FLEXIBLE CONNECTIONS IN HIGH PRESSURE GAS SYSTEMS

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1 Scope and purpose

1.1 Scope

The scope of this document includes flexible connections to transmit, charging and discharging), compressed, liquefied and dissolved gases in the temperature range -40 °C to + 65 °C. There are no upper or lower pressure limits.
Flexible connections that transmit cryogenic fluids are excluded which are covered by EN 12434.

Hose assemblies of rubber construction are not within the scope of this document e.g. LPG hose.

1.2 Purpose

The purpose of the document is to provide guidance on the design of systems that use flexible connections for the transmission of high-pressure gas, such that the integrity of systems using these components is further improved.

2 Definitions

Flexible connections are used extensively in the industrial gases industry for a variety of applications for the transmission of gases. They can be classified into the following types: -

- Flexible Hoses
- Pigtails
- Articulated joints

For the purpose of this document, a flexible connection is the generic term covering any of the above connection types.

2.1 Flexible hoses

Flexible hoses are the most widely used type of flexible connections, and these can be divided into two groups:

a) Hoses incorporating a plastic liner with metal or filament over braiding (see fig1).
b) Hoses incorporating a corrugated metallic liner with over braiding.

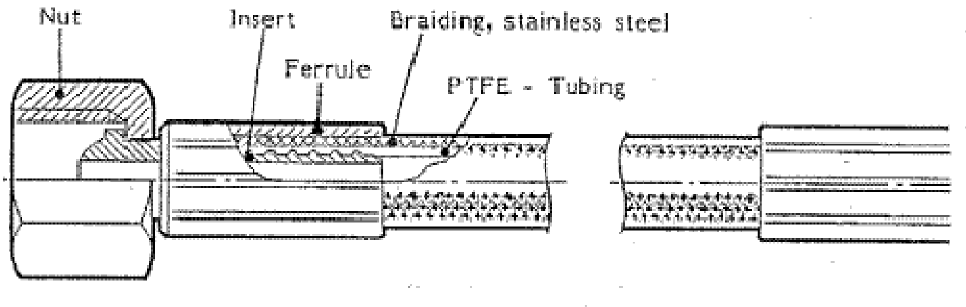


Fig 1 Construction of a typical hose with a PTFE (Polytetrafluroethylene) liner

PTFE lined hoses have been used successfully in high-pressure gas systems for many years. However, hose failures, in particular ignition of the hose liner when used in oxygen service, have been reported from time to time.

Although most of the reported failures are associated with distribution manifold systems, typically at customer installations, failures have also been reported at cylinder filling stations.

2.2 Pigtails

Pigtails are usually manufactured from solid tube with a mechanical connection at each end, which connects two high-pressure systems. Pigtails are semi flexible and usually form part of a fixed installation. Pigtails are also used in applications where a flexible hose is unsuitable, for example in applications using corrosive gases, or the permanent installation of gas cylinders, e.g. bundles.

Fig 2 Pigtails used in a cylinder bundles installation

2.3 Articulated joints

Articulated/swivel joints are where a length of pipe is articulated about a union and the pipe takes the place of the flexible hose. These types of connections are used where frequent “making and breaking” of the connection takes place and when a flexible hose is not suitable.

Fig 3 An articulated joint

3 Failures of flexible connections

The flexible connection has in many cases been the weakest link of a pressure system, and therefore it is important to consider this in the design of any pressure system and apply the appropriate engineering standard.

Flexible connection failures can be grouped into two types:

a) Mechanical failures
b) Hose ignitions.

Linked to this the following have been identified as significant factors in connection failures;

- Poor design and/or manufacture
- Material compatibility
- Contamination
- Rapid pressurisation, (adiabatic compression) and depressurisation
- Particles
- Misuse, damage and poor maintenance

These are considered in more detail below.

3.1 Poor design and/or manufacture

Typical faults are:

a) Incorrect design pressure, where the flexible connection is used beyond the design parameters of the connection.
b) Incorrect design, including incorrect design of end fittings, poor attachment of end connections, etc. This may be due to a number of factors such as incorrect specification or an uncontrolled deviation in the process conditions.
c) Manufacturing defects: where the flexible connection is not constructed to the manufacturing specification.
d) Inadequate material: This may include defective materials or material with inadequate properties, e.g. strength, toughness.

3.2 Material compatibility

Material compatibility is vital to ensure that a flexible connection will perform safely in service. There are numerous publications on the subject of compatibility, see EN ISO 11114-1 and 2
Flexible connections incorporating non-metallic materials such as PCTFE, nylon, neoprene and nitrile liners are available for gas service, but they must be compatible for use with the gas service.
For oxygen service the auto ignition temperature of most common plastics are too low. PTFE has one of the highest auto ignition temperatures in oxygen, and also suitable mechanical properties as a hose liner.

