health hazards associated with the use of the material. Refer to this information for guidance.

3.3.1 Oxidants

Oxidants such as oxygen (O_2), ozone (O_3), fluorine (F_2), nitrogen trifluoride (NF_3) and tungsten hexafluoride (WF_6) are often pumped in vacuum systems. Oxidants react readily with a wide range of substances and materials and the reaction often produces heat and an increased gas pressure. The potential resultant hazards include fire and over-pressure in the pump and / or exhaust system.

To pump these gases safely, you must follow the gas supplier's safety instructions, together with the following recommendations:

- Always use a PFPE (perfluoropolyether) lubricant in pumps which are used to pump oxygen in concentrations above 25 % by volume in an inert gas.
- Use PFPE lubricants in pumps which are used to pump gases in which the percentage of oxygen is normally below 25 % by volume, but which could rise to above 25 % under fault conditions - if other oxidants other than oxygen are pumped, please consult the lubricant supplier for recommended levels of the oxidant present.
- PFPE lubricants are the preferred lubricants, but hydrocarbon type lubricants can be used if a suitable inert gas purge is used to guarantee that the oil is not exposed to unsafe levels of the oxidant.

Under normal circumstances, PFPE lubricants will not oxidise or break down in an oil-sealed rotary vane or piston pump oil box or gear box and so this reduces the probability of an explosion.

Note that thermal decomposition of PFPE lubricants may occur at or above a temperature of 290 °C in the presence of air and ferrous metals. However, the thermal decomposition temperature is lowered to 260 °C when titanium, magnesium, aluminium or their alloys are present.

If you do not want to use PFPE lubricants in oil-sealed rotary vane or piston vacuum pumps, you may dilute the oxidant to a safe concentration with an inert gas such as dry nitrogen. This approach is only feasible for low flow rates of oxidant gases. You must install safety features in your system to ensure that the minimum flow of the inert dilution gas required to reduce the concentration of the oxidant to a safe level is always available, and to ensure that the flow of oxidant does not exceed the maximum allowed flow rate. You must design your system so that the flow of oxidant stops immediately if these conditions are not met.

We recommend that you use Edwards dry pumps when you pump oxidants (see Section 7.2). Dry pumps have no sealing fluids in the swept volume and so there is a greatly reduced probability of the occurrence of an explosion if you use a dry pump to process oxidants. Edwards recommends an inert gas purge for the bearings and into the gear box when a hydrocarbon lubricant is used.

3.3.2 Flammable / Explosive materials

Many gases and dusts, such as hydrogen (H_2), acetylene (C_2H_2), propane (C_3H_8) and finely divided silicon dust are flammable and / or explosive in certain concentrations in an oxidant if an ignition source is provided. An ignition source could arise, for example, from a localised heat build-up. This is discussed in Section 6.8.

You can avoid the explosion hazard by ensuring that the concentration of the potentially flammable mixture is kept outside the flammable zone. Further details are given in Section 6.5.

Another method you may be able to use to reduce the probability of explosion is to eliminate the ignition source. Further details are given in Section 6.8.

Where it is not possible to avoid the flammable zone, you must ensure that the equipment is designed to avoid or to contain any resulting explosion without rupturing or transmitting a flame to the outside atmosphere. The use of flame arrestors is discussed in Section 6.7. If the external atmosphere of your vacuum system is hazardous you must ensure that all equipment is suitably rated for it.

Within the European Union the ATEX directive gives clear guidance on the design of equipment that is to be used in potentially explosive atmospheres.

Where it is possible to avoid pumping potentially explosive atmospheres under all conditions, all types of Edwards vacuum pumps may be used to pump flammable vapours or gases.

3.3.3 Pyrophoric materials

Under most conditions, pyrophoric gases such as silane (SiH_4) and phosphine (PH_3) or pyrophoric dusts spontaneously react with air at atmospheric pressure, so that combustion could occur when these gases come into contact with air, or other oxidant, where the pressure is sufficiently high to support combustion. This can happen if air leaks into the system or if the system exhaust comes into contact with the atmosphere. The heat from the reaction of an oxidant and pyrophoric gas can act as an ignition source for explosive materials.

If exhaust gases from different processes are vented through a common extraction system, combustion and / or an explosion could result. It is therefore recommended that you use independent extraction systems when you pump pyrophoric materials.

Processes that use phosphorus may cause solid phosphorus to condense in the vacuum system or its exhaust. In the presence of air and subject to even slight mechanical agitation (for example, activation of a valve or pump rotation caused by a pressure differential), phosphorus can spontaneously burn to release toxic gases. It is recommended that pumps are operated with an inert gas purge and run sufficiently hot to minimise the condensation of phosphorus.

PFPE lubricants can absorb process gases which, in the case of pyrophoric materials, can lead to local ignition when the lubricant is exposed to air. This hazard can become particularly apparent during servicing, or where an oxidant is pumped through the system after a pyrophoric gas or dust. You can reduce the probability of an occurrence of this hazard if you use Edwards dry pumps which contain no lubricants in the swept volume. You must ensure that all pyrophoric material has been passivated before it is vented or handled.

3.3.4 Sodium azide

Sodium azide is occasionally used in the preparation of products for freeze drying and in other manufacturing processes. Sodium azide can produce hydrozoic acid. Hydrozoic acid vapours can react with heavy metals to form unstable metal azides. These azides may explode spontaneously.

The heavy metals include:

- Barium
- Cadmium
- Caesium
- Calcium
- Copper
- Lead
- Lithium
- Manganese
- Potassium
- Rubidium
- Silver
- Sodium
- Strontium
- Tin
- Zinc
- Copper/zinc alloys (such as brass)

Brass, copper, cadmium, tin and zinc are commonly used in many components in vacuum pumps, accessories and pipes. If your process system uses or produces sodium azide, you must ensure that the gas path in your process system does not contain heavy metals.

3.4 Toxic or corrosive materials

Many vacuum applications involve the processing and handling of toxic and corrosive materials and require specific procedures.

3.4.1 Toxic materials

Toxic materials by their nature are hazardous to health. However, the nature of the hazard is specific to the material and its relative concentration. You should comply with correct handling procedures provided by the supplier of the material and applicable legislation.

