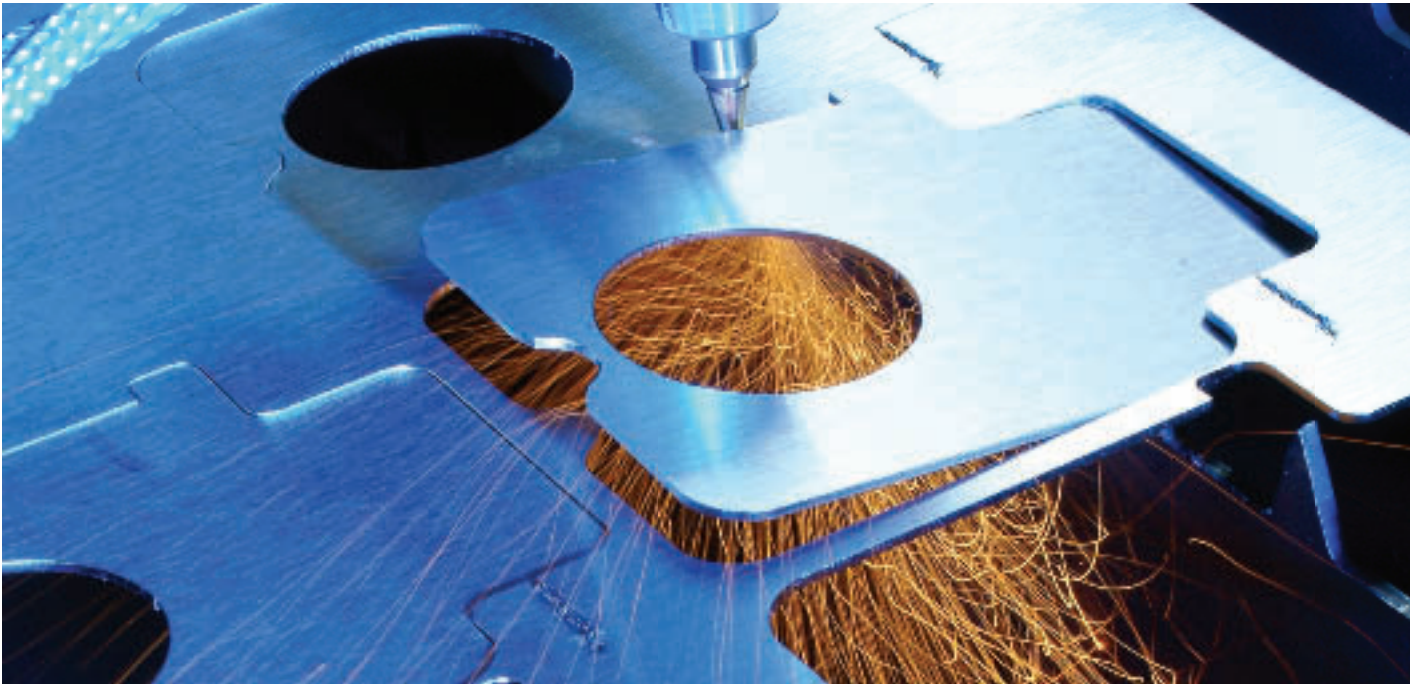


Laser gases and
gas supply systems.
LASERLINE[®] Technical.

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Introduction.



Lasers are used in many materials-processing applications: laser cutting, laser welding and surface treatment of metallic and non-metallic materials. Gas lasers and solid state-lasers are commonly used for these applications. Carbon dioxide (CO₂) gas lasers are the most frequently used for laser cutting of metals. In contrast, a variety of different laser types (including solid-state lasers) are being used for laser welding and surface treatment of metals. For laser welding, solid-state lasers are increasingly being used.

Gas lasers such as CO₂ or excimer require a gas mixture to generate a laser beam. Gas mixtures may vary depending on the type of laser. The purity of these mixes is critical to ensure best performance, efficiency and a higher return on investment.

High-purity laser gases are supplied in gas cylinders, however there is no guarantee that the laser gas mixture in the resonator is of the same quality. Gas distribution systems and operators must be able to handle high-purity laser gases correctly in order to maintain the highest purity levels.

This document outlines the role of gases required to generate a laser beam and also facts about the gas distribution system for reliable laser operations. These facts were obtained from a variety of projects carried out in The Linde Group's application labs and from projects initiated and sponsored by The Linde Group.

Lasers for materials processing.