Material	Auto ignition temperature °C
PTFE	450-500
PCTFE	400-430
Polyamide(Nylon)	200-230
Nitrile Rubber	170-250
Neoprene	170-200

Fig 4 Auto ignition temperatures of some common plastic/elastomeric materials in oxygen at 130 bar

Apart from PTFE no other non-metallic material should be used for oxygen service unless it has been thoroughly evaluated in both laboratory and field trials.

Note : For medical and breathing applications PTFE and other halogenated non metallic materials shall not be used for customer installations due to the risk of generating toxic gases, see EIGA Doc 73/00, High Pressure breathing gas systems – toxicity risks of using non metallic materials and ISO 15001.

PTFE has a high permeability to certain gases for example helium, hydrogen and hydrogen chloride and this has to be taken into account when using these gases. Furthermore it has to be considered that the plastic materials have relatively low electrical conductivity and that static build up in a hose liner could produce pinhole leaks by static discharge through the liner, (see ref.1).
When plastic liners can not be used, see recommendations

3.3 Contamination

Contamination, particularly with oils and greases, is a well-known cause for oxygen hose ignition. Hydrocarbon oils and greases have low auto ignition temperatures (AIT) in oxygen, (e.g. AIT = 150-200 °C). In high-pressure oxygen atmospheres these oils and greases ignite with explosive force and if they are in contact with a PTFE hose liner they could initiate a fire in the hose.
Even hoses with metal liners can be set on fire by the ignition of a contaminant in the hose. However the amount of contaminant needed would be several orders of magnitude greater than that necessary to cause ignition of a PTFE liner

3.4 Rapid pressurisation, (adiabatic compression) and depressurisation

A rapid pressurisation e.g. a pressure shock resulting from sudden opening of valves can lead to mechanical damage to hose and couplings as well as ignitions in the case of hoses transmitting oxygen or air.
The vast majority of PTFE lined hose ignitions have occurred at customer installations shortly after the cylinder valve has been opened. Damage to the hose has been reported in some instances as a small hole at the dead end, but in other reports the hose has ignited at the other end or at positions between the two ends. In some instances the hose has ignited at several locations and damage is extensive. A red glow has been observed just before the hose ignited.
Where the hose ignited at the dead end adiabatic compression (see Appendix 1) was attributed as the cause. Particle impingement was assumed as the mechanism where ignition occurred at a distance from the dead end. See also 3.5.1.

	Sequence of Events	Explanation
1	Empty cylinders replaced by full cylinders.	Pressure in Hoses 1 atmosphere.
2	Cylinder No 1 opened.	Manifold and Hose No 1 pressurized. Non-return valves Nos. 2 and 3 closed.
3	Cylinder No 2 opened.	Oxygen in hose No 2 is compressed against NRV. Heat produced by adiabatic compression is transferred to PTFE liner.
4	Hose glows red and ruptures.	PTFE liner spontaneously ignites. In some instances a red glow is observed which is surface combustion of the PTFE liner. At some point the ignition breaks through the liner and burns out through the stainless steel braiding.

During disconnection of an empty cylinder, air will diffuse into the flexible hose and mix with the oxygen. This process is slow and the resulting oxygen-enriched air would be expected to have an oxygen content of at least 90%.

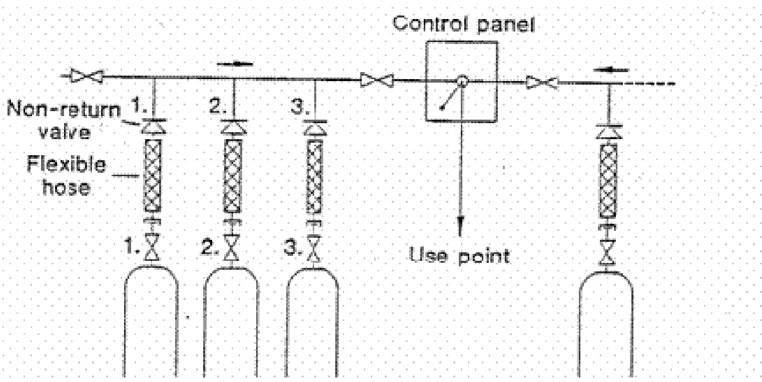


Fig 5

The mechanism by which ignition could propagate in a PTFE hose was not well understood. The industry initiated research programmes to investigate the ignition process. The results of one such programme are reported in Ref. 2.
Under laboratory conditions PTFE lined hoses were subjected to pressure surges of between 240 and 260 bar via a quick opening valve. Hoses were observed to ignite not only at the dead end but also at the opposite end and at intermediate positions in between. In some cases a red glow which started at the dead end moved slowly along the hose to the opposite end. Ignition in some cases was delayed by up to one minute after the original pressure surge.
These tests indicated that the majority of hose ignitions occurring at customer installations were caused by adiabatic compression and not by particle impingement as had previously been assumed.