You should also consider the following points:

- **Gas dilution** - Facilities exist to allow dilution of toxic process gases as they pass through the vacuum pump and into the exhaust. You may use this dilution to reduce the concentration below the toxic limit. We recommend that you monitor your dilution gas supply to alarm if the supply fails. Specifically for oil sealed pumps, refer to the pump instruction manual for possible oil return kits required.

- **Leak detection** - Edwards vacuum systems are generally designed to be leak tight - to a level of $< 1 \times 10^{-3}$ mbar l s^{-1} ($< 1 \times 10^{-1}$ Pa l s^{-1}). However, the leak tightness of the adjoining system cannot be ensured. You must use a suitable leak detection method (for example, helium mass spectrometry leak detection) to confirm the integrity of the vacuum and exhaust system.

- **Shaft sealing (Edwards dry pumps)** - Many dry vacuum pumps use a gas purge system to ensure process gases do not enter the gearbox and bearings and thereby potentially the atmosphere surrounding the vacuum system. You must ensure the integrity of this gas supply when handling toxic materials. Non-venting regulators must be used in combination with a non-return check valve, as discussed in Section 7.4.3.

- **Shaft sealing (Edwards other pumps)** - Oil flooded shaft-seal designs (for example, EH mechanical booster pumps and EM rotary vane pumps) minimise the risk of process gas leakage (or of the in-leakage of air), and can give a visual warning (oil leakage or oil level reduction) before a hazard arises. Other seal designs may not give adequate warning of failure.

- **Magnetic drives** - Where total hermetic sealing is required, Edwards EDP dry vacuum pumps can be supplied fitted with a magnetic drive employing a ceramic containment vessel which eliminates the need for shaft sealing on the motor input shaft.

If pressure relief valves or bursting disks are used to relieve excess pressure, ensure that they are safely vented into a suitable exhaust system, which prevents a toxic hazard.

When you return contaminated vacuum equipment to Edwards for service or maintenance, you must follow the specific procedures (Form HS1) and complete the declaration (Form HS2) given in the Instruction Manual supplied with the equipment.

3.4.2 Corrosive materials

When pumping corrosive materials with Edwards vacuum pumps, you should take note of the following points:

- **Moisture ingress** - You must take special care to prevent the ingress of moist air which can accelerate corrosive effects. An inert purge should be used as part of the shut down procedure in order to flush corrosives out of the system prior to shut down.
- **Dilution** - Use a suitable inert dilution gas to prevent condensation of corrosives and hence mitigate the resulting corrosion.
- **Temperature** - Increase the pump and exhaust line temperature to prevent condensation of water vapour which can therefore limit corrosion. In some cases higher temperatures can increase corrosion rates, please refer to the paragraph below.
- **Corrosion of safety equipment** - Where safety critical equipment (such as flame arrestor elements, temperature sensors and so on) could be damaged by corrosive products in the process gas flow, their materials of construction must be selected in order to remove this hazard.
- **Phase changes** - Unplanned phase changes can result in condensation. Consideration of changes in temperature and pressure is required to avoid this hazard.
- **Unplanned reactions** - Unplanned chemical reactions can lead to the generation of corrosive products. Careful consideration should be given to the possibility of cross contamination when equipment is used for more than one purpose.

Some corrosive materials such as fluorine, chlorine, other halogens or halides and oxidizing agents such as Ozone or reducing agents such as Hydrogen sulfide can also attack the materials they are in contact with, without the need for any liquid to be present. In these cases the partial pressure of the corrosive material should be minimized through the use of a suitable dilution gas. The materials of construction of the vacuum system and the pump model should be selected as being compatible with the particular gas in the concentrations expected. High temperatures can accelerate corrosion and so should be minimized where other process considerations allow. Maintenance intervals should be reviewed to consider the effect of corrosive materials on the system.

3.5 Summary - chemical sources of hazards

- Consider all possible chemical reactions within your system.
- Make allowance for abnormal chemical reactions, including those which could occur under fault conditions.
- Refer to Material Safety Data Sheets when you assess the potential hazards associated with your process materials.
- Use dilution techniques to minimise reactions with oxidants and flammable materials.
- In the EU where a flammable zone has been specified, you must use a suitable certified ATEX vacuum pump. For all other regions Edwards recommends the use of pumps that have been certified under the ATEX directive wherever possible.
- Use the correct type of lubricant in your pump when you pump oxidants, and consider the use of a dry pump.
- Do not use heavy metals in the gas path of your process system if your process uses or produces sodium azide.
- Take specific care when handling toxic, corrosive or unstable materials.

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4 Physical sources of hazards

4.1 Types of over-pressure hazard

The over-pressure of components in a vacuum system can be a result of any of the following:

- the introduction of high pressure gas into the system
- the compression of gas by the system
- a sudden increase of temperature of volatile gas in the system
- a phase change leading to the deposition of solid product
- reaction inside the vacuum system
- blocked exhaust.

Other causes are possible.

4.2 Over-pressurised pump exhaust

A common cause of an over-pressurised exhaust is a blockage or restriction in the exhaust system. This can lead to failure of the pump or other components in the system.

Vacuum pumps are compressors which are specifically designed to operate with high outlet-to-inlet compression ratios.

In addition to the potential over-pressure caused by the operation of the pump, the introduction of a compressed gas (such as a purge or dilution gas) can also over-pressurise the system if the exhaust system is restricted or blocked.

Where a pump is fitted with flame arrestors or other equipment like filters or condensers on the exhaust side, it is essential that the exhaust back pressure does not exceed the maximum limit stated in the vacuum system Instruction Manual. A suitable maintenance program should be employed to ensure that process deposits do not block the exhaust system and flame arrestor. If this is not practical, then a pressure sensor located between the pump and the flame arrestor should be used to detect blockage. Similar considerations should be given to other exhaust equipment such as filters and condensers.

Sublimation or phase change can lead to blockage by solid deposits of process pipework and an over pressure hazard.

Refer to the Instruction Manuals supplied with the vacuum pumping system for maximum and recommended continuous back-pressures of all your exhaust components including your vacuum pump. Design the exhaust system so that these limitations can be met.

