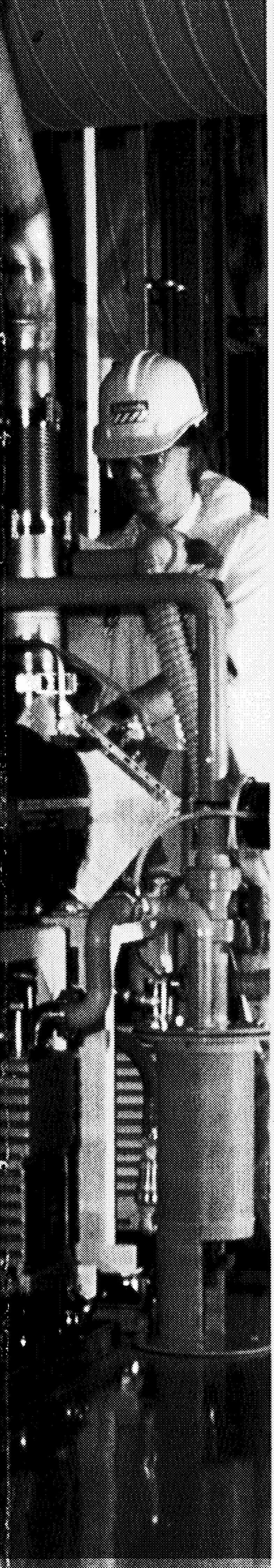

Vacuum pump and vacuum system safety

EDWARDS

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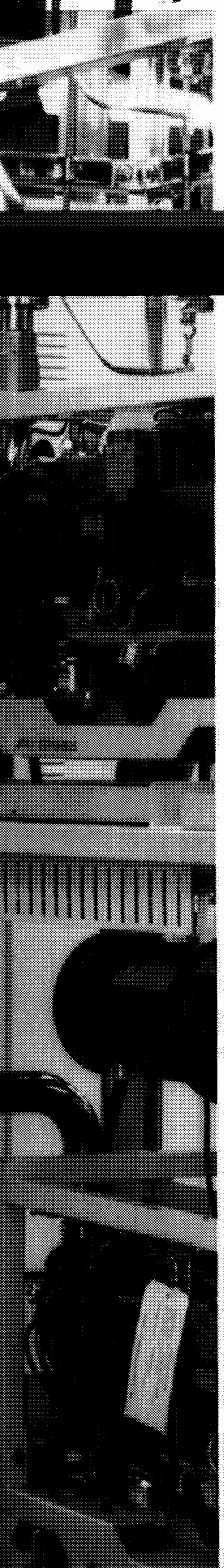
Associated publications

Publication number	Title
P500-10-000	Leak testing CDP installations

SECTION A

INTRODUCTION



SECTION 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 the potential hazards which can arise and provides guidelines intended to help you minimise the probability of safety hazards and to ensure that – if a hazard arises – it is suitably dealt with.

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

- the instruction manuals supplied with your vacuum equipment
- information provided by the suppliers of your process gases and chemicals.

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

1.2 Explosion risks

The rupture or fragmentation of vacuum system components (including pumps) can occur as a result of:

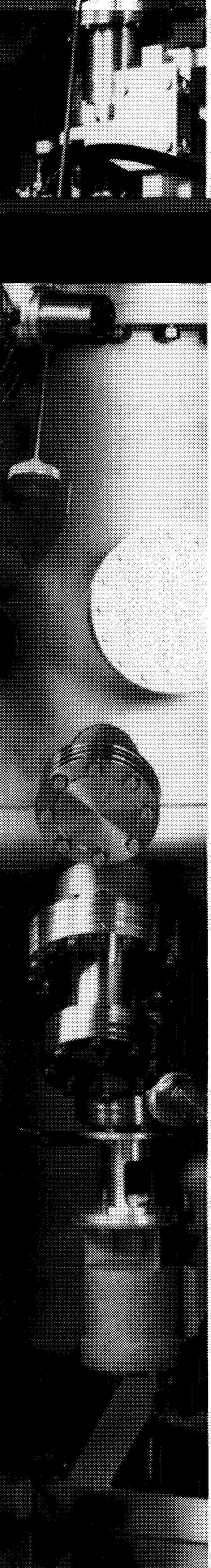
- The violent reaction or explosion of combustible gases or vapours with air or other oxidants. These conditions and suitable protection measures are discussed in Section 3.

