Oerlikon
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Safety Information

Vacuum pump and pumping system safety

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Introduction

Oerlikon Leybold Vacuum pumps and vacuum pumping systems have been operated safely for many years without problems, however with the increasing use of hazardous process chemistries there exists a greater potential for a hazardous condition to occur.

Oerlikon Leybold Vacuum has gained considerable experience in the safe specification, design, operation and maintenance of vacuum systems; this document records this experience for the benefit of users of Oerlikon Leybold Vacuum pumps and pumping systems.

This document is designed to be read by anyone who is involved in the specification, design, operation and maintenance of vacuum systems, and should be used in conjunction with other relevant data such as:

- Pump manual
- System manual
- HAZOP analysis
- Material safety data sheets
- General standards, machinery directive , etc

The information contained in this document cannot be considered as an exhaustive list, instead it is intended to communicate those foreseeable hazards which Oerlikon Leybold Vacuum has knowledge of. It is essential that any user of vacuum equipment undertakes their own hazard / risk analysis in order to demonstrate compliance with regulatory requirements.

The structure of this document considers safety in the following areas:

- Hazardous process gases
- Vacuum system design
- Vacuum system installation
- Vacuum system operation
- Vacuum system maintenance
- Modification of vacuum systems

All these areas need careful consideration in order to minimise the risk.

Where you require additional information regarding the safety of Oerlikon Leybold Vacuum systems please contact your supplier or Oerlikon Leybold Vacuum.

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Hazardous process gases

A hazardous process can be defined as a gas which falls into one or more of the following headings:

- Flammable
- Corrosive
- Pyrophoric
- Radioactive
- Toxic
- Explosive
- Oxidants

Due to their hazardous nature it is essential to consider their characteristics and the way in which they can impact on the safety of the vacuum system. It is normal to discuss these types of process gases with your vacuum supplier when specifying a vacuum system; however the following points give an overview of some of the hazards.

Note: The reaction of non hazardous process gases inside a vacuum system can sometimes result in the generation of by-products which may be considered hazardous.

Flammable gases / vapours:

Flammable gases / vapours are gases / vapours that when mixed with a certain quantity of air or oxidant can create an explosive mixture, however not all concentrations are hazardous.

The hazardous concentrations fall within the flammable range[1] and are generally call “Potentially explosive atmospheres” due to the fact that they can be ignited to create an explosion.

In accordance with the European Union Explosives Atmospheres Directive (ATEX100 94/9/EC) the preferred method to ensure the safety of flammable gases is to ensure that their concentration in air does not fall within the flammable range, there by ensuring that they cannot burn in the event of an ignition source occurring. It is therefore necessary to undertake one of the following actions:

Operation below the lower flammable limit (LEL):

The lower flammable limit can normally be found in the MSDS[2] provided by the suppliers of the gas or vapour; this is the minimum air / oxidant concentration where a flammable gas mixture could be ignited and sustain a flame or explosion.

To avoid a potentially explosive atmosphere and provide a safety margin it is necessary to dilute with an inert gas until the fuel / air [or oxidant] concentration is 25% of the concentration at the lower flammability limit.

This is a preferred operating mode as the effect of an air leakage into the vacuum system only dilutes the flammable gases / vapours further; however, it is necessary to consider the inert gas system as safety critical.

[1] The flammable range is the range of fuel / air concentration between the upper flammable limit and the lower flammable limit. Mixtures in this range will burn or explode if they are in contact with an ignition source. [2] Material safety data sheet

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Operation above the upper flammability limit (UFL):

The upper flammable limit can normally be found in the MSDS provided by the suppliers of the gas or vapour; this is the maximum air / oxidant concentration where a flammable gas mixture could be ignited and sustain a flame or explosion.

To avoid a potentially explosive atmosphere and provide a safety margin it is necessary to limit the air / oxidant concentration to 60% of the air / oxidant concentration required at the upper flammability air / fuel limit.

This operating mode requires careful control of air leakage from the process vessel, pipework and vacuum system; in addition, it is necessary to consider accidental ingress of air due to operational or maintenance activities such as opening valves or replacing inert gas cylinders.

The advantage of this approach is that it is not necessary to use an inert gas purge making the abatement of process gases easier / possible and saving cost.

