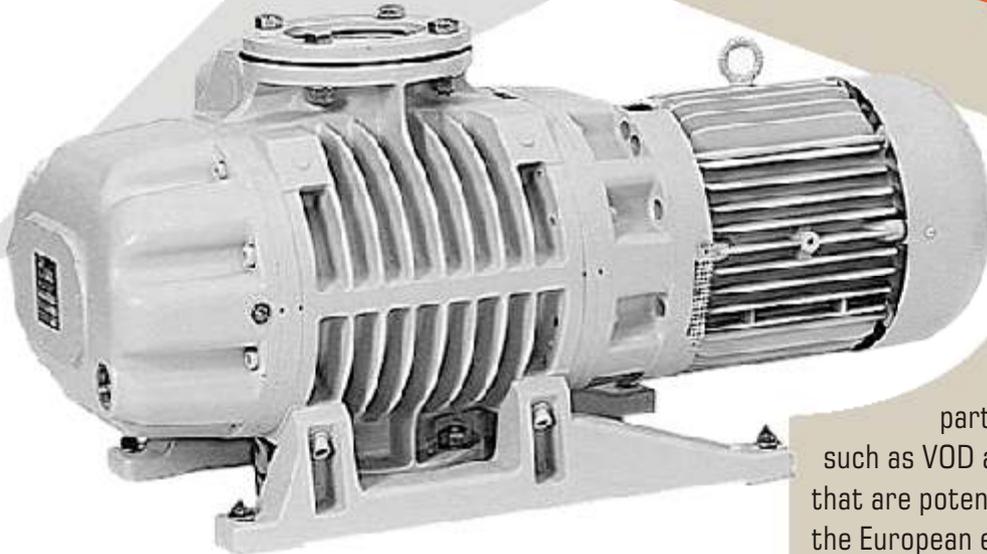


Explosion, Protection, Safety in Secondary Steel Degassing

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Over the last decade, mechanical vacuum systems have proven to be very practicable, reliable and powerful for steel degassers and, compared with conventional steam ejector technology, they dramatically reduce operation costs and CO₂ emissions. Today's international standards for mechanical vacuum systems are based on the latest generation Roots-type vacuum pumps and dry screw-type vacuum pumps. Selecting such modern mechanical pump solutions also offers outstanding process control possibilities, and employs a very reliable design, enabling the pumps to survive inside the harsh steel plant environment. By installing standard pumps in multiple arrangements, even highest suction requirements can be fulfilled with competitive pricing (see Figure 1)

In recent years, plant manufacturers and end users have made increased efforts to analyse the gases produced during the various steel degassing and decarburisation processes. Attention was given to the presence of flammable gases, such as carbon monoxide (CO) or hydrogen (H₂) which, in combination with oxygen in the right concentration, could generate explosive gas mixtures. Then, having identified potentially explosive mixtures, the user must ensure that they cannot cause a hazardous explosion if ignited by a potential ignition source.

As mechanical pumps containing fast rotating parts could theoretically become a source of ignition, this article highlights that by employing the European equipment for explosive atmospheres (ATEX – Appareils destinés à être utilisés en ATmosphères Explosibles) regulations, safe and still cost-effective mechanical vacuum solutions are possible. The directive 94/9/EC provides the technical requirements to

Today's international standards for mechanical vacuum systems are based on the latest generation Roots-type vacuum pumps and dry screw-type vacuum pumps. Degassers, particularly those using oxygen injection, such as VOD and RH-OB, can result in off-gases that are potentially explosive. Equipment supplied to the European equipment for explosive atmospheres (ATEX), provides safe and cost-effective mechanical vacuum solutions.



Fig. 1 : Modern Mechanical Vacuum System for Steel Degassing

be applied and the relevant conformity assessment procedures before placing any equipment or protective systems intended for use in potentially explosive atmospheres on the European market.

Risk Assessment

Within the ATEX regulations, the user has the responsibility to analyse the specific degassing process and to define appropriate explosion protection zones both for the equipment itself and its surroundings. The user needs to identify if the gas mixtures which could appear inside these areas are explosive and how likely this is.

During a typical steel degassing process potentially flammable fuels as CO or H₂ are produced, but the appearance of such gases alone does not create a danger.

Only if the gas is mixed in the right concentration with oxygen does the gas mixture become dangerous. This can occur if their concentration lies between the lower explosion limit (LEL) and upper explosion limit (UEL) values.

On analysing a typical degassing cycle we find that we do not see a clear ‘fuel with air’ gas mixture, but that the fuel is mixed with various other gases. LEL and UEL can therefore only be a guideline to analyse if the identified gas mixtures are dangerous or not.

In addition, LEL and UEL are dependent on pressure, but the literature only mentions valid data for atmospheric pressure. Under vacuum conditions, the ‘explosive bandwidth’ becomes smaller and below a certain vacuum level (minimum ignition pressure) no gas mixture can be ignited (see Figure 2).