- The restriction or blockage of a pump or compressor exhaust, which causes over-pressure of components and their failure: such failures may be violent or "explosive" and are discussed in Section 4.

Explosions in pump exhaust systems have occurred with low frequency throughout the world, especially (but not uniquely) in systems for semiconductor processing applications. Explosions are invariably caused by accidental misuse of equipment. Nevertheless, some of the incidents of explosion have been extremely violent and could have caused serious personal injury or death.

The most common cause of violent rupture of a vacuum system component is the blockage or restriction of the pump exhaust. Pay attention to the following to ensure the safe operation of your vacuum pumps and systems:

- Ensure that exhaust blockages cannot occur during operation, either because of mechanical components (for example, valves or blanks) or because of process by-products (in pipelines, filters and so forth).
- During operation, ensure that there is always a suitable supply of inert gas to dilute flammable and pyrophoric gas to safe levels. This is particularly relevant when you pump gases such as silanes.
- Use only PFPE (perfluoropolyether) oils to lubricate oil-sealed rotary vacuum pumps when you pump pure or high concentrations of oxygen or other oxidants. Other types of oil which are sold as "non-flammable" may only be suitable for use with concentrations of oxidants up to 30% vv.
- 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.



SECTION 2

WHEN HAZARDS ARISE

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

- design
- construction
- operation
- maintenance

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 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)

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

You must establish design procedures to ensure that errors in 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 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, flammable or pyrophoric substances have been pumped or produced.

2.3 Operation

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 information supplied by Edwards and your other suppliers in the form of instruction manuals, training and after sales service.

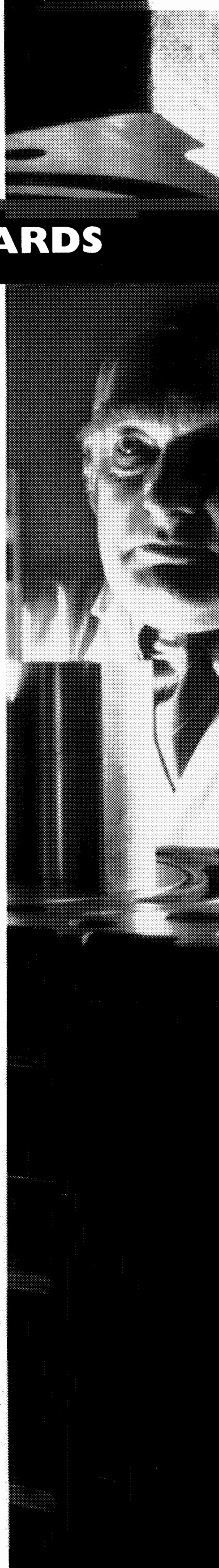
2.4 Maintenance

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, flammable or pyrophoric substances have been pumped or produced.

Consideration should be given to the safe disposal of components which may be contaminated with dangerous substances.

SECTION 3

CHEMICAL SOURCES OF HAZARDS



3.1 Chemical reactions and explosions

You must carefully consider all possible chemical reactions which may occur at any point within your vacuum system and, in particular, reactions which involve gases and vapours which can lead to an explosion or deflagration. This is particularly important in semiconductor process systems, as the system designer may lack the necessary detailed knowledge of the process and may not be aware of all of the chemicals that will be present. In addition, the type of gas phase reaction and its rate can vary enormously with changes in the pressure of the reaction. Consequently, the reaction inside a semiconductor process chamber may be different to the reaction inside a rotary pump during a compression cycle.