Fig. 1 – Excitation of laser gas in a laser resonator



Light Amplification by Stimulated Emission of Radiation (laser) produces a narrow, powerful beam of light at a single specific wavelength. Lasers transform one form of energy (electricity, photons, radiation) into another, i.e. laser light (see Fig. 1). This produces a laser beam capable of travelling over large distances; focusing it onto a small spot creates very high temperatures.

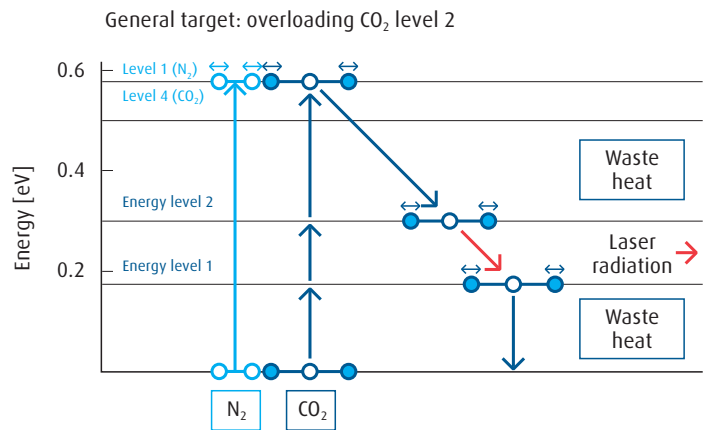
Typically, there are two types of laser used for materials processing – gas lasers and solid-state lasers. Common gas lasers are CO₂ and excimer lasers. The CO₂ laser is most frequently used for laser cutting. The laser medium is a gas or, more accurately, a mixture of gases with CO₂ as the active ingredient. Excimer lasers are ideal for surface-treatment applications and micromachining. The excimer gas mixture consists of a rare-gas/halogen combination. The name excimer (originally short for excited dimer) was given to a short-lived molecule that bonds a halogen atom and a noble gas atom when in an electronically excited state. In the excited state these form a metastable compound, the “excimer”.

The group of solid-state lasers covers a number of systems such as Nd:YAG or Yt:YAG lasers, diode lasers and fibre lasers, where the laser medium is a solid. Consequently, these lasers do not require gases to generate the laser beam.

More information about the laser principle and the types of laser can be found in the Laser Basics brochure.

Laser gases.

Fig. 2 – Role of nitrogen in the CO₂ excitation process



Gas lasers for materials processing can be separated into two groups: CO₂ and excimer. Each generates laser radiation in the invisible spectrum. There are also a number of low-power gas lasers. The helium-neon (He-Ne) laser, for example, generates a visible laser beam, which is used for aligning material on a CO₂ laser processing system.

Laser gases for CO₂ lasers

As their name implies, gas lasers rely on gases to generate the laser beam. The most popular is the CO₂ laser where CO₂ is the active laser medium. The laser gas mixture contains carbon dioxide but also other components such as helium and nitrogen. Depending on the type of laser, small amounts of other gases such as oxygen (O₂), carbon monoxide (CO), hydrogen (H₂) or xenon (Xe) may be required in the mix.

Role of carbon dioxide

CO₂ is the gas that is active in generating the laser light, i.e. infrared radiation with a wavelength of 10.6μm. The radiation is created by transitions between different vibrational energy levels in the carbon dioxide molecule.

Laser radiation is created when:

1. CO₂ molecules are excited to an upper laser level by collision with electrons in the electric discharge.
2. 10.6μm laser radiation is created by transitions from the upper level to a lower laser level.
3. After reaching the lower laser level, the CO₂ molecules are transferred to the lowest energy level by collisions with other gas molecules. This is called “relaxation”.

Fig. 3 – Safety cabinet for excimer gases



It is possible to run a CO₂ laser using only CO₂ as the constituent laser gas. However, in order to create the power required for laser cutting and welding, it is necessary to add nitrogen and helium.

Role of nitrogen

It is relatively easy to excite a nitrogen (N₂) molecule to its first vibrational energy level via an electric field or discharge. This first energy level of nitrogen has almost the same energy content as the upper level of CO₂. (see Fig. 2). Transfer of vibrational energy from N₂ to CO₂ is achieved through collision between the two molecules. Thus it is easier to excite the upper laser level of CO₂ by introducing nitrogen. Adding nitrogen to CO₂ results in higher laser power.