Operation below the minimum oxygen concentration (MOC):

The minimum oxygen concentration is the oxygen concentration where a potentially explosive atmosphere can exist. At oxygen concentrations below this level it is not possible for the flammable mixtures to sustain a burn or explosion.

To avoid a potentially explosive atmosphere and provide a safety margin it is necessary to limit the oxygen concentration to 60% of the minimum oxygen concentration.

Again this operating mode requires careful control of air leakage from the process vessel, pipework and vacuum system; in addition, it is necessary to consider accidental ingress of air due to operational or maintenance activities such as opening valves or replacing inert gas cylinders.

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Corrosive

Corrosive gases have the potential to damage the vacuum system and create a hazardous situation.

All corrosive materials should be identified and their compatibility with the materials in the vacuum system should be confirmed, however it is important to note the following:

- Corrosion is based on physical, chemical or electro chemical reactions
- The most common metallic corrosion is based on an electro chemical reaction and therefore an electrolyte is necessary; this normally means the presence of water. Where the corrosive material is anhydrous [without water] it is not possible for a reaction to take place.
- Certain chemicals for example halogens or organic acids can react with pump material without the presence of water and generate reaction products consisting of ions from the pumped materials and the corrosive gas . Depending on the type of material these reaction products can build layers which then will prevent/minimize further reaction. Some of the reaction products e.g. $AlCl_3$; SiF_4 have a relatively high vapour pressure and will be removed with the gas stream. Under such conditions the pump material will be removed over time and destroy the pump.
- Strong oxidizing materials like NF_3 or fluorine can react with organic material used inside the pump and destroy these components. Such materials are seals, gaskets, grease oil etc.
- Where corrosive materials can be kept in the vapour phase it is not normally possible for corrosion to take place.
- Chemical or physical reactions can take place on polymer and ceramic materials.

To avoid corrosion the following steps can be taken:

Addition of purge gases at the gas ballast port or the exhaust of the pump can ensure that corrosive gases are kept in the vapour phase.

If pumps are turned off it is recommended that a small purge gas flow (e.g. shaft seal purge) is kept running in order to purge the pump of corrosive materials and prevent the ingress of wet air from the exhaust line. In addition, the Installation of a check valve in the exhaust line next to the pump will avoid back streaming of moisture when the pump is switched off. This is strongly recommended where wet scrubbers are installed for gas abatement

Cold surfaces and surfaces at high pressure are where condensation is most likely to take place leading to corrosion. The highest risk is therefore in the exhaust pipeline especially if the pipeline is located in a cold location (e.g. outdoors), it is recommended that the specification of the exhaust line is carefully considered to avoid hazardous corrosion. Sealing materials should be carefully selected to ensure their compatibility with the corrosive materials.

The use of aluminium or aluminium alloys is not recommended for pumps handling halogens; to avoid a reaction between the pump material and halogens or acids, coating of the pumping chamber is common practice. . The use of copper or brass in contact with reactive process gases is not recommended.

For pumping corrosive gases or strong oxidizers with oil sealed pumps or with pumps using grease lubricated bearings in the vacuum chamber PFPE is recommended to avoid oil degradation

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Pyrophoric gases / dusts / powders

A pyrophoric gas will spontaneously ignite in contact with air; it is effectively a flammable gas with an upper flammability limit of100%.

It is not just gases that are pyrophoric, it is possible for dusts and powders to also be pyrophoric, and this is especially true of metal dust and powders that have been formed by sublimation in the vacuum chamber. These dusts have not formed a protective oxide layer and are therefore sensitive to self ignition on exposure to air.

The dust can also function as an absorber for flammable and pyrophoric process gases. The adsorption rate into the dust is increased by high pressure, low temperature and large surface area.

When handling pyrophoric gases, dusts or deposits it is essential to exclude air leakage which could create a hazardous reaction. Small air leakages will react with the pyrophoric gas but might not create a hazardous situation, the level of allowable leakage needs to calculated for each application and a suitable safety margin determined.

Flammable dusts and powders can be collected in filters or might just form layers in the pipework, when exposed to atmosphere there is a real possibility that it could react very exothermically. Steps should be taken to ensure that the air is excluded from these systems in normal operation, during maintenance and during fault conditions. When the system needs to be vented to atmosphere it is recommended that nitrogen is used for this purpose and if the vacuum system needs to be disassembled protective equipment should be used in case of an unplanned reaction. Note: Care should be taken to identify all hazardous materials and determine a suitable handling strategy.