Reactions can be:

- Homogeneous
- Heterogeneous

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 and oxygen is always homogeneous. Therefore, if you use this reaction in a semiconductor manufacturing process to deposit silicon oxide onto wafer crystals, 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. 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 semiconductor manufacturers since it minimises the effects of reactions which occur within the chamber, reduces the amount of particulates 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 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 design does not anticipate. This can occur, for example, when there is a leak which allows either atmospheric gases to leak into the system or toxic, flammable or explosive gases to leak out into the atmosphere.

To prevent the occurrence of these reactions, you should maintain a leaktightness of 1 x 10^{-5}mbar.ls^{-1}, or lower, in your system. You must also ensure that all valves in the system are leaktight 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 may be present in the process chamber after routine maintenance procedures. This could occur after the process chamber has been washed and cleaned. Water vapour may also enter the system from exhaust ducts and exhaust scrubbers.

3.3 Explosion hazards

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

- Oxidants
- Flammable materials
- Pyrophoric materials
- Sodium azide

Note that, in the UK, suppliers are required by law to publish physical and chemical data for materials which they sell. 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 volume; the potential resultant hazards are fire and over-pressure in the pump or exhaust system.

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

- 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.

Under normal circumstances, PFPE lubricants will not oxidise or breakdown in a rotary vane pump oil box or gear box and so this reduces the probability of 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; the thermal decomposition temperature is lowered to 260°C when titanium and its alloys are present.

If you do not want to use PFPE lubricants in rotary vane 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 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 an Edwards Drystar® pump when you pump oxidants (see Section 7.2). Drystar 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 Drystar pump to process oxidants.

3.3.2 Flammable materials

Many gases, such as hydrogen (H_2), acetylene (C_2H_2) and propane (C_3H_8) are flammable and explosive in certain concentrations in air if an ignition source is provided. An ignition source may easily arise, for example, from a localised heat build-up.

You may be able to reduce the explosion hazard by reduction of the concentration of flammable gases and vapours with an inert gas. The inert gas can be introduced at several points in the pump or system; further details are given in Section 6.4. However, in some systems, it may not be desirable to use an inert dilution gas; for example, if your system uses a burn box to dispose of waste gas products.

Another method you can use to reduce the probability of explosion is to eliminate the ignition source. This method is commonly used in process industries to reduce fire and explosion hazards from flammable materials and this approach forms the basis of much of the flameproof electrical codes. It is, however, difficult to remove all ignition sources when you have a flow of flammable material inside a process system, because there is a possibility of static discharge or friction hot spots where rotating machinery is employed.

3.3.3 Pyrophoric materials

Under most conditions, pyrophoric gases such as silane (SiH_4) and phosphine (PH_3) are spontaneously flammable in air at atmospheric pressure, so combustion could occur when these gases come into contact with air anywhere in the vacuum system. This can happen if air leaks into the system or if the system exhaust comes into contact with the atmosphere. In a confined space (such as an exhaust duct, a dust filter or an oil box of a mechanical pump), the combustion can cause an explosion.

If, in addition to pyrophoric materials, an oxidant is also present in the process, the probability of explosion at both atmospheric and process pressures increases greatly. If oxidants from other processes are vented through a common extraction system, combustion or an explosion could result. You must, therefore, use independent extraction systems when you pump pyrophoric materials.

The use of PFPE lubricants in the pump will not prevent the ignition and explosion of pyrophoric materials. It will, however, ensure that a subsequent oil fire will not occur.

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. You can reduce the probability of an occurrence of this hazard if you use an Edwards Drystar pump as the backing pump because it has no oil in the swept volume.

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.