Role of helium

The primary role of helium is to help CO₂ to relax, i.e. to move from the lower to the lowest energy level and re-enter excitation process. Helium atoms collide with CO₂ molecules and vibrational energy is transferred from CO₂ molecules to the helium atoms. As a result, higher laser powers can be obtained.

Helium also helps to conduct heat away from the electric field or the electric discharge (it has the highest heat-conduction coefficient of all gases). This is essential for slow-flow CO₂ lasers, where excess heat must be conducted to the walls of the discharge tube. For fast-flow CO₂ lasers, helium gives a more stable electric discharge and supports the excitation efficiency.

Laser gas composition

CO₂ laser gas mixtures almost always contain helium, nitrogen and CO₂ as basic components. Some lasers may also require small additions of CO, O₂, H₂ and/or Xe, which trigger the chemical process in the resonator. CO and O₂ counteract the decomposition (dissociation) of CO₂,

allowing higher output powers. Hydrogen has a similar effect and can contribute to a more uniform electric discharge in the resonator. Output power and efficiency can also be improved by the addition of Xe. This has the lowest ionisation potential and largest ionisation cross-section, thus becoming the primary source of ions in the discharge.

Laser gases can be delivered in separate cylinders, or pre-mixed in a single cylinder.

Laser gases for excimer lasers

Excimer lasers are also multi-gas lasers. There are several spectral lines (wavelengths) that can be generated depending on the type of rare gas/halogen combination in the laser gas mixture. In the excited state these form a metastable compound called “excimer” (excited dimer). As this compound disintegrates, it emits UV radiation. Krypton-fluorine (Kr-F) lasers are typical examples of this type of laser, generating laser radiation at 248nm. Another type is the xenon-chlorine (Xe-Cl) laser, emitting radiation at 308nm. Rare gases are usually argon, krypton or xenon, buffer gases, helium or neon, and fluorine or chlorine representing the halogen.

Fluorine and chlorine are toxic and highly corrosive (especially when in contact with moisture) and require special processes and procedures for the gas supply system and when handling waste laser gas (see Fig. 3).

Excimer lasers are generally supplied with custom-blended pre-mixtures where the halogen component is diluted to below 10%.

Purity of laser gases.



Purity of gases is described as a percentage figure or a two-digit number that shortens the percentage figure. The latter counts the number of nines and adds the last digit, e.g. Helium 99.996% corresponds to Helium 4.6.

“Minimum purity” of laser gases has been agreed by all the major laser manufacturers:

Minimum purity of laser gases

Laser helium	99.996% (4.6)
Laser nitrogen	99.996% (4.6)
Carbon dioxide	99.995% (4.5)

Unfortunately, these purity levels alone are no guarantee of reliable laser operation. Some impurities present in the gas can impact laser performance, even at these high purity levels. However, nitrogen as an impurity in helium would have no effect, as nitrogen is already a component of the laser gas mixture. However, other impurities can have disastrous and detrimental effects on laser performance.

Impurities and laser performance

Certain impurities in the laser gas mixture can affect the performance of CO₂ lasers resulting in some of the following:

Instability of electric discharge

Negative ions such as NO₂⁻, H⁻ or OH⁻ cause an increasing number of thermal instabilities in the electric discharge. This may result in contraction of the ordinary glow discharge to an undesired arc discharge (arcing) or fluctuations in current and voltage. Thus electrodes or power generation components may be damaged.

Deposits on the mirrors

Dust particles and dissociation in the electrical discharge of hydrocarbon compounds (such as oil vapour) will cause deposits on the water-cooled mirrors, affecting their reflectivity. Deposits on mirrors absorb laser radiation and can cause intermittent overheating, and severe damage to the mirror coatings (see Fig. 4). The uniformity of the laser beam will be destroyed and the mirror will eventually fail due to increased thermal impact. Catastrophic failure, such as melting of the copper substrate, is possible.

Loss of laser power

Impurities can reduce laser power in several ways. Some impurities absorb the 10.6µm laser radiation. These may dissociate and further react with other elements present. Other impurities may collide with CO₂ molecules excited to the upper level. These excited CO₂ molecules lose their energy without emitting laser radiation. This is called laser relaxation from the upper laser level.

Fig. 4 – Damaged laser optic



Effect on laser performance

It is not easy to attribute laser performance problems to impurities in daily operations. Laser power losses will be minimal in the beginning and can be compensated for by increasing the power setting or reducing cutting speed. Small dents in beam profile caused by mirror deposits can also be compensated by power or speed adjustment up to a certain point. Thus laser breakdowns usually occur unexpectedly and can be costly, not just in terms of repair and component costs but also in terms of revenue loss through laser downtime, production delays and lost customers.