For limits during continuous operation please refer to the pump instruction manual.

4.3 Protection against exhaust over-pressure

We generally recommend that pumps are operated with the exhaust piped into a freely vented exhaust system. However, your exhaust system may incorporate components which may cause a restriction or blockage of the system. If so, you must also incorporate suitable methods of protection against over-pressure. Such methods include, for example:

Component	Protection Method
Valve in exhaust pipeline	Interlock the valve so that it is always open when the pump is operating.
	Incorporate a pressure relief by-pass.
Exhaust scrubber	Incorporate a pressure relief by-pass.
	Incorporate a pressure monitor and interlock this with the pump so that the pump is switched off when the exhaust pressure is too high.
Flame arrestor	Exhaust pressure measurement.
	Differential pressure measurement.
Oil mist filter	Incorporate a pressure relief device.

To summarise, if the pressure in the exhaust system approaches the maximum allowable pressure:

- Reduce the pressure by a device in a gas path parallel with the restriction or blockage.
- Reduce the source of the pressure. Stop the pump or shut down any compressed gas supplies.

4.4 Inlet over-pressure

4.4.1 Compressed gas supplies and back pressure

It is common to underestimate the required pressure rating of the pipeline connecting the pump to the vacuum system, due to the belief that this pipeline will not be subjected to pressures above atmospheric pressure. In practice, this is only true under normal design operating conditions. You should estimate the required pressure rating to allow for higher pressures caused by abnormal or fault conditions.

A common cause of over-pressure in pump inlet pipelines is the introduction of compressed gases (such as purge gases) when the pump is not operating. If components in the inlet pipeline are not suitable for the pressures which result, the pipeline will rupture and process gases will leak from the system. A back flow of gases from the system into a process chamber which itself is not capable of withstanding the pressure which results, will also cause ruptures and leaks.

When you connect compressed gas supplies to your system through pressure regulators which are designed to provide a low pressure flow, ensure the pressure is within the rating of the system.

The non-venting pressure regulators commonly used will cause the pressure within the system to rise to the pressure of the gas supply to the regulator, if operated under conditions where there is no process gas flow through the system. You must therefore use one of the following two methods to prevent over-pressurisation:

- reduce the pressure, allow the gases to by-pass the pump and flow into a freely vented exhaust
- monitor the pressure of the system and use a positive closure valve to shut off the supply of compressed gas at a preset pressure level.

4.4.2 Incorrect pump operation

Special precautions must be taken until it has been established that the pump is operating correctly.

If the direction of rotation of the pump is incorrect and the pump is operated with the inlet blocked or restricted, the pump will generate high pressure in the inlet pipeline. This could result in rupture of the pump, the pipelines and / or components in the pipeline.

Always use a blanking plate loosely secured by screws to the pump inlet until you have established that the direction of rotation of the pump is correct.

Operation at high rotational speeds could result in pump break up. Do not operate the pump at rotational speeds above the maximum designed speed of rotation; this is particularly important where frequency inverters are used for speed control.

4.5 Summary - physical sources of hazards

- When you perform safety calculations, ensure that the safe working pressures for all components in the system are taken into account.
- Ensure that the pump exhaust cannot become blocked or restricted.
- If there is a risk of high pressures in excess of the pressure rating of any part of your vacuum system occurring, we recommend that your system incorporates suitably positioned pressure measuring equipment. This must be connected to your control system to put your system in to a safe state, if an over-pressure condition is detected.
- Take account of abnormal and fault conditions when you assess the required pressure rating of the vacuum system and pump components.
- Ensure that you incorporate the correct type of pressure relief device and that it is suitably rated for your application.
- Ensure that compressed gas supplies are properly regulated and monitored. Switch off these supplies if the pump is switched off.
- Where possible, ensure the supply pressure to any regulated purges is lower than the maximum allowable static pressure of the system. Alternatively, ensure that pressure relief is possible in the event of component failure.

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5 Hazard analysis

The techniques of hazard analysis provide a structured approach to the identification and analysis of the hazards in a system in normal use, and the hazards which may arise under fault and failure conditions. Such techniques provide a route to hazard management; the use of these techniques may, in many circumstances, be a statutory / legal requirement. To be fully effective, hazard analyses must begin during the initial design of a system and must continue through the installation and operation, as well as the maintenance and decommissioning of the system.

A detailed study of hazard analysis techniques is beyond the scope of this publication. There are, however, many hazard analysis techniques described elsewhere. An example of a technique commonly used in the chemical processing industry is HAZOP (Hazard and Operability Study). This is a procedure for hazard analysis which is concerned with the identification of potential hazards and operating problems.

Typically, hazard analyses generate information about the type of hazards, the severity of these hazards, and the probability that the hazards will occur. This information can be used to decide on the best way to reduce the effects of the hazards to acceptable levels. Depending on the origin of the hazard, it may be possible either to eliminate the hazard, or to reduce the severity of the hazard, and / or to reduce the probability that the hazard will occur. It is, however, rare that hazards can be eliminated completely.

You must consider all possible effects of a hazard when you decide on the best way to manage the hazard. For example, a small hot surface may present a minor hazard for an operator as it could cause a burn. To reduce the probability of the occurrence of a burn, the system designer may provide a visible warning of the hot surface, or may put a guard around the hot surface. However, the hazard analysis of the system may also indicate that the same hot surface could provide a source of ignition for flammable vapours; this might lead to an explosion or to the release of a toxic vapour cloud. To reduce the probability of ignition, the system designer must reduce the temperature of the hot surface, or ensure that the flammable vapours cannot contact the hot surface.

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6 System design

6.1 Pressure ratings in a system

As discussed in Section 4 vacuum system pipelines and components are designed to work with internal pressures below atmospheric pressure. In practice, however, it is usually necessary to design your system for use with internal pressures above atmospheric pressure as well. If necessary, you must incorporate pressure relief devices to prevent over-pressurisation.

It is important that you do not allow the inlet pipes and other inlet components to become the weakest part of the system, on the assumption that they will always operate under vacuum, even under fault conditions.