Before opening the pump system to air it is recommended to operate for a time with purge gas to remove the adsorbed gases from any dust layers. A controlled oxidation by pumping oxygen in low concentrations can be used to remove the pyrophoric gases within the dust and also to oxidise the dust. This approach needs to be carefully defined as there is the potential risk that only the material on the surface will be treated while the bulk of the dust layer retains its absorbed gas.

The use of water or oil baths in to which vacuum system components can be submerged after disassembly can be very effective; however, the safety of such a procedure needs to be considered for each application.

Other materials such as silicon and poly-silicon can form unstable deposits inside vacuum systems, these materials are border line between pyrophoric and explosive. See section on explosives.

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Toxic

Many process gases and vapours can be toxic to people and the environment, therefore it is essential to consider the safety of these materials.

Vacuum systems are an excellent way of handling toxic materials as a leakage on the vacuum side will only draw in air from the atmosphere and will not allow toxic process gases to escape. The situation is different when you start to consider the exhaust line of the vacuum system, here the pressure is close to atmosphere or just above atmosphere and a leakage will result in a leakage of any toxic gas being pumped.

The first step is to try and dilute the toxic gas to a level below the permissible exposure level by using a dilutant gas.

If dilution is not feasible or possible then it is recommended that the design of the exhaust line is carefully considered to ensure that it is of a leak tight construction. The use of vacuum standard pipework such as ISO-KF or ISO-K is recommended due to the fact that it is designed to be leak tight to vacuum standards.

The exhaust of the vacuum system must be carefully considered as it might not be possible to vent toxic materials straight into the atmosphere. In this case it is recommended that the advice of a gas abatement company is sought in order to find a safe way of disposing of the waste gas stream.

Where toxic gases have been pumped there is a high possibility that the internal surfaces or trapped internal volumes might contain toxic material. Before removing pumps or components which have been in contact with toxic gases it is recommended to purge them to remove all hazardous gases.
Note: Care should be taken to identify all hazardous materials and determine a suitable handling strategy

On removal of the pump all vacuum flanges should be sealed; parts which cannot be sealed should be stored in air tight containers. When the pump needs to be stripped for maintenance purposes it is essential that it is returned to a service facility where specialist decontamination facilities are available.

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Explosive:

Explosive materials can react without the presence of air or an oxidant, they are particularly hazardous to pump.

Explosive poly-silicon solids can be created in vacuum systems and will collect on horizontal surfaces. It is normal to minimise the amount of material forming by regularly performing an etch step with a strong oxidant such as NF3 or SF6, this ensures less material is present in the vacuum chamber and reduces the possibility of a hazardous event. Special care should be given to the design of the vacuum system in order to avoid volumes where the poly silicon deposits could form but which are not effectively flushed by the etch gases. A common example of such a design is horizontal bellows where deposits can form within the convolutions but etch gases can only etch the small exposed surface.

The solution here is to either avoid the use of bellows or mount them in a vertical orientation.

Oxidants:

These materials are able to react with a wide range of substances in a vacuum system including elastomers such as ‘o’ rings, polymers and oils, creating potentially hazardous conditions. Typical oxidants could be F2, NF3, O2, O3, etc

The actual effect of these oxidants will depend on the pressure and temperature of the gas; both affect the rate of reaction. As the rate of reaction increases so to does the potential for a possible over pressure or fire. The following guidelines should be used with oxidants:

- Where the concentration of oxygen is greater then 25% by volume it is essential to use PFPE lubricant and chemically resistant polymers for components such as ‘o’ rings, pump vanes etc. When pumping pure oxygen the use of an O2 qualified pump is essential.

- If PFPE oil is not available then use an inert gas dilution to reduce the concentration of the oxidant to safe levels.

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Vacuum system design

Leak tightness:

Atmospheric air leakage

Vacuum systems handling hazardous process gases have to be carefully evaluated in order to determine the consequence of inward air leakage. It is recommended that a risk analysis is conducted in order to determine the level of risk; this should consider normal operation, failure modes and maintenance procedures. Typical issues are:

- Reaction with pyrophoric gases
- Moving flammable gases and vapours into the flammable region
- Corrosion due to the ingress of atmospheric moisture
- Undesirable reactions with process gases

No vacuum system is 100% leak tight, there is always some level of air leakage even on ultra high vacuum system. Where a lack of leak tightness can create a safety issue, calculations should be undertaken to establish what level of leak tightness is necessary to create a safe condition.