Critical impurities in laser gases

Impurities can have a disastrous effect on laser performance and represent a real risk.

Water vapour

Water vapour (H_2O) impurities can decompose in the electric discharge and generate negative OH^- and H^- ions so that the discharge becomes unstable. The problem is particularly serious for high-power lasers because these always operate under extreme conditions. Active oxygen generated in the decomposition can create a further reaction, including damage to the fragile mirror and output window surfaces.

Hydrocarbons

Hydrocarbon impurities can affect laser performance in several ways. Hydrocarbons decompose in the electric discharge and may form carbon or polymer deposits on the mirrors. Hydrocarbons can also reduce the gain of the laser. The gain is a measure of the ability of the laser to amplify the laser radiation that affects the output power and performance of the laser.

Oxygen

Oxygen is formed when CO_2 dissociates in the electric discharge and oxygen concentration can reach several thousand ppm. Oxygen acts as an impurity in fast-axial-flow CO_2 lasers and can have a disastrous effect on the optics even in amounts less than 1000ppm. The negative effect of oxygen contaminants on the optics is as a result of the creation of ozone in the electric discharge, causing erosion in the optics. Axial-flow lasers are typically more sensitive to oxygen than transverse-flow lasers; the reason is not yet fully understood. Higher beam intensity in axial-flow lasers, however, may serve as one potential explanation.



Non-critical impurities in laser gases

Non-critical impurities usually do not affect the lasing process unless they appear in concentrations over 1000ppm, when they affect the balance of the laser gas mixture.

Nitrogen is a laser gas itself and its presence in other laser gases is therefore irrelevant.

Carbon monoxide (CO) is generated inside the laser cavity as a result of CO₂ dissociation in the discharge. CO impurities in the gas cylinders of the laser gases are therefore irrelevant.

Argon impurities have no influence on laser performance in any of the laser gases.

Nitrogen oxides (NO, NO₂, N₂O, N₂O₃) can have detrimental effects on the performance of lasers. NO₂ and N₂O₃ in particular can affect stability of discharge, even in very small amounts. Fortunately, these are not common impurities. NO, on the other hand, is formed in the laser as result of reactions between dissociated nitrogen and oxygen atoms from dissociated carbon dioxide. Impurity content of nitrogen oxides in the laser gases is therefore irrelevant.

Sources of impurities

It is often assumed that impurities come from the gas cylinders. Generally this is not the case, as gas cylinders undergo a number of checks and inspections before being shipped. Potential sources of impurities in the laser resonator gas mixture could be:

- Disconnected hoses during cylinder replacement
- The gas pipeline
- Gas leakage
- The beam generation process where impurities may be created in the electric discharge by dissociation, decomposition and reactions between dissociated elements forming secondary compounds
- Particles formed by sputtering from inner electrodes (arcing)

In many cases, the gas supply system represents the highest risk of contamination of the pure laser gases on their way from the gas cylinders to the resonator.

Facts About: laser gas purity

- LASERLINE® gas purities have been defined by laser manufacturers
- Water vapour and hydrocarbon impurities are significant even in very small concentrations (less than 10ppm)
- Oxygen impurities are significant in large concentrations (over 100ppm)
- The most likely sources of impurities are during gas cylinder replacement, gas pipelines and pressure regulators

Gas containers.

The type of gas supply depends upon consumed volumes and consumption profile. Economic aspects and business perspectives are always taken into account during the design of a LASERLINE® gas supply system.

Gas containers for laser gases

Laser gases are typically supplied in compressed gas cylinders due to relatively small volume requirements. If many lasers are supplied via a gas distribution network, cylinder bundles are an alternative mode of supply.

Hands-on/hands-off

The simplest form of laser gas supply offered is delivery of gas cylinders, ordered and connected by the laser machine operator. In this instance, the laser operator is responsible for the safe handling and correct replacement of gas cylinders, as well as cleaning and servicing after cylinder exchange. To avoid running out of gas unexpectedly, switch-over manifolds and run-empty alarms can be added, but all responsibility rests on the user/operator.