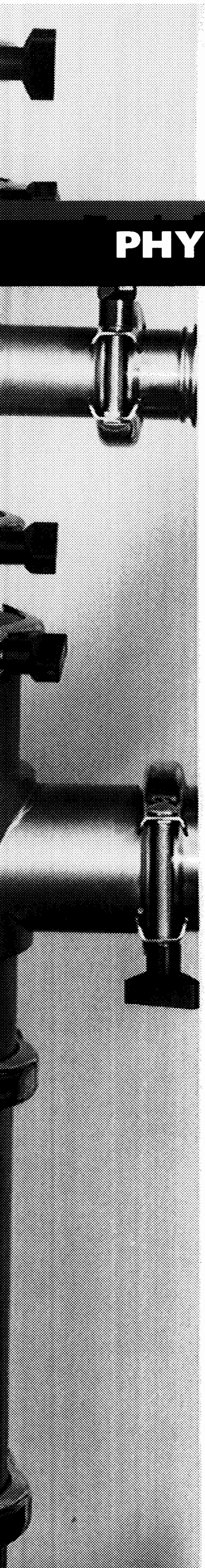
The heavy metals include:

- 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 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 data sheets when you assess the potential hazards associated with your process materials.
- 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 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.



SECTION 4

PHYSICAL SOURCES OF HAZARDS

4.1 Types of over-pressure hazard

The over-pressure of components in the system can be as 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

4.2 Over-pressurised pump exhaust

The most common cause of an over-pressurised exhaust is a blockage or restriction in the exhaust system.

All vacuum pumps are compressors which are specifically designed to operate with high outlet-to-inlet compression ratios; they are also designed to exhaust to atmospheric pressure or to a pressure only slightly higher than atmospheric.

If the exhaust is restricted or blocked, the pump can generate an exhaust pressure in excess of 7 bar; this can lead to failure of the pump or of other components in the system.

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.

4.2.1 Oil sealed rotary pumps

Oil sealed rotary pumps are not designed to operate with the exhaust restricted or blocked. Operation of the pump in such a situation will cause rupture of the pump components.

You must therefore design the exhaust system so that the pump is subjected to a maximum back pressure of 1.3 bar gauge (19 psig). Under normal operating conditions, the pump should not be run continuously with a back pressure of more than 0.35 bar gauge (5 psig).

4.2.2 Drystar pumps

Dry pumps also generate high exhaust pressures when the exhaust system is restricted or blocked, though the pressure rating of Drystar pumps (typically in excess of 7 bar gauge maximum static pressure) is considerably higher than the pressure rating of oil sealed rotary pumps.

However, it is equally important that Drystar pumps are not operated continuously with an exhaust pressure higher than 0.35 bar gauge (5 psig). We recommend that your system incorporates a trip to switch off the pump at an exhaust pressure of 0.55 bar gauge (8 psig).

4.2.3 Exhaust system design pressure

We recommend that you design your system so that the exhaust system can withstand an internal pressure of, at least, 1.3 bar gauge (19 psig).

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-pressurisation.

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.*
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
- Remove 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.

The most 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 backflow of gases from the system into a process chamber which is not capable of withstanding the pressure which results will also cause ruptures and leaks.

Take care before you connect compressed gas supplies to your system through pressure regulators which are designed to provide a low pressure flow, at a pressure within the rating of the system.

The non-venting pressure regulators most commonly used will cause the pressure within the system to rise to the pressure of the gas supply, 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 pipeline or components in the pipeline.

Always use a loose, unsecured blanking plate on the pump inlet until you have established that the direction of rotation of the pump is correct.

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.
- Design the exhaust system for a maximum continuous operating pressure of 0.35 bar gauge (5 psig) and a maximum static pressure of 1.3 bar gauge (19 psig).
- Monitor the pressure in the exhaust system and generate a warning at a pressure of 0.35 bar gauge (5 psig); switch off the pump at a pressure of 0.55 bar gauge (8 psig).
- Take account of abnormal and fault conditions when you assess the required pressure rating of the pump inlet pipeline.
- 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 the supplies if the pump is switched off.