If the provision of a leak tight system is safety critical then the performance level of the vacuum system should be calculated in order to establish the level of risk.

Where the leak tightness is essential to avoid a hazardous condition, it is necessary to conduct regular checks to confirm that the system remains leak tight. Special consideration should be given to maintenance activities that can lead to accidental air leakage and possible hazards.

Note: Where the leak tightness of a system is safety critical but it is not possible to provide the required level of integrity, it is recommended to use inert gas dilution of the process gases in order to bring them below the safe limit.

Leakage of water into the vacuum system

Where process gases and vapours are being pumped which can create a hazard in the event of contact with water, it is necessary to consider the leak tightness of the cooling water system.

Suck back of exhaust gases

When a vacuum pump is turned off with vacuum at the inlet, there will be a suck back of exhaust gases from the exhaust pipework / system. If this gas contains air / oxygen then there could be undesirable reactions with process gases or internal deposits. It is recommended that where this might be a possibility, the exhaust of the vacuum pump should be fitted with a non-return check valve to slow the back flow of exhaust gases. In addition, the use of a nitrogen purge when the vacuum pump stops will ensure that air is excluded from the vacuum system.

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Pressure:

Over pressure in vacuum system:

Vacuum systems are normally designed and operated at pressures ranging from just above atmospheric pressure to full vacuum. They are not designed for high pressure and therefore care should be taken to avoid conditions that could lead to hazardous over pressure conditions . The areas that need consideration are as follows:

Exhaust blockage:

There are a number of ways in which the exhaust of a vacuum system can become blocked resulting in over pressure. The most obvious is the fitment of a valve in the exhaust line, clearly if the valve failed to open the vacuum pump will create a pressure which could lead to a hazardous over pressure condition. Where a valve is essential then its operation should be carefully interlocked with the operation of the vacuum pump.

The formation of process deposits in the exhaust line can also lead to an over pressure condition occurring when the pump is operating with a high gas flow. This will normally result in the vacuum pump stopping due to excess motor current, but it is still possible in certain conditions for the vacuum pump to produce a significant hazardous over pressure. The potential for process deposits to build up in the exhaust of the vacuum system should be evaluated and where this can not be avoided then some form of pressure sensing should be used to detect over pressure conditions. Consideration should be given to preventing the pressure sensor from itself becoming contaminated with process deposits.

On some applications it is possible to use temperature management on the pump and / or the exhaust pipe in order to avoid blocking. Such a technique would be used with process by products with high vapour pressures.

Over pressure from purge systems:

It is common for vacuum systems to be fitted with purge systems in order to assist with the reliable pumping of process gases and the prevention of hazardous chemical reactions. While these purges perform a very useful function, they can also create their own over pressure hazard if their implementation is not carefully considered.

The purge gas is supplied from a purge gas tank or bottle and will arrive at the vacuum system with a supply pressure some where between 2 bar.g and 10 bar.g, in most cases it is necessary to reduce this pressure through the use of a pressure regulator. A pressure regulator will reduce the gas pressure from the incoming supply pressure to the desired operating pressure, it is quite normal to have operating pressures in the region of 0.1 bar.g to 1 bar.g.

Where the purge gas is bring supplied into an open system these regulated purge systems work well, however if the system is a closed system or a closed system is created by an action such as closing a valve, then there is the risk of an over pressure situation.

There are two types of pressure regulator: One is call a “relieving” regulator while the other is called a “non relieving” regulator; these operate differently and can create their own hazards.

The relieving regulator will control the pressure in a closed system by venting excess pressure to atmosphere, while this appears to be a good feature it must be remembered that this excess pressure could be in the form of a hazardous process gas.

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In the case of the non relieving regulator, this is designed to be used with an open system and will not reduce pressure in an over pressure situation. If a non relieving regulator is used in conjunction with a closed system, then over time there will be a small leakage of gas from the supply side of the regulator into the system; eventually this will result in the system being pressurised to the supply pressure. As most open vacuum systems have the potential to become a close system in the event of a failure condition, there is a risk from using this type of device that need to be considered.