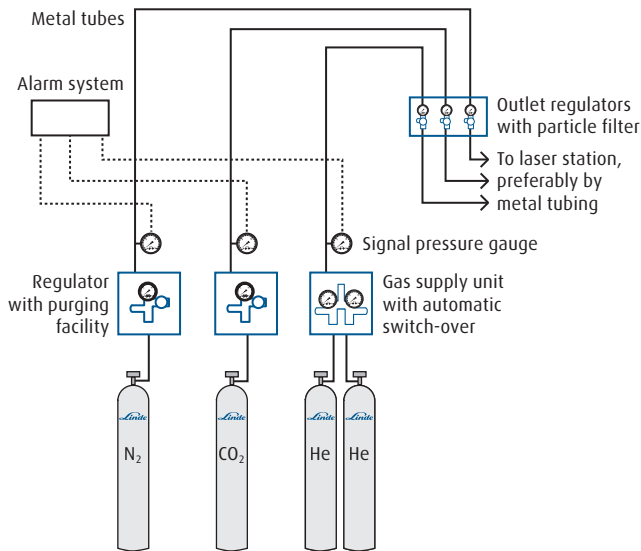
For businesses looking for a more automated and managed gas supply service, The Linde Group offers a number of solutions that reduce involvement of the operator and ensure a low-risk and hassle-free supply.

Facts About: laser gas containers

- Gas cylinders are the most common form of laser gas supply
- Supply service options are also available for a more hands-off service

The laser gas supply system.

Fig. 5 – Gas supply system setup



The laser gas system connects the gas cylinder to the resonator (see Fig. 5). It consists of regulators, tubes/hoses, outlet valves, fittings and special equipment. The gas supply system starts at the gas cylinder where the filling cylinder pressure has to be reduced to working pressure.

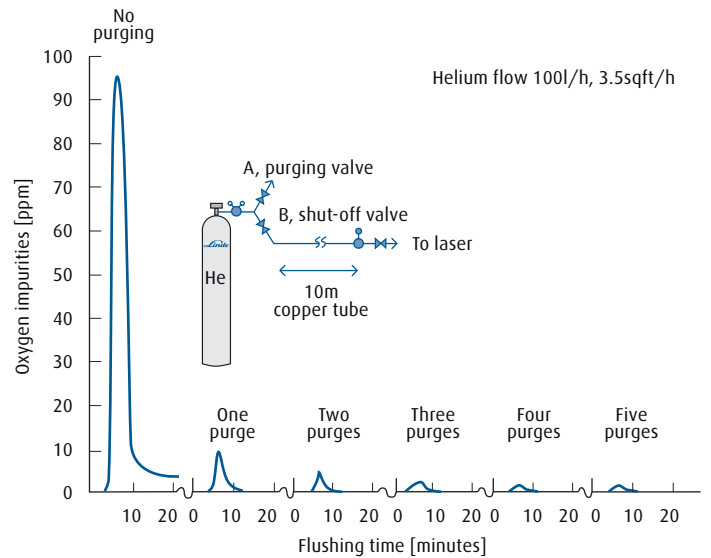
Pressure control

High-purity gases are delivered in gas cylinders compressed to over 100 bar (1450 psi), allowing the storing of larger amounts of gas in the cylinder. This filling pressure must be reduced to working pressure (generally below 10 bar). Gas supply lines of varying length bring the gases to the point of use where the laser is connected. Frequently, outlet valves or outlet regulators operate at this point.

High-purity regulator

A stable pressure must be maintained, generally requiring two-stage regulation either with a two-stage high-purity regulator at the gas cylinder or with two single-stage regulators: one at the gas cylinders and one at point of use. Another advantage of high-purity regulators over standard welding regulators is the metallic membrane, which, unlike a standard polymer membrane, does not emit particles or allow permeation of impurities.

Fig. 6 – Oxygen impurities after cylinder replacement and purging procedure



Purging facility

During replacement of gas cylinders, the high-pressure connection of the gas cylinder is exposed. Dust, smoke, humidity and other gases present can enter the hose and be blown into the resonator by the replacement gas unless preventive measures are adopted. Consequently, these impurities must be purged before the new gas cylinder is connected to the laser resonator.

Using two additional valves helps to avoid any such problem: one to close the connection to the laser resonator (B) and the other to open the gas line to the atmosphere releasing the contaminants (A) (see Fig. 6). Measurements of the oxygen impurity levels (as an example), have shown that only a few purges are required to cleanse the regulator and hose of the oxygen impurities (as seen in Fig. 6). Purge cycles are controlled by quickly opening and closing valve A. Continuous gas flow with valve A open for minutes will not be sufficient because it will not remove impurities from traps such as dead ends effectively. By contrast, the contaminated atmosphere in the high-pressure hose will be diluted whenever valve A is closed and the contaminated gas mix will be released (to surroundings) when valve A is opened.