The literature provides no clear information for the minimum ignition pressure, and specific data for H₂ and CO cannot be found. Traditionally pressures below 50-100mbar have been declared as safe areas, but recent literature shows that under certain conditions ignition is also possible at much lower pressures.

Even if assuming that the degasser is operating below the minimum ignition pressure, the user must hold in mind that the extracted gases are compressed to atmospheric pressure by the vacuum pump system and might become hazardous inside the pumps or at their exhaust side.

Another way to define if a gas mixture is safe is the use of the Minimum Oxygen Concentration (MOC), also known as the Limiting Oxygen Concentration (LOC). This value defines the limiting concentration of oxygen below which combustion is not possible, independent of the concentration of fuel. The MOC varies with pressure and temperature and is also dependent on the type of inert (non-flammable) gas (eg, argon used for circulation). In Table 1 some sample literature data are listed.

Table 2 : ATEX Product Categories

ATEX zone	ATEX equipment category	
Zone 0	Cat. 1	No ignition source with rare malfunctions
Zone 1	Cat. 2	No ignition source with expected malfunctions
Zone 2	Cat. 3	No ignition source in normal operation

(The temperature class and gas specific explosion groups are important for the selection of the right equipment. These values will not be further discussed in this article. The auto ignition temperature is only valid if oxygen is present.)

As it is technically possible to measure the oxygen concentration inside the evacuated gases this could be a vital way to ensure safety. Nevertheless, working with literature data which is defined under standard conditions, the user is advised to add an additional margin of at

Table 1 : Flammability Limits of Hydrogen and Carbon Monoxid

	CO	H ₂
Lower explosion limit – in air (LEL), %	12	4
Upper explosion limit – in air (UEL), %	75	75
Minimum oxygen concentration (MOC), %	5.1	4.6
	3.1 (60% level)	2.8 (60% level)
Auto ignition temperature, °C	605	570
Temperature class, °C	T1 (>450°C)	T1 (>450°C)
Explosion group	IIB	IIC

Fig 2 : Pressure Dependency of LEL and UEL

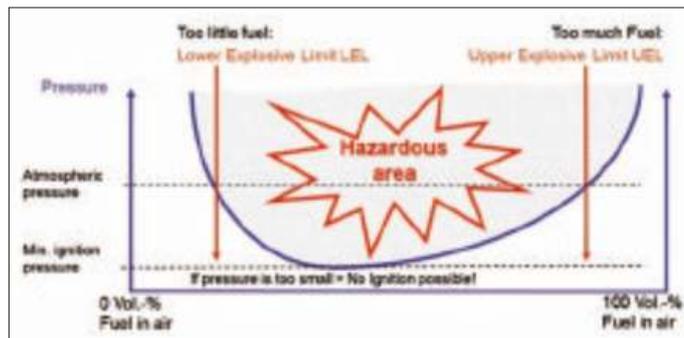
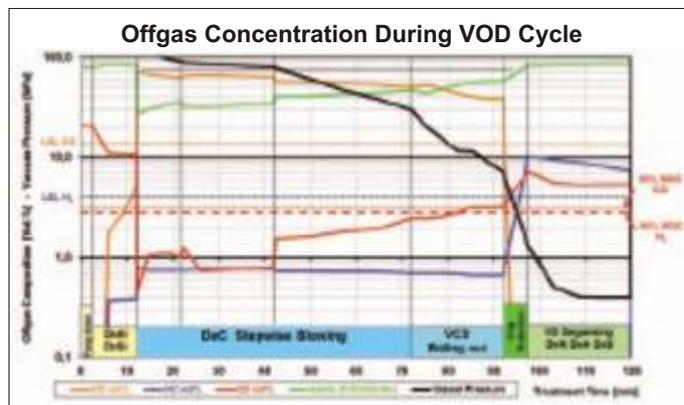


Fig 3 : Off-gases During A Typical VOD Cycle



least 60% to ensure safety for specific, non-standard conditions.

Figure 3 shows a sample gas-analysis for a typical VOD process. The concentrations of the important gases are as follows :

Hydrogen

The H₂ concentration varies between 0% and 15% during the cycle and so is between the LEL (4%) and the UEL (75%) for part of the process, which means that the gas mixture is potentially explosive if the residual gas contains enough oxygen.

Carbon Monoxide

The CO concentration varies between 0% to 72% during the cycle and so is between the LEL (12%) and the UEL (75%) for part of the process, which means that the gas mixture is potentially explosive if the residual gas contains enough oxygen.

Oxygen

The O₂ concentration varies between 0.6% and 20% during the cycle. The maximum suggested 60% MOC value is 3.1% and as the O₂ concentration is above this

3% level at least part-time, there is enough O₂ present to make the CO content explosive.