SECTION B

HAZARD REDUCTION

SECTION 5

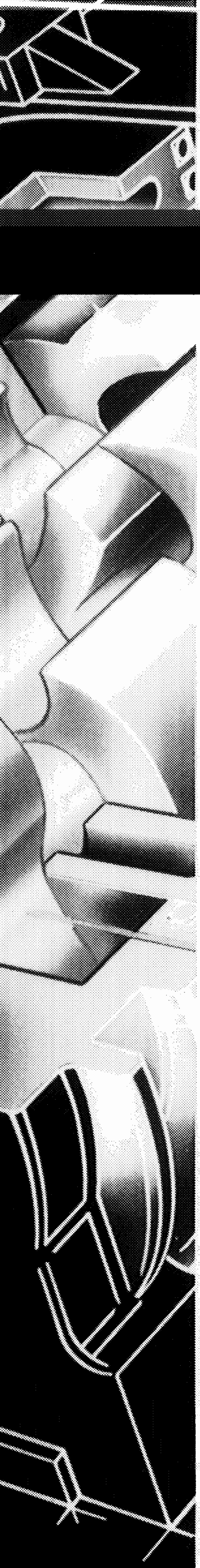
HAZARD ANALYSIS

The techniques of hazard analysis provide a structured approach to the identification and analysis of the hazards in a system in normal use, also of 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 requirement. To be fully effective, hazard analysis must begin during the initial design of a system and must continue through the installation and operation 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), which is a quantitative procedure for hazard analysis which is concerned with the identification of potential hazards and operating problems.

Typically, hazard analysis generates information about the type of hazards, the severity of these hazards and the probability that the hazards will occur. You can use this information 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, or to reduce the probability that the hazard will occur. It is, however, rare that a hazard 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 a major 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.



SECTION 6

SYSTEM DESIGN

6.1 Pressure ratings in a system

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. 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 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.

6.2 Elimination of stagnant volumes

A stagnant volume is any closed 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 the 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 between the introduction of incompatible gases will guard against the risk of explosion.

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

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.

6.4 Use of gas dilution systems

This method of protection has been covered briefly 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 must use a high integrity alarm and interlock system to prevent the operation of the system when the gas dilution system is not operational.

When you calculate the required dilution concentrations and flow rates for potentially explosive materials, use one quarter of the lower explosive limit of the material rather than the upper limit. If you maintain a dilution ratio which reduces the concentration of the explosive material well below one quarter of the lower explosive limit, you maintain a safe mixture in the process system which is also inherently safe in the event of a leak from the system. As a general rule, if you dilute flammable gases or vapours to below 1% concentration by volume, this will ensure that they are below their lower explosive limit. You must, however, check this information with the material's supplier.

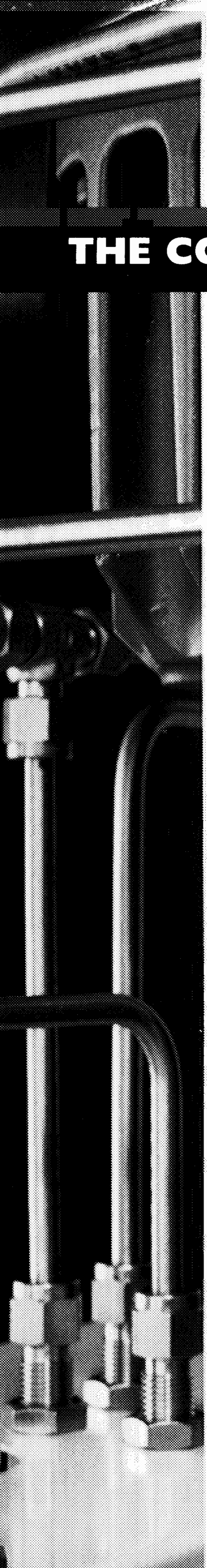
For example, hydrogen in oxygen has an upper limit of flammability of 93.9% and a lower limit of 4.65%. So, if you maintain the hydrogen concentration above 93.9% or below 4.65%, combustion reaction will not occur.