Cylinder regulator or wall-mounted manifold

Cylinder regulators are simple and easy to install. Nevertheless, cylinder regulators do not allow uninterrupted operation. Wall-mounted manifolds allow uninterrupted laser operation even during replacement of empty gas cylinders. Cylinders can be stored at a central point far away from the point of use to satisfy safety legislation and allow more workspace. The safety of operating personnel is improved and the number of cylinders can be reduced, making the cylinder park easier to manage and monitor. Re-ordering alarms and fully automatic gas cylinder replacement options are also available.

The laser gas supply system.

Fig. 7 – Resistance of hose materials to permeation of water vapour

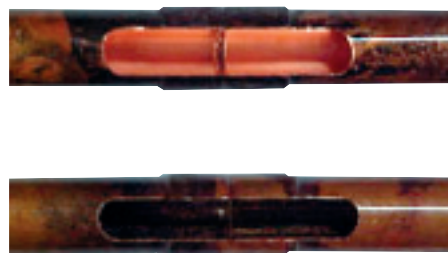
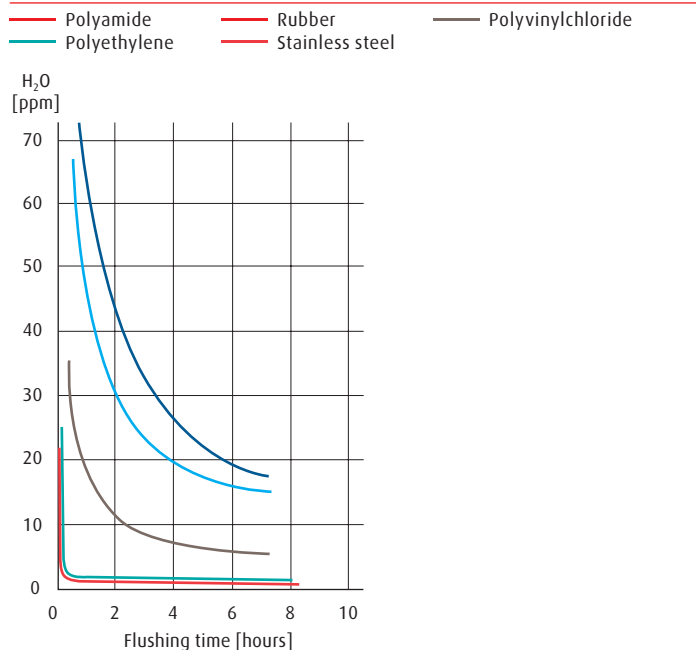


Fig. 8 – Contamination of laser gas caused by poor brazing

Gas supply lines

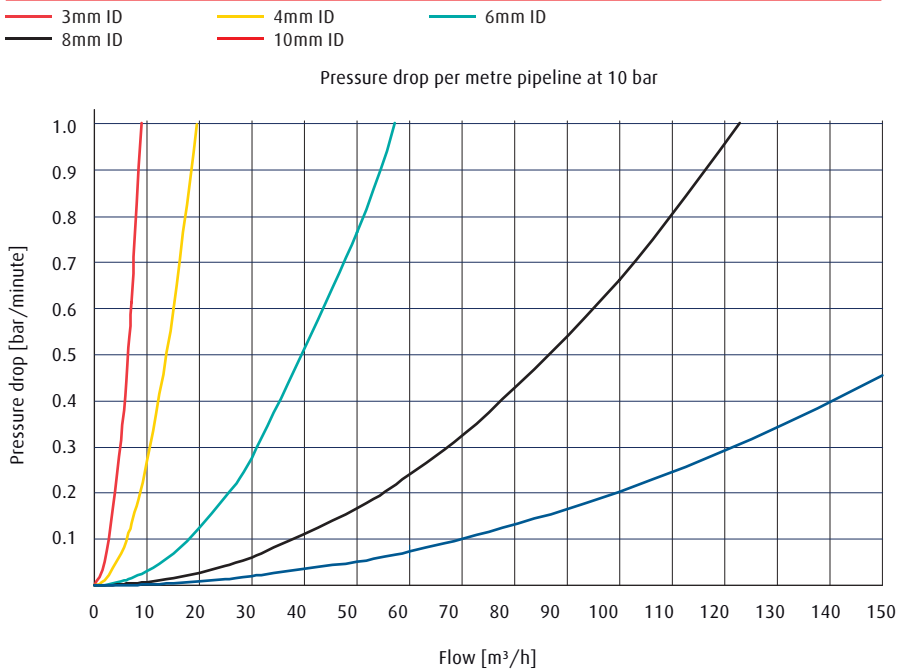
Gas supply lines connect the high-pressure regulator to the point of use and the laser resonator. These can be several metres in length depending on the local gas cylinder storage situation and safety legislation requirements.

