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Best practice guidelines for operating standard vacuum pumps with flammable gas mixtures outside the flammable gas range – the ATEX implications

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Introduction

The key safety objective in operating vacuum pumps with flammable gas mixtures should be to maintain the pumped gas mixture *outside* the flammable gas range, as far as possible. There are vacuum pumps and systems designed and approved or certified, to handle flammable gas mixtures *inside* the flammable range, however these can be necessarily complex and expensive. The alternative is to avoid pumping in the flammable region so that standard pumps and systems can be used, but this may need to be achieved using systems for diluting or inerting the pumped gas mixture, or otherwise ensuring that the flammable range is never entered. Within Europe any such systems employed to do this became safety-critical features under the ATEX regulations, which have been mandatory for new plants in European locations since June 2003. In such systems it is the process operator's responsibility to assess the risks, to define and comply with any hazardous area requirements, to ensure that suitable working practises are employed, and to assure the integrity of safety equipment and systems.

This article sets out best practice methods for pumping gas mixtures outside the flammable range using standard primary vacuum pumps.

Flammability

The concept of the flammability of gases and vapours is illustrated in the flammability triangle (Fig. 1). Inside the flammable region, any mixture can be ignited. Outside the flammable region, no mixture can be ignited. The upper and lower boundaries of the flammable region therefore represent the upper explosive limit (UEL) and lower explosive limit (LEL) of the particular flammable gas or vapour in question.

Note also that a line of constant oxygen concentration exists below which no mixture can possibly be ignited. This defines the minimum oxygen concentration (MOC) required for any mixture of the flammable gas/vapour to be ignitable (Fig. 2).

Pumping any gas mixtures *inside* the flammable region should be forbidden with all vacuum pumps which have not been specifically designed and approved or certified for such flammable region operation.

Risk assessment

ATEX requires that a suitable risk assessment must always be conducted by the process operator in order to assure the integrity of the vacuum pumping system. This should include (but not be limited to) consideration of:

- the method(s) to be employed to achieve and/or maintain flammable concentrations outside the flammable region
- the reliable provision of adequate diluent gas supplies where required, and the precautions needed to avoid or combat the effects of any diluent loss or leakage
- the effects of possible process variations or excursions (e.g. variations in pressure, temperature, composition, flow, etc.), and of possible equipment failures, on the flammable gas concentrations and the steps required to maintain the concentration outside the flammable region
- the required equipment, procedures, systems, controls and interlocks, and their appropriate fail-safe interactions
- the enforcement of appropriate routine maintenance, inspections and testing

Operating regimes outside the flammable region

There are three possible operating regimes which permit the pumping of flammable gases and vapours outside the flammable region. They are to maintain the pumped gases:

- - below the lower explosive limit (LEL)
- - below the minimum oxygen concentration (MOC)
- - above the upper explosive limit (UEL)

The major objective with each is avoiding the flammable region in the gas as it transits through the pump from the inlet (which will be at pressures ranging from vacuum to atmospheric), through the various stages of the pump, and to the pump outlet where the gas emerges from the exhaust at atmospheric pressure, or above.

Concentrations below the lower explosive limit (LEL)

To minimise any risk of accidental incursion into the flammable region best practise requires an adequate safety margin for below-LEL operation should always be used; below 25% LEL is recommended. Excursion concentrations up to 50% LEL may be permitted but only for very short durations (≤ 60 seconds).

The preferred method of ensuring this level is never exceeded is to use inert gas dilution (e.g. with nitrogen). Air dilution is not good practise for flammables. Inert diluent gas can be introduced:

- upstream of the pump, or at its inlet (although this may affect pump performance)
- via the pump's standard gas ballast inlet
- via the standard shaft seal purge (where fitted)
- through the oil box on oil-sealed vacuum pumps

The quantity of diluent gas required to maintain below 25% LEL operation in the primary pump should be decided by the risk assessment. Typically this will take into account the maximum potential flammable gas flow, and the methods and entry points of any required dilution.

As the below-LEL mixture leaves the pump it mixes with atmospheric air in the exhaust pipe, which further dilutes the mixture.

Oxygen concentrations below minimum oxygen concentration (MOC)

In applications dealing with higher concentrations of flammable gas, especially where these concentrations may vary, below-MOC operation may be the preferred option.

The lowest MOC for common flammable gases and vapours is 5.0 vol.% oxygen (this is the MOC for both hydrogen and carbon disulphide). NFPA 69 2002 is a useful US general industrial standard for explosion prevention systems and its Annex C lists these and many other MOCs. The process operator's risk assessment must include the determination of the lowest credible MOC for the process under consideration.