A solution is to use a relieving regulator fitted with a non return “check” valve between the regulator and the vacuum system. The regulator will ensure that the pressure on the system side will be controlled at the desired pressure, while the non return “check” valve will prevent a back flow of gas from the system towards the regulator. Check valves are available with a pressure differential as low as 25 mbar, there by minimising the pressure drop. It should be noted that where there are other sources of pressure in the vacuum system, then these should be considered independently as the relieving regulator will not vent this excess pressure.

If over pressure vent valves are used it is essential to consider the type of gas that it being vented and where the gas is being vented to. It is possible to vent hazardous process gas into the local atmosphere is this is not considered.

Design pressure

The design pressure of a vacuum system has to be carefully considered in order to ensure that it can withstand the maximum pressures that it can be exposed to in normal operation and also during fault conditions. The vacuum system includes all the vacuum pipework to the vacuum pump but also the exhaust pipeline to atmosphere (or suitable abatement). It is normal to specify the system to handle “full vacuum” but the over pressure capability of the system is often over looked.

The over pressure capability of the vacuum system should normally be restricted to a pressure of 0.5 bar.g in order to avoid the requirement in Europe to comply with the pressure equipment directive. In this case the setting of any pressure regulators should be limited to this pressure as well.

Where a system is expected to have the potential to contain an internal explosion it is common practice to specify a system design pressure of 10.0 bar.g, however at this pressure it is normal to have to comply with a local pressure vessel code for both the vacuum system and the pipework.

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Temperature:

Thermal cycling

Where equipment is subject to thermal cycling [e.g. due to the normal vacuum pump down cycle] it is important to recognise that over time these thermal cycles can lead to fasteners and fittings coming loose if they are not correctly locked with sealants or mechanical devices. Where there is a risk of thermal cycles and the consequence of the fasteners coming loose could create a hazardous situation then the tightness of these fasteners should be checked on a regular basis.

Hot surfaces

Vacuum systems and vacuum pumps often exhibit hot surfaces due to the nature of the process. For example on some processes it is necessary to heat the exhaust lines in order to prevent the condensation of hazardous gases. Where hot surfaces above 70^{0}C occur it is recommended that a hot surface warning label is attached to the hot surface, if the temperature is in excess of 100^{0}C then it is necessary that the surface is protected by some form of guard to prevent contact.

Ambient operating temperature

Vacuum systems are normally designed to operate at a maximum ambient operating temperature of 40^{0}C. At temperatures above this level it is possible that elastomeric seals in vacuum pumps could over heat leading to possible leaks and possibly the creation of hazardous decomposition products. Care should be taken to understand the hazards associated with high ambient operating temperatures.

Low ambient temperatures can also result in hazards due to the embrittlement of elastomers such a ‘o’ rings or the condensation of process by products to form hazardous liquids. A hazard analysis should take into account the minimum design temperature of the vacuum equipment and the possibility of the process by products to condense.

Exhaust line heating

Exhaust line heating should be used where there is a possibility for process gases to condense or solidify in the exhaust line leading to blockage, corrosion or explosions. Where exhaust line heating is used it is essential to consider the safety of such a system, especially in failure conditions where the temperature could rise out of control and over heat elastomeric seals within the pipework.

Design temperature.

Where a vessel or pipework is designed to contain a pressure it is necessary to define the maximum design temperature up to which the vessel or pipework is pressure rated. Do not operate a system above the maximum design temperature.

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Chemical reactions:

Pre / post process purges

In order to avoid undesired chemical reactions it is common practice to purge vacuum pumps with an inert purge gas for 15 minutes before and after admitting process gases. A preprocess purge will remove all traces of atmospheric oxygen and water while a post-process purge will remove residual process gases.

Cross contamination

Vacuum systems are often switched to applications where different process gases are used, this can be due to equipment being re-used on a different application or even due to different process steps on a given application.

In all these cases it is necessary to consider the possibility of cross contamination between process gases / vapours / materials from one process with the process gases / vapours / materials from another, in some cases hazardous reactions can occur between two materials that normally present no hazard when pumped individually.