Rapid depressurisation can result in high oxygen velocities which coupled with any residual contamination or particles will also result in ignitions, see below.

3.5 Particles

Apart from the possible mechanical damage that can be caused by particles, the main risk is ignition in oxygen service. With particles there are two mechanisms that can cause ignition. These are impingement and static electricity build up.

3.5.1 Particle impingement

Particle impingement is a known source of ignition in oxygen steel pipelines. As the particles flow along the pipe they make contact with the metal surfaces and are heated by friction. On impact the heat generated can ignite the metal. This mechanism has been put forward as the cause of PTFE lined hose ignitions. However as PTFE is a soft material and has a very low coefficient of friction and hoses have relatively short lengths this mechanism is less likely to occur. This phenomenon is more likely in metallic flexible connections, e.g. pigtails and articulated joints.

3.5.2 Static electricity

Particles in the gas stream are the major cause for the build up of static electricity inside plastic hoses. Although this mechanism has often been assumed as the cause of hose ignitions, it has never been substantiated for oxygen, though it is strongly suspected when incidents have occurred with flammable gases, see section 3.4 and reference 1.

3.6 Misuse, damage and poor maintenance

There are a number of causes for misuse of and damage to flexible connections. These include, stretching, kinking, rough handling, mechanical impact, fatigue, abrasion, corrosive atmospheres, accidental exposure to fire and heat etc. All can damage the flexible hose and subsequently lead to failure.

An appropriate maintenance regime compatible with the intended service needs to be established and documented. This shall include regular exchange of parts regardless of their service worthiness based on time or use cycles.

4 Recommendations for the prevention of failures of flexible connections

In section 4, the main causes for hose failures and their mechanisms have been described. This section gives recommendations to avoid such failures.

4.1 Design specification and manufacturing control

Since the publication of the original document, work on the design of flexible hoses has been carried out at the International Standards level. This work has resulted in a number of standards being

published. Where applicable these standards should be the basis of any manufacturing specification for a flexible connection.
The design and quality of the finished hose are of paramount importance to the service life of the hose and its satisfactory operation in service.
Before any flexible connection is specified, there must be a complete understanding of the conditions under which it is going to be used.

A design specification should include:

- The applicable standard (s) the flexible connection is to be constructed to.
- Intended Gas Service.
- Internal diameter of the flexible connection.
- Maximum working pressure.
- Operating temperature range.
- Minimum number of pressure cycles over the expected life of the hose, at working pressure
- Minimum bursting pressure (typically 3 to 4 times the working pressure, except for acetylene hoses where a much higher value applies, more than 35 times the working pressure)
- Material specification.
- Minimum bend radius.
- Hose restraining wire.
- Spring guard
- Distance pieces/heat sink (see Appendix 3)
- Length.
- Markings.

It should be noted that an increased bore and increased number of braids will result in a greater bending radius.

A new design of hose should undergo type approval tests, which may include the following:

- Adiabatic compression test (See Appendix 1)
- Burst pressure test
- Pressure cycle test
- Hydraulic pressure test (permanent deformation check)
- Pneumatic leak test (including permeability measuring)
- Impact test for end fittings
- Bend radius test
- Integrity of restraining wire arrangement
- Material compatibility test (See 4.2)

Quality Assurance inspections may include:

- Hydraulic pressure test (typically 1.5 times maximum working pressure)
- Pneumatic leak test (at normal working pressure)
- Cleanliness check (see 4.3)
- Visual inspection (especially of the end fittings)

Some of the type approval tests may be carried out on representative samples from each batch.

The requirements are different for an articulated joint as it is a collection of mechanical components where the need is to consider the mechanical stresses of the design.
In addition there will be a need to consider material of any elastomers used for sealing.

For solid pigtails, these should be designed in accordance with a recognised piping code such as EN 13445*. Particular attention needs to be paid to the design to ensure that bend radii are sufficient such that the pipe thickness is not reduced excessively with bending.*
Solid pigtails may be required to undergo pressure testing that complies with design code used. Certain pigtails, e.g. copper based, may be required to be annealed in cases where excessive cold work has been introduced.