To ensure an adequate safety margin for operation below the lowest credible MOC at pressures up to atmospheric, best practise recommendations are:

- - where continuous oxygen (O₂) concentration monitoring in the pump exhaust is provided, with process safety interlocks, or where a full system leak check is conducted before each process cycle, then to provide an adequate safety margin the oxygen concentration should be maintained at, or below, either: 2 vol.% O₂ *below* the MOC; or 60% *of* the MOC if the MOC is less than 5 vol.% O₂.
- - where continuous monitoring is not provided but regularly scheduled O₂ concentration checks in the pump exhaust are made, or where a full system leak check is conducted on a regular basis, then to provide an adequate safety margin the oxygen concentration should be maintained at, or below, either: 60% of the MOC; or 40% of the MOC if the MOC is less than 5 vol.% O₂.

The preferred methods of ensuring that a flammable gas mixture is maintained adequately below the MOC before it exits from the primary vacuum pump are: to use inert gas dilution (e.g. with nitrogen) – refer to dilution comments above in *Concentrations below the lower explosive limit (LEL)*); or to use a maintained level of whole system integrity such that no significant change of O₂ level of the pumped gas is possible.

In either case any air leaks must be rigorously excluded from the pump and system – see below.

Concentrations above upper explosive limit (UEL)

In other applications dealing with intermediate or high concentrations of flammable gas where inert gas dilution for below-LEL operation is not practical or desirable, specific user intervention and systems will be required either to increase the concentration of the flammable gas to above-UEL, or to prevent a normally above-UEL concentration from falling under fault conditions. The risk assessment should also confirm whether below-MOC operation would actually be a more preferable option to above-UEL operation.

In either of these cases it will also be necessary to rigorously exclude air from the pump and system – see below.

To minimise any risk of accidental incursion into the flammable region an adequate safety margin for above-UEL operation should always be used. By analogy to the appropriate margins for below-MOC operation, the residual oxygen level at UEL should be further reduced to 60% to derive a suitable safety margin above the UEL for the flammable gas concentration.

Excluding air from pumps and pump systems

The above-UEL and below-MOC methods both require air to be completely eliminated from the pump and system, to ensure flammable gas concentrations stay within safe levels.

This should be achieved by eliminating all air leaks, and then either purging the system with nitrogen to sweep out all air, or fully evacuating the system, before the flammable gas is admitted.

Whichever is the preferred approach, air must always be rigorously excluded from all parts of the system when flammable gas is present, and the system (and especially the pumps) must also be configured so that it is not physically possible to inadvertently connect any source of compressed air to any purge connections.

Conclusion

ATEX compliance requires the process operator to carry out a full risk analysis and maintain safe operation of the system at all times. Standard primary vacuum pumps should never be operated with flammable gas mixtures in the flammable region. Below-LEL operation is the preferred approach using standard pumps, but below-MOC and above-UEL operation with standard pumps may also be acceptable, if the risk assessment allows. Operation *in* the flammable range requires the use of specialised pumps and systems approved under ATEX. Best practise should be noted and followed in all cases.

As a designer and manufacturer of standard vacuum pumps, pumping modules and bespoke systems, as well as certified equipment, including units approved for pumping flammable gases *in* the flammable range under ATEX, BOC Edwards also has the ability to provide solutions for all vacuum pumping requirements. Their worldwide team of applications engineers and specialists are available to give expert advice on the specification, installation and safe operation of all types of vacuum pump.

[1300 words approx]

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Fig.1

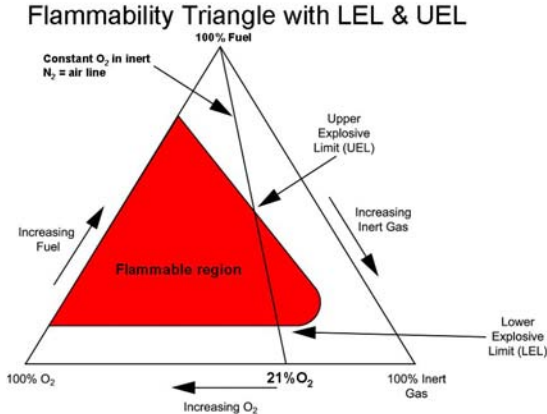


Fig. 1 illustrates the concentration line for 21 vol.% oxygen with nitrogen as inert gas, and hence indicates the lower explosive limit (LEL) and upper explosive limit (UEL) of the given flammable gas in air.