Where hazardous reactions could occur it is normal practice to purge with an inert gas between process steps for ~15 minutes, this often removes the first material before the second material is pumped; however, it should be noted that in some vacuum systems there is the potential for trapped pockets of process gas to exist which are not effectively removed by the purge step. Where a hazardous reaction could occur, careful consideration should be given to the design of the vacuum system and the identification of any trapped volumes.

Phase change

A vacuum system is designed to raise the pressure of pumped gases and vapours from vacuum to atmospheric pressure, in doing so it is possible for the materials to change phase into a liquid or even a solid form. Materials that have under gone a phase change have the potential to cause hazards such as blocked pipework, corrosion or even flammable materials. Normally the phase change will occur as the pressure approaches atmosphere inside the dry pump; however, under very cold ambient conditions it is possible for materials to under go a phase change in the fore line to the vacuum pump.

Where this could create a hazardous condition it is recommended that either trace heating is used or dry inert purge gases are used.

If solid particles are forming in the fore line there is the potential for layers to form on the walls, after time these can fall off and move into the pump – see section on “Formation of deposits in pipework”

If it is desirable to recover the condensed materials then it is recommended that a condenser and receiver is installed into the vacuum system where these materials can be safely collected.

Back streaming of exhaust gases

When a vacuum pump is turned off with vacuum at the inlet, there will be a suck back of exhaust gases from the exhaust pipework / system. If this gas contains air / oxygen then there could be undesirable chemical reactions with process gases or internal deposits. It is recommended that where this might be a possibility, the exhaust of the vacuum pump should be fitted with a non-return check valve to slow the back flow of exhaust gases. In addition, the use of a nitrogen purge on the vacuum pump will ensure that air is excluded from the vacuum system.

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General practice:

Formation of deposits in pipework

In some applications it is possible for deposits to form in the fore line of the vacuum system, such an example would be the formation of silicon layers after a semiconductor deposition step. These solid deposits form in the vapour phase and form layers that present a number of hazards.

- As the layers increase it is possible for them to break off and move towards the vacuum pump. In some cases the vacuum pump can be damaged by such layers and in rare cases it is possible for the layers to cause significant mechanical damage and rupture the pump casing.

- The layers are deposited under vacuum and therefore often do not have protective oxide layers that prevent them from burning in contact with oxygen. Care must be taken when these materials are finally exposed to atmosphere.

- The build up of significant layers can block fore lines leading to loss of vacuum performance.

It is recommended that where process deposits could break off from the walls of the fore line, that a dead leg should be installed in the fore line to trap the largest particles. In addition a metal mesh screen should be installed in a vertical position next to the dead leg or a cyclone separator in order to prevent particle carry over into the pump.

Where the process deposits could be of a hazardous nature it is essential that the user of the vacuum system conducts a risk analysis to determine the safe way of handling these materials.

Use of frequency inverters – use of passwords

Frequency inverters are often used to enhance the performance of a vacuum system, however care has to be taken to correctly set the maximum rotational speed.

Many frequency inverters are able to create a maximum output speed of up to 200hz which when coupled to the right sort of motor could result in a rotational speed of 12,000 rpm. As most vacuum pump operate at rotational speeds between 3000 rpm and 6000 rpm there could be considerable risk if the inverter is accidentally programmed with a higher rotational speed.

It is recommended that where frequency inverters are used, the maximum rotational speed in the parameter list is protected by a password. This will help to ensure that accidental adjustment of the maximum speed parameter is avoided.

Normal operating limits – do not exceed normal operating limits

There are many components that can form a vacuum system. In all cases these components must be selected and operated within their designed operating limits. Failure to do so could lead to an unexpected failure.

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Inlet valve position

The inlet valve located between the vacuum system and the process chamber is often used to isolate the vacuum system while maintenance is carried out. It is essential that this valve is in the correct position while the maintenance is being conducted.

Where the position of this valve is safety critical it is recommended that it is reviewed as part of the hazard analysis in order to determine safe operating practices.

Hot traps

The use of hot traps to trap / react process gases before they reach the vacuum pump create hazards of their own. The main hazard is thermal, it is normally for these traps to operate with internal temperatures of many hundreds of degrees Celsius. This temperature does not normally fully transmit to the external surfaces, however there is the possibility for adjoining components such as elastomeric ‘o’ rings etc to be thermally damaged. Extra care should be taken when specifying a hot trap.