Exhaust systems must always be designed to offer the smallest possible back-pressure to the pump during operation. It is important, however, that you design your exhaust system with an adequate pressure rating; it must be suitable for use with the pressures that can be generated by the pump and also for example by the introduction into the system of a compressed gas, and be suitable for use with the over-pressure protection measures used.

When you perform your hazard analysis, you should always consider:

- External inlets, such as inert gas connections
- Isolation and constriction from all sources, especially in exhaust lines
- Reactions between process gases.

It should be noted that where a vessel contains a volatile liquid and can be isolated from the rest of the system, then the application of external heat (for example, from a fire) may result in internal pressures greater than the design pressure of the vessel. You must consider the need for suitable pressure relief in this case.

6.2 Elimination of stagnant volumes

A stagnant volume is any volume in a vacuum pipe or component which is not subjected to a through flow of gas. Examples are the gear box of a mechanical booster pump or the gauge head of an instrument. Valved pipework and nitrogen gas inlet pipes can also become stagnant volumes when they are isolated

Stagnant volumes must be taken into account when you consider the mixture and reaction of process gases which are not normally present together in the process chamber. Pipes, pumps and process chambers generally transport gases linearly, with one gas or gas mixture followed by another. Gases transported in such linear flows are not normally mixed unless the velocity of the exhaust gas is reduced by a restriction or blockage. A stagnant volume is not purged and may be filled with process gases as the pressure in the system rises and falls. In this way, gases which pass through the system at one stage of the process can be retained. These may then react with gases from a subsequent phase of the process. Thorough evacuation of the chamber between the introduction of incompatible gases will guard against the risk of explosion.

You must take special care when considering cross-contamination in stagnant volumes and when the gases are potentially explosive. In particular, you should consider the hazard of build-up in filters and separators and other components. Where appropriate, use high integrity, continuous flows of inert purge gas to reduce the probability of cross contamination.

When pumping flammables, it is possible for stagnant volumes to fill with potentially explosive gases or vapours that cannot be removed by normal purging. Where an ignition source could also be present, specific purging of the stagnant volume should be considered.

6.3 Exhaust extraction systems

It is important that you use the correct type of exhaust extraction system for your process. As previously stated, the extraction system must be designed to withstand the pressures of operation and, when hazardous materials are produced or processed, must be sufficiently leaktight to contain the process materials and their by-products and prevent hazardous releases to atmosphere.

6.4 Sources of potentially explosive gas or vapour mixtures

When a flammable gas or vapour is mixed with the correct concentration of oxygen or other suitable oxidant, it will form a potentially explosive mixture which can ignite in the presence of an ignition source.

While it is generally apparent if a pumped material is potentially explosive, there are, in the experience of Edwards, some conditions where a potentially explosive mixture is produced due to conditions which were not considered during the design of the system for the process. You must identify all possible process conditions and possible sources of potentially explosive mixtures which could be generated by your equipment. Some examples from Edwards experience are listed below, but the list is by no means exhaustive:

- **Cross contamination** - Where a vacuum pump is being used for a number of duties, it is possible that its use with individual materials is safe, but if the pump is not purged before use with another material, then cross contamination could occur with unexpected reactions.
- **Cleaning fluids** - An application may be viewed as benign, but the use of flammable cleaning fluids and the subsequent drying by evacuation through the vacuum pump can create a potentially explosive mixture.
- **Unexpected materials** - On 'house vacuum' duties where the vacuum pump is used to provide a distributed vacuum system, it is possible to pump flammable materials which were not considered during the system design. These materials may have auto-ignition temperatures lower than the internal temperatures or temperature rating of the vacuum pump.
- **Dissolved vapours** - These can evolve during process operation, and care needs to be taken to select the correct internal Temperature rating for your process. Typically in the Chemical process market, this is covered by ATEX requirements.
- **Air leakage** - The accidental ingress of air or oxidant into a system may change the concentration of a flammable gas or vapour and create a potentially explosive mixture.
- **Flammable sealing liquids** - Where a flammable liquid is used as the sealing liquid in a liquid ring vacuum pump, the ingress of air will create a potentially explosive internal mixture.
- **Condensed process materials -** If there is the possibility of flammable material condensing inside your system, you must be aware that they could react with oxidants from other process steps or with air (for example in the exhaust). This can be avoided by suitable temperature or partial pressure control.

6.5 Avoiding the flammable zone

A flammable material will only create a potentially explosive atmosphere if it is combined with air or oxygen or other oxidant and its concentration lies between the Lower Flammability Limit - LFL (or Lower Explosion Limit - LEL) and the Upper Flammability Limit - UFL (or Upper Explosion Limit - UEL). Please note that most data found in literature refers to flammability limits in air, i.e. where oxygen is the oxidant. All further information given below will be based on that assumption.

To be potentially explosive, it is also necessary for the concentration of oxygen to be above the Minimum Oxygen Concentration - MOC (or Limiting Oxygen Concentration - LOC). The MOC (LOC) for the majority of flammable gases is 5 % vol. or greater. (*Note: This does not apply to pyrophoric materials which require special precautions.*)

There are a number of strategies that can be used to avoid operating with gas mixtures in the flammable zone. The choice of strategy will depend on the outcome of the risk assessment (hazard analysis) for the process and the pumping system:

- **Maintain the flammable gas concentration below the LFL (LEL)**

  To minimise the risk of the flammable gas accidentally entering the flammable zone, a safety margin for below-LFL (LEL) operation should be used.

  A safety margin should be determined by the user following a risk assessment. Some authorities suggest maintaining the concentration at below 25 % LFL (LEL).

  The commonly used method of maintaining a suitable concentration below LFL (LEL) is dilution with inert gas purge (for example, nitrogen), introduced into the pump inlet and/or purge connections. The required integrity of the dilution system and of any alarms or interlocks will depend on the hazardous zone which would result if the dilution system were to fail.