The concentrations of oxygen, inert diluent gas, and the particular flammable gas/vapour (i.e. the fuel), are shown plotted against each other. This diagram defines the flammable region (shown in red) in which mixtures can be ignited. The exact location and shape of this flammable region within the overall triangle will vary according to the flammable

gas/vapour type, and according to the inert diluent gas type. Note that the pressure of the mixture (and to a lesser degree the temperature) will also affect its shape.

Fig.2

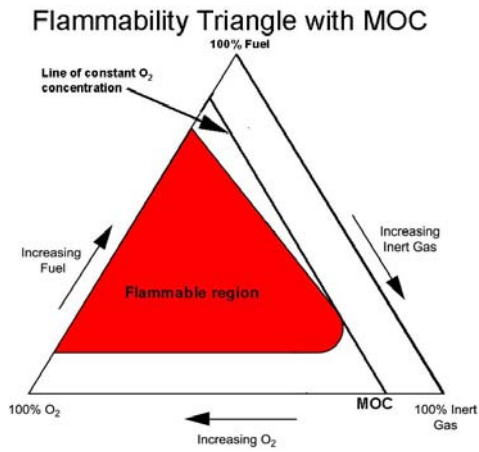


TABLE 2: Flammable gas pumping outside the flammable range

	<i>INTERNAL CONDITION: flammable gas is below LEL</i>	<i>INTERNAL CONDITION: oxygen is below MOC</i>	<i>INTERNAL CONDITION: flammable gas is above UEL</i>
<i>EXTERNAL AREA IS HAZARDOUS, & ATEX certification is required</i>	<p>cannot use standard primary pumps or boosters</p> <p>use ATEX-compliant primary pumps or boosters</p> <ul style="list-style-type: none"> - use inert gas dilution for operation up to 25% LEL - integrity of system dependent on Zone which would result if dilution failed 	<p>cannot use standard primary pumps or boosters</p> <p>use ATEX-compliant primary pumps or boosters*</p> <ul style="list-style-type: none"> - for operation up to 2vol.%O₂ below MOC, continuous O₂ monitoring is required - for operation up to 60% of MOC, regular O₂ checks are required - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if dilution/purge failed or leak arose - consult applications * booster with hermetic primary seal 	<p>cannot use standard primary pumps or boosters</p> <p>use ATEX-compliant primary pumps or boosters*</p> <ul style="list-style-type: none"> - for low-UEL gases consider below-LEL operation - for above-UEL operation maintain residual O₂ level at < 60% of actual UEL O₂ composition - use padding gas if necessary - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if padding/purge failed or leak arose - consult applications * booster with hermetic primary seal
<i>EXTERNAL AREA IS HAZARDOUS, but ATEX certification is NOT required</i>	<p>can use standard primary pumps or boosters with certified motor and electrics</p> <ul style="list-style-type: none"> - use inert gas dilution for operation up to 25% LEL - integrity of dilution system dependent on Zone which would result if dilution failed 	<p>can use standard primary pumps or boosters* with certified motor and electrics</p> <ul style="list-style-type: none"> - for operation up to 2vol.%O₂ below MOC, continuous O₂ monitoring is required - for operation up to 60% of MOC, regular O₂ checks are required - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if dilution/purge failed or leak arose - consult applications * booster with hermetic primary seal 	<p>can use standard primary pumps or boosters* with certified motor and electrics</p> <ul style="list-style-type: none"> - for low-UEL gases consider below-LEL operation - for above-UEL operation maintain residual O₂ level at < 60% of actual UEL O₂ composition - use padding gas if necessary - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if padding/purge failed or leak arose - consult applications * booster with hermetic primary seal

<p>EXTERNAL AREA IS NON-HAZARDOUS</p> <p><i>(ATEX certification does not apply)</i></p>	<p>can use standard primary pumps or boosters</p> <ul style="list-style-type: none"> - use inert gas dilution for operation up to 25% LEL - integrity of dilution system dependent on Zone which would result if dilution failed 	<p>can use standard primary pumps or boosters*</p> <ul style="list-style-type: none"> - for operation up to 2vol.%O₂ below MOC, continuous O₂ monitoring is required - for operation up to 60% of MOC, regular O₂ checks are required - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if dilution/purge failed or leak arose <p>- consult applications</p> <p>* booster with hermetic primary seal</p>	<p>can use standard primary pumps or boosters*</p> <ul style="list-style-type: none"> - for low-UEL gases consider below-LEL operation - for above-UEL operation maintain residual O₂ level at < 60% of actual UEL O₂ composition - use padding gas if necessary - exclude air - purge exhaust line - integrity of system dependent on Zone which would result if padding/purge failed or leak arose <p>- consult applications</p> <p>* booster with hermetic primary seal</p>
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