You can also dilute the concentration of oxidants to safe levels by this method, but a hazard could arise from the concentration of oxygen in air if a leak should occur. Leak testing of the system after installation will reduce the probability of a leak.

6.5 Summary – system design

There are a number of key points which you must note when you design safe vacuum systems:

- If you pump hazardous materials, you must design the system to fail to a safe condition.
- Use PFPE (perfluoropolyether) lubricants in rotary pumps when you pump oxidants.
- You must ensure that flammable gas is diluted by an inert gas, so that the concentration of flammable gas is below one quarter of the lower explosive limit of the gas.
- Leak test systems and equipment 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 Drystar pumps in preference to oil sealed rotary vane pumps where there are hazards associated with the oil in the swept volume.



SECTION 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 catalogue and in the equipment's instruction manual(s). In most instances, further information is available on request.

When you design your vacuum system, take into account the following mechanical pump parameters:

- Maximum static pressure (inlet and exhaust)
- Maximum operating inlet pressure
- Maximum operating exhaust pressure

For rotary pumps, you must also consider:

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

For Drystar pumps, you must also consider:

- Pressure specification of other components fitted to the pump
- Pressure monitoring in case the exhaust line becomes blocked
- Gas purging

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 dependent on the mechanical design of the pump. For example, the maximum static pressure of Edwards rotary pumps is 15 psig.

Rotary 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 4 psig for continuous operation). Pumps are designed to operate with unrestricted exhausts and an outlet pressure of 4 psig is usually high enough to drive exhaust gases through your exhaust extraction system and treatment equipment.

7.1 Oil sealed rotary vane pumps

Edwards oil sealed rotary vane pumps include the E1M and E2M series 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 boxes on rotary pumps are not designed as pressure vessels, although tests have shown that rupture pressures are generally 50 psig or more.

Rotary 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 downstream components of the system (such as polypropylene scrubbers or vacuum 'O' ring joints).

The flow rate of gas ballast into the pump is limited by the gas ballast valve before the performance of the pump is affected. A typical gas ballast flow rate for an Edwards E2M40 or E2M80 pump is 8 lmin^{-1}. To achieve a safe level of dilution, the gas ballast must 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 rotary pumps have significant oil box volumes which can retain flammable and explosive gas mixtures. The oil in the oil box has a normal operating temperature of about 80°C and 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 Drystar pumps

Drystar pumps have the same pressure specification as oil sealed rotary pumps even though the Drystar pump bodies have been tested to 18 bar (250 psig). The maximum static pressure is limited not by the pump, but by the components attached to the inlet and outlet, such as bellows and gauges. However, we recommend that you use a maximum static pressure of 15 psig.

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

Edwards Drystar pumps are also 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), you must fit a high integrity exhaust pressure monitor. Such monitors are fitted to a number of Edwards pumps and incorporate a two stage switching device; a high pressure warning is activated when the exhaust pressure reaches 5 psig and shutdown is activated when the pressure reaches 8 psig.

Drystar pumps have a high throughput gas ballast capability. The addition of a dilution gas such as nitrogen can be made progressively through the pump mechanism to optimise reaction suppression. Total nitrogen flow rates can be up to 70 $lmin^{-1}$ (40 $l.min^{-1}$ is typical).

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.

7.3.2 Braided flexible pipelines

Braided flexible pipelines are bellows with an outer protective layer of woven stainless steel braid. They are suitable for use as exhaust pipelines on Edwards dry pumps and other applications where there is significant gas pulsation or the possibility of high gas pressures.

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

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 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. Do not use flexible pipelines on dry pump exhausts.

7.3.4 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.

7.4 Physical over-pressure protection

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 protection:

7.4.1 Pressure relief

You may use bursting discs or pressure relief valves to relieve the pressure. 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 that 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.