Note: *Ensure that suitable precautions are taken to avoid the risk of asphyxiation.*

- **Maintain the oxygen concentration below the MOC (LOC)**

  This mode of operation requires the use of oxygen concentration monitoring of the pumped gases to ensure safe operation. To minimise the risk of the flammable gas accidentally entering the flammable zone, a safety margin for below-MOC (LOC) operation should be used. Available industry standards indicate that where the oxygen concentration is continuously monitored, it should be maintained at less than 2 volume percentage points below the lowest published MOC (LOC) for the gas mixture. Unless the MOC (LOC) is less than 5 %, the oxygen concentration must be maintained at no more than 60 % of the MOC (LOC). If monitoring is only undertaken in the form of routine oxygen level checks, the oxygen level should not be allowed to exceed 60 % of the lowest published MOC (LOC) unless the MOC (LOC) is less than 5 %, in which case the oxygen concentration must be maintained below 40 % of the MOC (LOC).

  The preferred method of maintaining the oxygen level below the lowest published MOC (LOC) is by the rigorous exclusion of air and oxygen from the process and pump system, together with dilution of the pumped gas with an inert purge gas (such as nitrogen), introduced into the pump inlet and/or purge connections, if needed. The required integrity of the air/oxygen exclusion measures and of any alarms and interlocks will depend on the hazardous zone that would result were the exclusion and dilution systems to fail.

  Precautions typically required to rigorously exclude air from the process and pump system are given at the end of this section.

- **Maintain the flammable gas concentration above the UFL (UEL)**

  Where flammable gas concentrations are high, then operation above UFL (UEL) can be more suitable. To minimise the risk of any accidental incursion into the flammable zone, a safety margin for above-UFL (UEL) operation should be used. It is recommended that the residual oxygen level in the gas should be maintained at less than 60 % of the absolute oxygen level normally present at the flammable gas UFL (UEL) concentration.

  The preferred method of maintaining the oxygen level below this safety margin, is rigorous exclusion of air and oxygen from the process and pump system. Dilution of the pumped gas with an inert purge gas (such as nitrogen) or with additional flammable gas ('padding' gas), introduced into the pump inlet and/or purge connections, may also be needed. The required integrity of the air exclusion measures, of any purge gas introduction system, and of any alarms and interlocks will depend on the hazardous zone that would result were the exclusion and dilution systems to fail.

- **Maintaining the flammable gas concentration below the minimum explosion pressure -** Every flammable material has got a minimum pressure below which an explosion can't be sustained. If the pressure at the inlet to the vacuum pump can be maintained securely below this pressure then ignitions starting inside the vacuum pump will not be able to spread to the inlet. Precautions, however, must be taken for the exhaust of the vacuum pump.

Precautions typically required to rigorously exclude air from the process and pump system are as follows:

- **Elimination of air leaks** - Use a leak detector or conduct a pressure ‘rate-of-rise’ test. Before admitting flammable materials into the process chamber, it is possible to perform a test to establish that air (oxygen) leakage into the vacuum system is within allowable limits.

  To perform a pressure ‘rate-of-rise’ test, the empty process chamber is evacuated to a pressure just below the normal operating pressure, and is then isolated from the vacuum pump. The pressure in the process chamber is then recorded over a fixed period of time. As the volume of the process chamber is known along with the maximum allowable air leakage, it is possible to calculate a maximum allowable pressure rise that can occur over the fixed period of time. If this maximum pressure limit is exceeded, action must be taken to seal the source of the air (oxygen) leakage into the process chamber; the test must then be repeated successfully before the admission of flammable materials into the process chamber is allowed.

  In some cases, the ability of the vacuum system to achieve a good base pressure can be used to indicate system leak tightness.

- **Remove all air from the system before the start of the process** - Before any flammable gas is admitted into the process, the system should be fully evacuated and/or purged with inert gas (such as nitrogen), to remove all air from the system. At the end of the process, repeat this procedure to remove any flammable gas before the system is finally vented to air.

- **For dry vacuum pumps** - Ensure that any shaft or purge seal gas cannot be supplied or contaminated with air under any circumstances, and ensure that any gas ballast port is either sealed, or only used to introduce inert gas.

- **For wet vacuum pumps (e.g oil sealed rotary piston or rotary vane pumps)** - Maintain the shaft seals fully in accordance with the manufacturer's instructions, and use a pumped and pressurised oil lubrication system with an alarm indication for loss of oil pressure. This system may comprise an external accessory to provide filtered and pressurised lubricating oil, with a pressure switch. Ensure that any gas ballast port is either sealed, or only used to introduce inert gas. Provide an adequate purge of inert gas to the oil box, to remove air before the start of the process.

- **For roots vacuum booster pumps** - Maintain the primary drive shaft seal fully in accordance with the manufacturer's instructions, and ensure that any purge or ‘breather’ port connections can only be used to introduce inert gas.

- **Reverse flow** - Ensure that the system operating procedures and facilities protect the system from any reverse air flow which might result from a pump failure. Ensure that any pumped flammable gases are safely disposed of at the final vent from the pump exhaust. Ensure that flammable gas mixtures cannot arise in the exhaust pipeline, by the use of suitable inert purging of the pipeline before the start of - and after the end of - the flammable gas process, and by the use of adequate inert gas purging during operation, to prevent turbulent back-mixing of air down the exhaust.

6.6 Levels of system integrity

Methods of protection using inert gas dilution have been discussed in earlier sections. The principle of the method is that you mix an inert gas (usually nitrogen) with your process gases to dilute them to a level where an explosion or reaction cannot occur. When you use gas dilution as a primary safety system to protect against possible explosion, you may require a high integrity alarm and interlock system to prevent the operation of the system when the gas dilution system is not operational. The integrity of the gas dilution system should be considered during the risk assessment (hazard analysis), and will depend on the internal zoning (i.e. level of risk) which would result were the dilution system to fail. Current best practice should always be applied to this risk assessment, to determine the required levels of system integrity.

For example, if a dilution system were used to maintain a flammable gas concentration outside the flammable zone, and the result of dilution failure would be that the pumped gas would be inside the flammable zone, continuously or for long periods of time (typically ATEX Zone 0 requirement would consider >50 %), then the dilution system must satisfy one of the following:

- It must be failsafe even in the event of rare malfunction
- It must be safe with two faults present
- It must comprise two independent dilution supply systems.

Alternatively, if the result of dilution system failure would be that the pumped gas would be inside the flammable zone occasionally (typically ATEX Zone 1 condition), then the dilution system must satisfy one of the following:

- It must be failsafe even in the event of expected malfunction
- It must be safe with one fault present.

