Pumping potentially explosive atmospheres

Clive Tunna shows how a close look at the process can drive down the cost of ATEX vacuum pump systems

THERE is no question that there are plenty of advantages to using dry vacuum pumps in process applications. What is perhaps less well-understood are the safety issues that need to be considered when using an all-dry, close tolerance machine to pump flammable vapours.

This article provides an introduction on how to apply the principles of ATEX legislation and its supporting documentation to the internal flammable atmospheres associated with vacuum pumps. Importantly, it identifies strategies that can significantly reduce the cost of the vacuum equipment.

ATEX approach

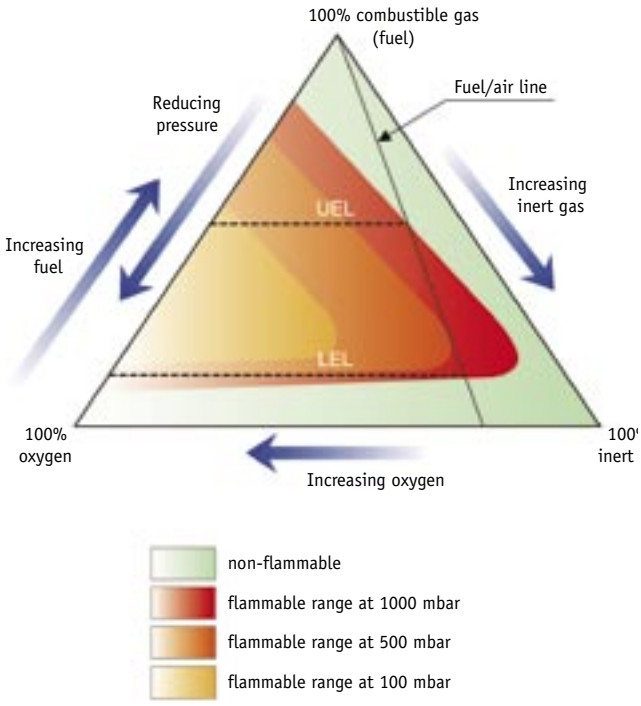
ATEX says that the responsibility for safe application of equipment in a chemical process rests with the process operator. The directive requires process operators to generate an "explosion protection" document, based on a risk analysis of the whole process, then to identify protection strategies to mitigate the risks.

ATEX requires the categorisation of each part of the process as Zone 0, 1 or 2 according to the risk of an explosion occurring. The European Standard EN1127 sets out fundamental principles regarding the minimisation of risk as being:

- **Prevention:** Avoid explosive atmospheres
- **Prevention:** Avoid possible ignition sources
- **Protection:** Limiting the effects of an explosion

Figure 1: The flammable range decreases with reducing pressure

The flammable range decreases with reducing pressure



avoid explosive atmospheres – operate at reduced pressures

The flammability of a vapour reduces as the pressure of the system reduces, and eventually reaches a point where flammability is not supported (see Figure 1). It is therefore often more effective (and cost-effective) to consider separately the zoning of the vacuum system inlet, and of the pump and exhaust since a mixture that is potentially explosive at atmospheric pressure may become non-explosive at a lower pressure.

There are a number of strategies that can be applied. To keep out of the flammable range it is necessary to operate the process so that the pumped vapours are either below the critical pressure which will support an ignition, above the upper explosive limit (UEL), below the lower explosive limit (LEL) or below the minimum oxygen concentration (MOC).

Operation outside the flammable range ensures that even if an ignition source is present there will not be an explosion, so no protective devices, such as inlet flame arresters are required.

operation below the lower explosion limit (LEL)

By controlling the relative concentrations of fuel and air it is possible to keep the concentration of the vapours below the LEL, thereby eliminating the risk of an explosion. It is common practice to introduce a safety margin and to design to a level of 25% LEL .

In order to keep below 25% LEL it may be necessary to dilute the flammables with nitrogen or air.

One disadvantage of dilution is that if it is used continuously in front of the vacuum system it can significantly increase the size of the vacuum pump required. It is therefore best used as a method of adjusting the flammability only during pump-down.

operation above the upper explosion limit (UEL)

The concentration of flammable vapour can be kept above the UEL to eliminate the risk of explosion. A suitable safety margin for oxygen concentration should be used, for example 60% UEL, and the system should be leak tight to avoid unnecessary purges of air or nitrogen into the system. A benefit of this strategy is that it minimises the size of the vacuum pump, and also leads to very efficient exhaust condensation.

operation below the minimum oxygen concentration (MOC)

MOC is the concentration of oxygen below which ignition is not possible. This can be controlled by minimising air leakage into the vacuum process, or by nitrogen dilution. The former minimises the size of the vacuum pump, and maximises the efficiency of any exhaust condensation.