Cold traps:

Where a nitrogen cold trap is used to condense materials that are usually gases or vapours at atmospheric pressure it is essential to consider the consequence of unexpected warming up. Liquid gases and vapours on warming will create large volumes of gas / vapours which if vented into a closed system could lead to a dangerous over pressure. Careful consideration should be given to how the system is vented in order to avoid the possibility of a dangerous over pressure.

Condensers:

Condensers are a very effective way of removing a vapour from a process stream, but it is essential to consider the possibility of the condenser blocking. Normally a condenser will be used with a suitable receiver vessel located below into which liquid can drain; this would then be fitted with a level indicator which is used to determine when to empty the receiver. If the receiver is not drained there is the possibility that the liquid will over flow into the vacuum pump and start to block the exhaust line.

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Vacuum system operation

The safety of a vacuum system is significantly influenced by the design; however, experience has shown that the correct operation of the system is just as important, especially when considering the potential for misuse or failures.

It is not possible here to provide a full list of hazards associated with the operation of any specific vacuum system; this should be established by the end user through the use of a suitable risk analysis.

It is particularly important that a detailed operating procedure is established which not only covers normal operation but also what to do in the event of a maintenance step or a failure. It is often these planned events that lead to unexpected hazards and the potential damage or injury.

Below are some examples in order to give an idea of the type of unexpected hazard that could occur:

- A process creating pure metal powders inside the vacuum system is operated with nitrogen purges in order to ensure that the atmosphere inside the vacuum system is oxygen free. During a process upset it becomes necessary to open the chamber to remove some damaged components, this procedure taking just a few minutes during which time the vacuum pump is isolated from the chamber by the inlet isolation valve. On completion of the maintenance step the chamber is sealed and then pumped down using the process pump, unfortunately the chamber now contains atmospheric air and the resulting rush into the vacuum pump results in an ignition of the reactive metal powders.

- On a furnace application the process materials are extracted via a filter located in the exhaust line which needs cleaning on a regular basis. Due to production pressures the cleaning step was missed and over time the filter blocked and caused the vacuum pump to trip out due to over pressure in the exhaust. This would normally have been a safe condition except for the fact that the process operator then tried to get the pump operating again by holding in the green start button and over riding the thermal protection for the motor. The consequence was that the vacuum pump generated an excess back pressure which caused the filter to explode.

- In a chemical plant a vacuum pump was fitted with an exhaust condenser to trap a corrosive by product before it entered the exhaust line. Part of the operating procedure was to drain the receiver when the high level switch indicated that it was full. The exhaust was connected into a common exhaust line which was normally at around atmospheric pressure, however due to a failure this was at a higher pressure. When the operator opened the receiver to drain it the corrosive liquid was forced out under pressure and splashed all over the operator with serious consequences.

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Vacuum system maintenance

All vacuum systems require maintenance at some point and the quality of this maintenance can have a significant effect on the safety of the system. The hazard analysis should take into account the details of the maintenance procedure in order to make sure that these do not lead to a hazardous condition. Some points to consider are:

- The inside of the vacuum system might be contaminated with process materials which may be hazardous to health.

- Particular materials such as PFPE oils might have been selected for use with the process gases. If these materials are changed during maintenance then it is possible to create a new hazardous situation.

- Pumps that stop unexpectedly may contain hazardous process gas, in this case special procedures might be necessary to protect personnel when the pump is removed.

- An over pressure situation inside a vacuum system might not be observed until a component is removed and it is forced out under pressure.

- Electrical equipment must be lock out before any maintenance procedure is started on the vacuum system.

- Consider the effect of cleaning solvents on the vacuum system, especially if they are corrosive or flammable.

A full hazard analysis should be conducted which includes all the maintenance procedures.

Do not conduct any maintenance without considering the possible risks and protective equipment required.

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Modification of vacuum systems

Vacuum systems are normally designed for a particular purpose and it is common to conduct a hazard analysis with a particular application in mind.

If the vacuum system is used for a different purpose or if the process gases being pumped are changed in any way then the original hazard analysis will no longer be valid and there will be a risk of an unexpected hazard occurring.

When ever a vacuum system is modified or the process gases are changed in any way, always conduct a new hazard analysis.

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