If the result of dilution system failure is that the pumped gas would be unlikely to enter the flammable zone, or might do so only for brief periods (typically ATEX Zone 2 condition), then the dilution system must be safe in normal operation.

6.7 Use of flame arrester protection systems

If the mixture of pumped gases and vapours is flammable (see Section 6.5) continuously or for long periods of time (i.e Zone 0 condition) and if there is a risk of an ignition source (see Section 6.8) becoming active during normal operation or foreseeable malfunction you must fit flame arresters as required to your primary pump (also see Section 7.4.4). Third party certification has been obtained for the use of specific flame arresters with Edwards vacuum pumps, demonstrating their ability to prevent flame transmission along the process pipework or into the surrounding atmosphere.

Where the flammable mixture is present for long periods of time an approved and tested temperature transmitter has to be installed on the inlet flame arrester to detect a continuous burn. If a continuous burn is detected the pump needs to be switched off and isolated from the fuel source. Please contact Edwards for advice on approved flame arresters and temperature transmitters. In order to protect the flame arrester and pump thermally under rare malfunctions (Zone 0) of the pump, an exhaust temperature transmitter must be installed in the exhaust of the pump. Switch off points are dependant upon pumping systems. Please consult the relevant ATEX manual for the pump.

If either temperature transmitter on the inlet or exhaust reach their maximum limit, indicating a fault condition, then suitable actions must be taken. This is application dependent but could include:

- **Stopping the supply of fuel** - Closing a valve located on the inlet of the vacuum pump will prevent the supply of fuel into the vacuum pump
- **Stopping the source of the ignition** - Stopping the vacuum pump by turning off the power to the motor
- **Inerting the area of the burn** - The rapid addition of inert gas into the area of burn (typically, but not always located in the exhaust manifold of the pump), will eliminate the flame. Note that it is possible for a flame to re-ignite if the source of ignition is not removed.

6.8 Sources of ignition

Where vacuum pumps are used to pump flammable mixtures, you must consider all possible sources of ignition. Below are some areas of consideration which you can use as part of an overall review. Depending upon your process you might be able to avoid some or all ignition sources. If are unable to avoid the ignition source because of your process condition or system requirement, you must then design your system accordingly.

Note: *Some Edwards pumps are certified by a third party to confirm that (if correctly applied) they will contain an internal explosion.*

- **Mechanical contact** - Mechanical contact of rotating and stationary parts inside the vacuum pump and system could provide an ignition source. All Edwards vacuum pumps are designed and built to keep the correct running clearances inside the pump during all operating conditions. To avoid this ignition source it is important to avoid deposition of materials on the internal surfaces or to clean the pump. The bearings must be kept in good condition, have sufficient lubrication and suitable purge gas to eliminate contact with process gases. The recommended maintenance regime for the bearings must be followed to ensure safe and reliable operation.
- **Particle ingestion** - All pumping mechanisms have the potential to ingest particles which have been created by the process or which are a result of the system manufacturing process. Where these are rolled between a moving surface and a static one, it is possible to generate heat. A suitable inlet screen (mesh) or filter will prevent the ingress of particles into the vacuum pump to reduce the size and volume of particles to a safe amount. Care must be taken to have a suitable maintenance regime for the inlet screen.
- **Dust build up** - The build up of fine compacted dust within internal clearances can occur where any pumping mechanism is placed on a dust generating process. Even with the use of inlet dust filters, it is still possible for small dust particles to enter the pump. With small dimensional changes due to thermal changes, compacted dust can touch a moving surface and create heat.
- **Heat of compression (auto-ignition)** - The internal heat of compression within any compressor must be considered in relation to the auto-ignition temperature of any gases or vapours which are pumped. You must ensure that the pump has a temperature classification that is at least the same or higher than the gases you are pumping.
- **Hot surfaces** - Where flammable gases or vapours are allowed to come into contact with a hot surface, they may ignite if the auto-ignition temperature is exceeded. *Note: Edwards pumps and flame arrestors should not be thermally insulated if this could cause increased surface temperatures internally (and externally) leading to auto-ignition.*
- **Externally applied heat** - Externally applied heat can occur, for example, in the event of a fire in the immediate area of the vacuum equipment. Under this condition, it is possible to generate internal pressures in excess of the maximum static pressure of the system, and temperatures in excess of auto-ignition temperature. This should be considered as part of the system hazard analysis.
- **Hot process gas flow** - High inlet gas temperatures can lead to internal (or external) surfaces exceeding the auto-ignition temperature of the materials being pumped. High temperature inlet gas can also lead to rotor/ stator seizure. Please consult your vacuum pump instruction manual for maximum allowable internal gas temperatures. Consult Edwards for further advice.
- **Catalytic reaction** - The presence of certain materials can lead to catalytic ignition. All materials of construction in the vacuum system should be considered for their potential to act in this way with the pumped gases or vapours.
- **Pyrophoric reaction** - The heat of combustion of pyrophoric materials caused by air or oxidant ingress could act as an ignition source for any flammable material present. See Section 3.3.3.
- **Static electricity** - Certain conditions can occur where static electricity can build up on insulated components before discharging to earth in the form of a spark. The potential for static build-up should be considered as part of the system design.
- **Lightning** - Where located in an outdoor location, a lightning strike can provide ignition energy. The potential of this event occurring should be considered as part of the system design.

6.9 Summary - system design

In order to design safe vacuum pumping systems, the following points must be taken into consideration. Depending on your application, there may be others.

- If you pump hazardous materials, you must design the system to fail to a safe condition
- Use PFPE (perfluoropolyether) lubricants in pumps when you pump oxidants
- Where inert gas is used to reduce the concentration of the flammable gas below the lower explosion or flammability limit or below the minimum or lower oxidant concentration you must ensure the integrity of the inert gas supply
- The concentration can also be kept above the upper explosion or flammability limit, but suitable safety precautions need to be put in place to ensure that the concentration cannot fall into the flammable range
- Leak test systems and equipment to ensure required leak tightness before use
- Dilute pyrophoric gases to safe levels with an inert gas before the gases are exhausted to atmosphere or mixed with oxidant gases
- You must not allow contact between sodium azide and heavy metals anywhere in the gas path of your system
- You must not allow the maximum pressure of the system to exceed the individual safe level of any single part of the system
- You must always consult the safety information supplied for the substances which you intend to pump
- Consider the use of dry pumps in preference to oil sealed rotary vane or piston pumps where there are hazards associated with the oil in the swept volume
- Where Edwards vacuum pumps are used to pump potentially flammable mixtures, you must consider all possible sources of ignition and the potential consequence of a possible explosion.