7.4.2 Over-pressure warning/alarm

This is the preferred method of protection and is widely used by Edwards on many of its semiconductor pump systems. This type of protection is recommended for any system, but is particularly suitable for systems which produce solid by-products.

The use of a warning/alarm system should incorporate a design of high integrity. You should not rely on a simple pressure switch or sensor attached to a flow line, as the condensation of solid particles or corrosion of the sensor can cause the device to fail without indication of the failure.

We recommend that you use a sensor which incorporates a nitrogen purge flow to the sensor attachment point. A purge flow keeps the attachment point relatively free from blockage and such a sensor is designed so that, if the sensor is blocked, the nitrogen supply pressure is high enough to operate the pressure warning or alarm. The normal pressure settings for such devices fitted to Edwards pumps is 5 psig for a warning and 8 psig for an alarm which will trip the pump.

You should design your control system so that both the pump and any gas inlets (which are capable of pressurising the system above its maximum operating pressure) are shut down when the trip level is reached.

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. Because of this, venting regulators are not normally used in the semiconductor industry where pipeline integrity is of paramount importance.

Non-venting regulators can only maintain a constant outlet pressure under flow conditions but are the type of regulator generally used in the semiconductor industry.

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 by a suitable isolator device (such as a solenoid valve) when isolation is required; alternatively, you must take measures to safely vent excess pressures.

7.5 Explosion pressure relief

On certain process applications, you may consider a provision for explosion relief. This method of protection is commonly used in the process industries.

The most common type of explosion relief device is a bursting disc, which vents the explosion by-products through a duct to a safe area. Pressure relief valves can also be used but can be less reliable. The rate of pressure rise, as well as the maximum explosion pressure, is important in the determination of the relationship between the system design pressure, the system volume, the relief pressure value and the vent volume.

The use of explosion relief is not normally practical in the semiconductor industry because of the following reasons:

- The large system area and the low operating pressure required of the relief device.
- The low reliability and the high frequency of inspections that would be required of bursting disc or pressure relief valves in systems where solid by-products could exist or condense.
- The problems of safely ducting away explosion products which may be highly toxic.

7.6 Flame arrestors

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

7.8 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.

SECTION 8

OPERATING PROCEDURES AND TRAINING

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

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

SECTION C

SUMMARY

SECTION 9

SUMMARY

- 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 when you assess the potential hazards associated with your process materials.
- 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 pressure 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 when you pump oxidants.

- Use an inert gas to dilute flammable and pyrophoric gas to safe levels.
- 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 Drystar pumps in preference to oil sealed rotary vane 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 arrestors where appropriate.
- Leak test systems and equipment before use.

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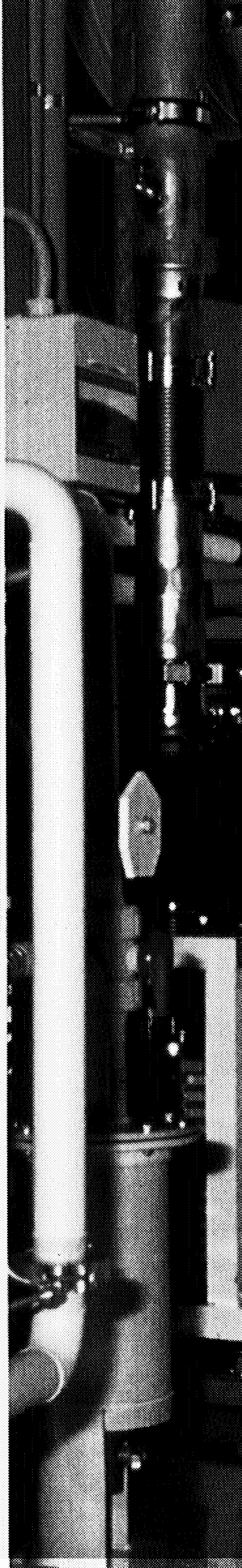

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Publication No. P300-20-000 Issue D