Reference to NFPA 69 2002 shows that a safety margin of 60% of the MOC value should be used to achieve a safe process, for example if the MOC value is 5%, then the safety margin would require the concentration to be maintained at 3%.

avoid possible ignition sources

The protection principle of constructional safety defined in European standard EN13493-5 specifies the way in which mechanical equipment should be designed to avoid active ignition sources. This is particularly applicable to the internals of dry vacuum pumps that commonly operate with small internal clearances.

The level of integrity of the equipment will vary according to its zone classification. For zone 2 applications it is only necessary to consider ignition sources that are

active in normal operation. In zone 1 applications it is necessary to also consider ignition sources that could become active following an expected malfunction. In zone 0 applications it is necessary to also consider ignition sources that could become active in rare malfunctions.

Virtually all dry vacuum pumps (with the exception of dry running rotary vane pumps) do not have ignition sources that are active during normal operation[1] and are therefore safe for operation in an internal zone 2 environment, without flame arresters.

To use dry vacuum pumps in zone 1 environments, it is necessary to consider the potential for process build up on internal rotating parts within the swept volume. This can be condensed or polymerised vapour deposits, or solid particles in the pump. They can be removed using solvent flushing and/or inlet filtration. The use of flame arresters is also recommended despite the fact that many dry vacuum pumps are ATEX category 2 compliant without them. This is because the consequences associated with an explosion, however rare, are potentially catastrophic. This is a subject that should be carefully considered in the operator's own HAZOP study.

Where constructional safety is being used as a strategy it is important that the manufacturer's maintenance instructions are followed closely to ensure that the pump does not suffer mechanical failure.

limiting the effects of an explosion

The avoidance of the flammable zone and/or the elimination of ignition sources is not always practical. House vacuum systems will often be required to handle a wide range of duties, are vulnerable to the sudden ingress of large volumes of air, and it may often not be known what the make-up of the pumped stream is. When other approaches are not practical then the remaining option is to contain any possible explosions. This may be done in a number of ways:

- **Pump construction:** Most dry pumps are designed to withstand an internal explosion, and are independently tested to ensure that they meet this requirement.
- **Flame arresters:** Flame arresters have been used effectively for many years within the chemical process industry to prevent the propagation of internal explosions. However, their performance is dependent on the geometry of the connecting pipework and pump. It is therefore essential that the performance of the flame arrester is tested *in situ* and that a full risk analysis is undertaken in order to prove that as a combination they will contain an explosion.

Depending on the internal zone selected there are a number of ways in which flame arresters can be used:

– Zone 1 flame arresters have been selected to withstand a single explosion of the type which would be associated with the seizure of a dry vacuum pump resulting from process build up. It is expected that this seizure would bring the pump to a halt and therefore stop the continuous supply of fuel (process gases).

– Zone 0 flame arresters have been selected to withstand a continuous burn situation that is considered a rare malfunction. In this scenario it is expected that the pump could remain running while a flame has been established on either the inlet or exhaust flame arrester. In this case it is necessary to use a temperature transmitter to detect the presence of a flame and stop the pump before the heat causes the arrester to fail. Typically the flame arrester would be expected to withstand the burn for approximately two minutes.

– Flame arresters provide a high level of protection and remove from the operator the need to take any additional action other than to keep the flame arrester element clean. This is easier to guarantee than ensuring that the swept volume of the pump is kept free of process deposits which is required if constructional safety is being used.

They provide a solution that is generally independent of the flammable gases and vapours being pumped (it is only necessary to select a gas group and temperature classification). This is especially important on multi-purpose plant or house vacuum systems where the pumped materials are not known at the point of purchase.

process containment

Flame arresters are very effective at providing protection from internal explosions but they can restrict the vacuum performance by anything up to 50% and are vulnerable to contamination. Therefore, it is desirable to determine other ways of containing an explosion. One such method is to use the fact that a pressure rating of 10 barg is considered suitable to contain internal explosions provided that the starting pressure is less than 500 bara. As most vacuum process chambers and inlet pipework are designed to this pressure rating then they will be capable of withstanding an internal explosion in the unlikely event of an ignition source in the vacuum pumps. If the vessel is in a flammable atmosphere, it should also comply with *EN50018 – Flame Proof Enclosures*, to ensure that there is no flame path from the vessel interior to the external atmosphere. It is the customer's responsibility to confirm that the vessel is suitable for this approach.

The conclusion from all of this is fairly straightforward – when defining zoning in dry vacuum pump systems, one of the first actions should be to see how the process can be modified to eliminate flammable atmospheres. This results in an inherently safer system, and reduces the cost of the vacuum system. ■

BOC Edwards T4 vacuum pump for Zone 0 applications

Footnote

[1] *When pumping flammables with low autoignition temperatures it is necessary to consider the potential of the internal temperatures within the vacuum pump acting as an ignition source*

Clive Tunna is global technical manager at BOC Edwards