The user now needs to analyse if a high O₂ concentration exists at the same time while higher CO or H₂ concentrations are present. The sample gas analysis shows that approximately between 84 and 92 minutes the O₂ concentration is above 3.1% (60% of MOC), at the same time as the CO concentration is above 12%. Between 96 and 120 minutes the O₂ concentration is above 2.8% (60% of MOC) while at the same time the H₂ concentration is above 4%.

It is not known whether, under the specific conditions inside the VOD and inside the vacuum pumps, such gas mixtures are really ignitable, but as it is at least possible, the user is advised to take active measures to ensure health and safety

Potential Safety Measures

The ideal safety measure would be to avoid the build-up of explosive gas mixtures. This means either the fuel or the oxygen must be avoided. Both are not possible here as :

- Any system will have leaks
- The VOD process involves an oxygen blowing step and as the operator cannot ensure that 100% of the blown oxygen will react with the melt, there will always be oxygen present in the off-gas
- As the carbon content of the steel will not fully react to CO₂, there will always be CO present inside the off-gas as potential fuel

Alternatively the user could dilute the off-gas with an inert gas (eg, nitrogen) to ensure that the fuel concentration stays below the LEL or the oxygen concentration below the MOC. The problems here are the unknown gas concentrations which appear in reality, next to the fact that the LEL and MOC literature values are defined for 'standard conditions' only, which are far away from those present inside a steel degassing system.

To ensure full safety, the user must create a worst case scenario. As a result, the required amount of inert gas to safely dilute the off-gas could increase the off-gas volume flow easily by factors of 2 to 10. This would then require investment in a 2 to 10 times bigger mechanical vacuum system, a dramatically higher investment, making each mechanical vacuum system not viable.

The most pragmatic and economical procedure to ensure safety, however, is offered by European Directive 1999/92/EC (or ATEX 137) which provides clear guidelines, not dependent on unclear gas compositions and safety data limits.

ATEX is designed to avoid igniting an explosive gas mixture simply by controlling the ignition sources. Several explosion risk levels are defined and rules for the appropriate equipment to be used for those. The higher the risk, the more unlikely the equipment should become an ignition source.

Following the ATEX 137 regulations three different ex-zones are defined:

Zone 0 : The explosive gas mixture is present >50% of operation time

Zone 1 : The explosive gas mixture is regularly present (>30min/yr, <50% of operation time)

Zone 2 : The explosive gas mixture is rarely present (<30min/yr)

Depending on the defined zone, the user must employ equipment designed to cope with the special requirements inside these explosion zones. The European Directive 94/9/EC (ATEX 95), defines the

following equipment categories (see Table 2):

Depending on the defined explosion zone, the user must select equipment certified for the corresponding equipment category to ensure a safe operation according to the standards.

ATEX Zone Analysis for VOD Cycle

VOD equipment Looking, for example, at the VOD process cycle described in Figure 3, it is apparent that in the worst case there is a 32 minute time period during which the off-gas might have an explosive concentration. Not even taking into consideration that the degasser and the pumps will have additional idle time without any offgas load, this would represent a maximum of about 25% of the total processing time.

Assuming that even in a best case scenario, the explosive gas mixture will be present for more than 30min/yr, according to the abovementioned zone definition such intermittent, periodically appearance would be defined as a Zone 1. The user must use equipment certified for Cat. 2

External equipment Considering that the interior of the degassing unit and all the vacuum pumps are always under vacuum conditions when the flammable gases appear, even leakages could not cause these flammable gases to escape to the higher pressure ambient area. Any leak would cause the ambient air to leak into the equipment, already defined as a Zone 1. The surrounding of the pumps would not be affected by such a leak.

Using mechanical pumps with hermetic sealed design and ensuring leak testing of the static seals at the exhaust side of the system, leak-tightness can be ensured also for those parts of the system inside which small overpressures could be present. The user will therefore very likely not need to define any explosion zone for the surrounding of the degasser or the vacuum system.

Additional to the explosion zone definition, the gas mixture must be classified into a temperature class and a gas explosion group. The temperature class defines the minimum surface temperature at which the gas would self ignite, whereas the gas explosion group sorts the different gas types according to their probability of ignition (see Table 1).

Fig 4 : RUVAC Wh7000



Fig 5 : Lab Setup for Atex Temperature Measurements



Summary VOD Process Risk Assessment

Upon analysing their process, plant operators will, very likely, define an explosion protection Zone 1 for the degasser itself, but no zone for the outside. A vacuum system for the VOD process involving CO and H₂ gas must therefore be certified for ATEX Cat. 2 (inside) temperature class T1 (or better) and explosion group IIC.

Standard pumps fulfilling such specifications are available on the market and could be combined with inside ATEX certified systems by knowledgeable and certified vacuum system manufacturers.