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7 The correct choice of equipment

To ensure that you choose the correct equipment for your application, you must consider the limits within which you will require the system to operate. The technical data for Edwards equipment is given in our Product Catalogue, Marketing Publications and in the equipment's Instruction Manual(s). In most instances, further information is available on request; please contact Edwards for further advice.

When you design your vacuum system, take account of the relevant mechanical pump parameters, for example:

- Maximum static pressure (inlet and exhaust)
- Maximum operating inlet pressure
- Maximum operating exhaust pressure
- Conductance of the inlet and exhaust components
- Pressure specification of other components fitted to the pump
- Pressure monitoring in case the exhaust line becomes blocked.

For oil-sealed rotary vane and piston pumps, you must also consider for example:

- Gas ballast flow rate
- Oil box purge flow rate
- Gases and vapours trapped in the oil box
- Gases and vapours absorbed into the oil in the oil box.

The maximum static pressure defines the maximum pressure to which an inlet or outlet connection of a pump can be exposed when the pump is not operational. The pressure is dependant on the mechanical design of the pump.

Oil-sealed rotary vane and piston pumps are designed to operate with inlet pressures at or below atmospheric pressure and, even though the maximum static pressure rating may be above atmospheric pressure, the maximum inlet pressure of the pump when it operates must not be allowed to go above atmospheric pressure. Some manufacturers limit the continuous inlet pressure of their pumps to pressures below atmospheric pressure. The maximum inlet pressure with the pump in operation is referred to as the maximum operating pressure.

The reason that the maximum operating pressure is limited, is not necessarily related to the mechanical integrity of the pump. The maximum pressure is usually proportional to the power rating of the pump at high inlet pressures, and is associated with the potential hazard of overheating the mechanical components of the pump or the electric motor.

For similar reasons, we recommend that you maintain the outlet pressure of your vacuum pump as low as possible (typically at or below 0.15 bar gauge, 1.15×10^5 Pa, for continuous operation). Pumps are designed to operate with unrestricted exhausts and an outlet pressure of 0.15 bar gauge (1.15×10^5 Pa) is usually high enough to drive exhaust gases through your exhaust extraction system and treatment equipment.

7.1 Oil-sealed rotary vane and piston pumps

Edwards oil-sealed rotary pumps include the E1M, E2M, ES and RV series rotary vane pumps, and the Stokes Microvac range of oil sealed piston pumps. Generally, all vacuum pumps are designed to operate with inlet pressures below atmospheric pressure and with the pump exhaust freely vented to atmosphere.

Oil-sealed rotary vane and piston pumps are positive displacement compressors and can generate very high exhaust pressures if the outlet is blocked or restricted. In these cases, the pressures can exceed the safe static pressure of the pump oil box and, in many instances, the safe static pressures of downstream components in the system (such as polypropylene scrubbers or vacuum O-ring joints). Therefore Edwards strongly recommends that you fit a high integrity exhaust pressure sensor in the pump exhaust line.

To achieve a safe level of dilution, the gas ballast can be augmented by an oil box purge (where this facility is available) connected to the oil box on the pump. An increase in the gas ballast and oil box purge flow rates increases the amount of oil carried over to the exhaust system.

All Edwards oil-sealed pumps have significant oil box volumes which can retain flammable and explosive gas mixtures. The oil in the oil box can effectively absorb or condense vapour and gaseous by-products. The vapours and gases trapped in the oil may be pyrophoric or toxic. You must, therefore, have special handling procedures to ensure safety during maintenance.

7.2 Edwards dry pumps

The maximum operating pressure is limited by the same factors that affect oil-sealed pumps (that is, the potential hazard of overheating the mechanical components of the pump or the electric motor).

Edwards dry pumps are positive displacement compressors and can generate high exhaust pressures. When the pumps are incorporated into a system where the process can result in solid by-products, (and so there is a possibility of a blockage in the exhaust line), Edwards strongly recommends that you fit a high integrity exhaust pressure monitor. Consult the pump Instruction Manual for the operating pressures to which the switches should be set.

Edwards dry pumps have a high-throughput gas ballast capability. The addition of a dilution gas such a nitrogen can be made into the pump mechanism to optimise reaction suppression. Please refer to your pump instruction manual for gas purge flow rates.

7.3 Pipeline design

7.3.1 Bellows

Bellows are short, thin walled components with deep convolutions. They are used to reduce the transfer of vibration from a pump to your vacuum system.

Always install bellows in a straight line with both ends rigidly constrained. When installed correctly, the bellows can withstand a small positive internal pressure (refer to the Instruction Manual supplied with your bellows for details). Do not use bellows on dry pump exhausts; use braided flexible pipelines (see Section 7.3.2).

Consider the possibility of bellows fatigue failure when used on frequent cycle applications.

7.3.2 Flexible pipelines

Flexible pipelines have a thicker wall section and shallower convolutions than bellows. Flexible pipelines provide a convenient method for the connection of vacuum system components and help to compensate for misalignment or small movements in rigid vacuum pipelines. Flexible pipelines can be formed into relatively sharp bends and will hold their position.

Flexible pipelines are intended for installation in static systems. They are not suitable for repeated flexing which could cause fatigue failure.

When you use a flexible pipeline, use the shortest possible length and avoid unnecessary bends. For applications where high exhaust pressures can occur, braided flexible pipelines should be used.

Braided flexible pipelines are bellows with an outer protective layer of woven stainless steel braid. When you install a braided flexible pipeline, you must observe the minimum bend radius given in the Instruction Manual supplied with the braided flexible pipeline.

7.3.3 Anchor points

You must anchor pipelines and pipeline components correctly. For example, if you anchor bellows incorrectly, they will not reduce the vibration generated by the pump and this could lead to fatigue in the pipelines.