Plastic hoses

Plastic hoses are convenient and easy to handle and set up, but are not generally suited to the supply of laser gases. Plastic hoses have a higher risk of contamination from impurities due to their permeation qualities. The amount of contamination depends on the type of plastic material and the type of impurity. This is illustrated in Fig. 7, showing relative orders of the impurity levels for tube and hose materials analysed in a test setup.

Test conditions allowed 100l/h (3.5sq.ft/h) helium 4.5 to flow through various test hoses and tubes at a length of 10m (33ft). Impurity levels of water vapour, oxygen and nitrogen were measured.

The amount of contamination depends on the type of plastic material and the type of impurity. Teflon for example, is good at keeping water vapour impurities low but is susceptible to oxygen and nitrogen impurities, as these continuously enter the hose from the ambient atmosphere by diffusion. Polyethylene and polyamide have the highest resistance to permeation of crucial laser impurities. These, however, are never as diffusion-tight as metal tubes and should be used in the shortest lengths possible.

Fig. 9 – Pressure drop per metre length of gas-supply line

Metal tubes

Metal tubes show the highest levels of resistance to permeation of critical laser impurities. Copper or stainless steel tubes must be cleaned from production residues and be professionally joined.

Orbital TIG welding with root protection and compression-ring fitting is recommended. Brazing is generally not accepted by many laser manufacturers because of oxides at the root side, contaminating the laser gas and impeding the lasing process (see Fig. 8).

Hoses or tubes

Metal tubing professionally joined is recommended to maintain the highest purity levels. If running the laser 24/7, plastic hoses (PE, PA) will suffice, as small amounts of impurities will enter the laser but also be removed during normal resonator gas refreshing cycle. Problems can occur during breaks in the gas flow (overnight or over the weekend), when larger amounts of impurities permeate the hose and accumulate. Those impurities will be flushed directly into the laser when gas flow resumes.

Dimensions of tubes or hoses

The required diameter of tubes and hoses depends on the length of pipeline, number of bends, number of lasers supplied etc. (see Fig. 9). The minimum diameter for a standard short-distance installation is 6mm

Point of use

At the point of use, gases transfer from the gas supply system to the laser. Shut-off valves will keep the gas lines clean before the laser is connected or whenever the laser is disconnected.

In case of extremely long gas-supply lines, the second pressure regulation stage should be positioned at the point of use (first stage at gas cylinders).

Micro-filters at the point of use provide additional safety for proportional valves inside the laser.

Facts About: laser gas supply system

- Two-stage regulators, suitable for high-purity gases with metallic membrane
- Purging facility for cleaning service after gas-cylinder exchange
- Wall-mounted manifolds for security and efficiency
- Metal pipelines, professionally welded or compression-ring-fitted
- Plastic hoses (PE or PA) if unavoidable, as short as possible
- Minimum internal pipe diameter 6mm

LASERLINE[®]. Laser gases and services.

With the Linde LASERLINE[®] programme, we offer our customers a complete package consisting of appropriate gases, customised gas supply system and comprehensive customer service.