7.3.4 Seals

Where there is the possibility of positive pressures occurring in any part of the vacuum system (even under failure conditions), you must use suitable seal types and materials which are capable of withstanding the expected vacuum and positive pressures.

7.4 Physical over-pressure protection

As discussed previously, over-pressure can be caused by a restriction or blockage in your system or in one of its components. The over-pressure may occur as a result of compressed gas flow from the pump or from external compressed gas supplies (such as those for a dilution system). There are two main methods of system over-pressure protection: namely pressure relief and over pressure alarm / trip, which are described in the following paragraphs.

7.4.1 Pressure relief

You may use bursting disks or pressure relief valves to relieve an over-pressure condition. The operating pressure of the device must be below the design pressure rating of the system. You must connect these devices with suitable pipelines to an area in which it is safe to vent your process gases and which does not have vent restrictions. If your process produces solid by-products, the pressure relief devices must be inspected regularly to ensure that they are not blocked or restricted. The design of such protection devices should take into account the effect of pressure pulsations on the fatigue life of the bursting disk or the life of the valve.

7.4.2 Over pressure alarm/trip

This method of protection is often used by Edwards. This type of protection is recommended for any system, but may not be suitable for systems which produce solid by-products.

7.4.3 Pressure regulators

There are two main types of pressure regulators: venting and non-venting.

Venting regulators vent gas to atmosphere or to a separate vent line to maintain a constant outlet pressure under no-flow conditions. Venting regulators are generally used where pipeline integrity is of paramount importance.

Non-venting regulators can only maintain a constant outlet pressure under flow conditions.

Under no-flow conditions, the outlet pressure of some regulators can rise to the level of the supply pressure. The rate of rise is dependent on the characteristics of the regulator and the volume to which its outlet is connected. The rise can take from a few minutes to several months.

Pressure regulators are not designed to be shut-off valves and must be used in combination with a suitable isolator device (such as a solenoid valve) when isolation is required. Alternatively, you must take measures to safely vent excess pressures.

7.4.4 Flame arresters

Flame arresters are not explosion prevention devices. They are designed to prevent the propagation of a flame front along a pipe or duct (please refer to Section 6.7). Flame arresters offer a large surface area and small conductance gaps to the flame front, and so cause the flame to be quenched. Flame arresters are generally only suitable for use in systems which are used for clean gases or vapours.

The explosive energy of gas mixtures increases with pressure. Most flame arresters are designed to protect areas where the internal pressure does not exceed atmospheric pressure. You must ensure that the operating pressure in the exhaust extraction system leading up to the flame arrester is not allowed to exceed the maximum operating pressure. However in the case of arrestors certified for use with Edwards Chemical dry vacuum pumps, please refer to the ATEX instruction manual for maximum allowable pressures. You must also consider the maximum allowable back pressure of your vacuum pump.

Flame arresters operate by removing the heat of combustion from the flame front, and therefore have a maximum safe operating temperature. You must not allow this temperature to be exceeded by trace heating, insulation or the temperature of the gas flow passing through them.

The ability of a flame arrester to arrest a flame depends on the speed of the flame front, which in turn depends on its distance from the source of ignition. When used with Edwards Chemical vacuum pumps they should be closely coupled to the inlet and exhaust. The use of Elbows and Tee pieces between the pump and the arrester is acceptable for some pumps under certain conditions. Please consult Edwards for advice.

7.5 Purge systems

Inert gas purge systems can be fitted to equipment in order to remove process gas remaining in the system after the end of a process cycle.

The correct use of purge can ensure that corrosive products are removed, preventing them from damaging the pump and more importantly damaging protective systems such as flame arresters. In addition, the removal of process gases ensures that undesired and potentially dangerous chemical reactions do not occur between materials used on different process cycles.

7.6 Summary - the correct choice of equipment

- Select the correct type of equipment for your application
- Incorporate all of the appropriate safety devices necessary to ensure safety in the event of a failure
- Eliminate stagnant volumes
- Ensure that the system is suitably controlled and regulated
- Where appropriate, incorporate pressure relief devices
- Use flame arrestors where appropriate
- Leak test systems and equipment before use.

8 Operating procedures and training

The operating safety of equipment requires proper training, clear and concise instructions and regular maintenance. It is important that all personnel who use vacuum equipment are properly trained, qualified and, where necessary, supervised.

If you are unsure about any detail of operation or safety which relates to Edwards equipment, please contact us for advice.

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9 Summary

- Perform a hazard assessment to identify and where possible eliminate and if not mitigate all hazards. This needs to be carried out for vacuum system design, construction, commissioning, operation, maintenance and decommissioning.
- Consider all possible chemical reactions within your system. Make allowance for abnormal chemical reactions, including those which could occur under fault conditions.
- Refer to material data sheets/Material Safety Data Sheets when you assess the potential hazards associated with your process materials, for example, auto-ignition.
- Use dilution techniques to minimise reactions with oxidants and flammable materials.
- Use the correct type of lubricant in your pump when you pump oxidants and pyrophoric materials.
- Do not use heavy metals in the gas path of your pumping system if your process produces or uses sodium azide.
- When you perform safety calculations, ensure that the safe working pressures for all components in the system are taken into account. Ensure that you also take account of abnormal and fault conditions.
- Ensure that you incorporate the correct type of pressure relief devices and that they are suitably rated for your application.
- Ensure that exhaust blockages cannot occur.
- Ensure that dilution gases are properly regulated and monitored.
- If you pump hazardous materials, you must design the system to fail to a safe condition.
- Use PFPE (perfluoropolyether) oil and lubricants when you pump oxidants.
- Use an inert gas to dilute flammable and pyrophoric gas to safe levels or ensure that you stay above the upper flammable / explosion limit considering suitable safety factors during all process conditions including faults.
- You must not allow the maximum pressure of the system to exceed the maximum pressure rating of any single part of the system.
- Consider the use of dry pumps in preference to oil sealed pumps where hazards associated with oil in the swept volume exist.
- Eliminate stagnant volumes.
- Ensure that the system is suitably controlled and regulated.
- Use flame arresters where appropriate.
- Leak test systems and equipment before use.

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