Author

Laser Solutions Team

Date

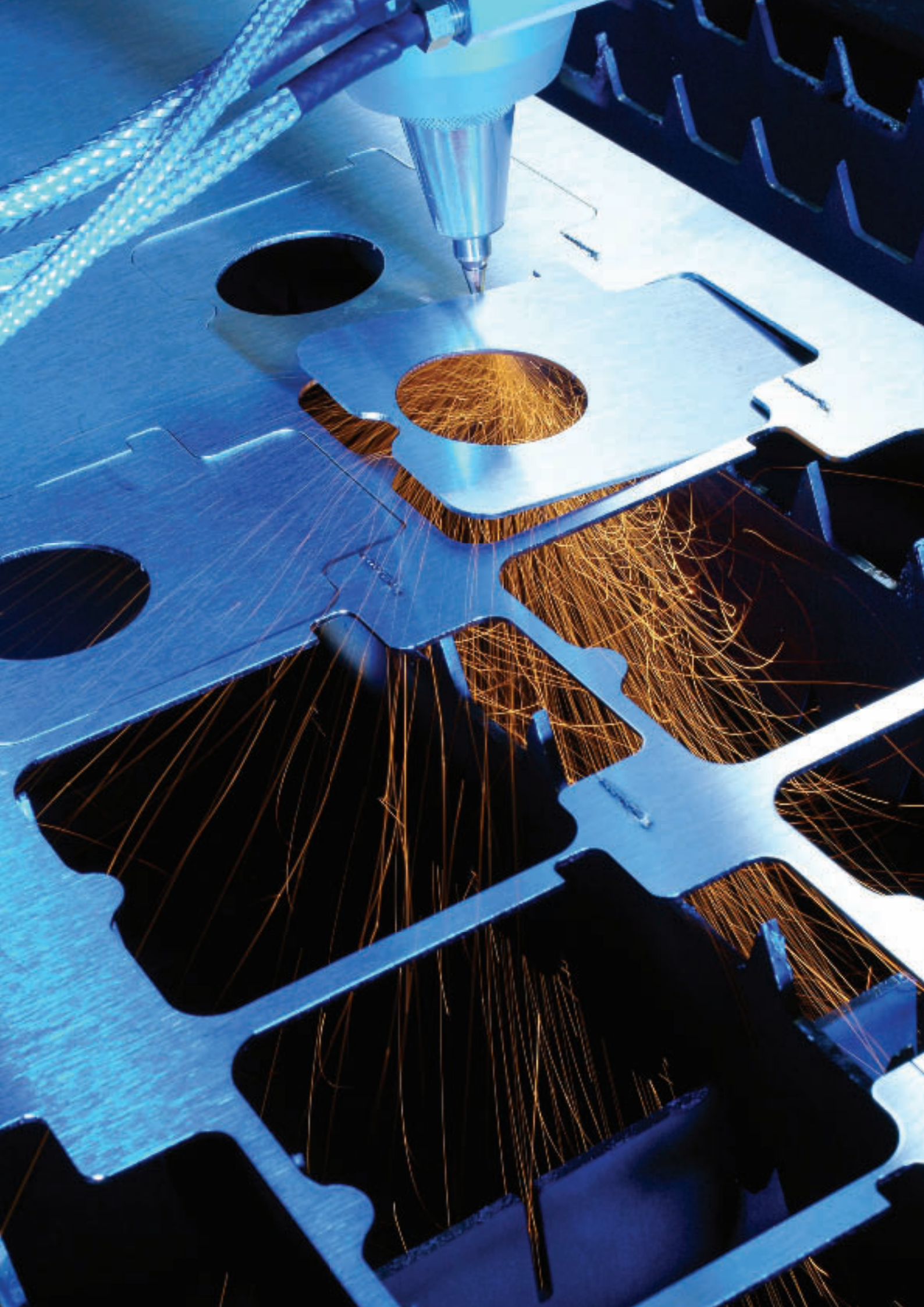
June 18, 2008

References

1. Broden Gert et al: Gas-supply systems for CO₂ lasers, IIW-Doc. 1108-91,
2. Hsu, C.R. et al: The Influence of Laser Cavity Gaseous Impurities on the Performance of an Industrial CO₂ Laser, Journal of Laser Applications (1996) 8, 275-283

For a selection of other LASERLINE[®] Technical brochures, please contact your local Linde representative.

[Laser basics](#), [Laser cutting](#), [Laser welding](#).



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BOC is now part of The Linde Group, a world leading gases and engineering company.

With its innovative concepts, Linde is playing a pioneering role in the global market. As a technology leader, it is our task to constantly raise the bar. Traditionally driven by entrepreneurship, we are working steadily on new high-quality products and innovative processes.

Linde offers more. We create added value, clearly discernible competitive advantages, and greater profitability. Each concept is tailored specifically to meet our customers' requirements – offering standardised as well as customised solutions. This applies to all industries and all companies regardless of their size.

If you want to keep pace with tomorrow's competition, you need a partner by your side for whom top quality, process optimisation, and enhanced productivity are part of daily business. However, we define partnership not merely as being there for you, but being with you. After all, joint activities form the core of commercial success.

Linde – ideas become solutions.