Additionally the attachment of end fittings shall ensure that mechanical integrity is achieved.

4.1.1 Restraining wires/ Anti-whip cable (personnel protection)

The use of a restraining wire/anti-whip cable or a similar solution is recommended for pressures above 40 bars, (see ISO 14113) as they have been proven to prevent hoses from flailing around in the event of a failure and significantly reducing the risk of injury. Other solutions, e.g. a protective cage, assume the hose will flail, but provide personnel protection.

The restraining wire should be securely fastened at each end to prevent the hose from flailing in the case of a fitting failure.

Some hoses are provided with an internal cable to prevent injury in the case of a failure.

An internal restraining wire should only be used when it is certain that the wire will be compatible with the gas being carried through the hose, e.g. oxygen. It should be ensured that any manufacturing process does not leave contaminants on the wire, which may react with the gas. Additionally a check should be carried out that the wire does not restrict flow.

4.2 Material compatibility

Checks shall always be made to ensure that the materials used for the construction of flexible hoses are compatible for use with the gas at the service temperature and pressure.

There are a number of documents and standards to assist in the verification of material compatibility e.g. EN ISO 11114 - 1, 2 and 4.

4.2.1 Hoses incorporating a plastic liner

For oxygen service, PTFE lined hoses are used (see 4.2), whereas for hydrogen, helium and toxic gases service a material less permeable than PTFE should be considered.

4.2.2 Hoses incorporating a metallic liner

The main concern of metallic lined hoses is to confirm the compatibility of some stainless steels with hydrogen and other embrittling gases, see EN ISO 11114 - 1 and 4.

4.3 Cleanliness

Regardless of gas service, flexible hoses shall be cleaned to remove traces of oil, grease, combustible materials and particles. Particular attention shall be paid to hoses in oxidising gas service.
This cleaning is normally conducted by flushing out the hose with a clean compatible solvent with ultrasonic assistance to remove contaminants. This operation is normally conducted under the manufacturers' specification and the hoses then suitably packed, e.g. sealed into clean plastic bags, for shipment to the point of use. This is done to ensure that no contaminants can enter the hose after it has been cleaned.
The hose supplier should carry out quality assurance checks.
To confirm that the cleaning procedure used by the manufacturer is adequate, a sample of each batch of hose should be checked for contamination. For oxidising gas service the hydrocarbon contamination level shall be consistent with the pressure and oxygen content concerned. Values in the range of 100 to 500 mg/m^2, see AIGA 012/04 Cleaning of equipment for Oxygen Service - Guidelines).

4.4 Rapid pressurisation (Adiabatic Compression)

In principle, rapid pressurisation should be avoided to prevent adiabatic compression. Where prevention is difficult, and rapid pressurisation leads to a temperature increase at the dead ends (see 3.4), a number of precautions should be taken when using plastic lined hoses, e.g. customer manifolds with non-return valves (see fig. 5).

Where such effects can occur in oxidising or compressed air service the following solutions are recommended to avoid ignition:

- Use of metallic pigtails, corrugated metal hose, articulated joints.
- Use of distance pieces/heat sink (see Appendix 3) fitted to PTFE lined hoses.

It is recognised that the quantity of gas compressed is an important criterion in hose ignitions. Shorter hoses (less than 1 m) are more difficult to ignite than longer hoses because of this fact.
The distance piece should be fitted to the dead end, i.e. normally the downstream end of the hose. Such distance pieces may also be fitted to both ends of any hose so that the ends can be interchanged. The distance piece absorbs the heat from any hot gas produced by compression and prevents the contact of the hot gas with the hose liner.
Experiments (ref.2) have shown that copper distance pieces are more effective in preventing ignitions from adiabatic compression effects than brass or stainless steel. The thermal conductivity of the material appears to be a significant factor in the effectiveness of the distance piece.
A method of calculating the effective length of a distance piece is given by ASTM (ref.3) Typically however experiments have shown that a 150 mm length of copper pipe or a 250 mm length of stainless steel pipe is sufficient to prevent ignitions in a one metre length of hose used for filling or emptying a single gas cylinder at an oxygen pressures up to 240 bar. For bundle hoses longer distance pieces may be required.

Such distance pieces are intended to prevent ignition of a PTFE liner, i.e. to prevent temperatures exceeding 450°C. However above 300°C PTFE decomposes with the formation of toxic vapours. Consequently the use of such distance pieces may not be sufficient for medical or electronic applications, where even trace amounts of such vapours must be avoided, see EIGA Doc 73/00, “High Pressure breathing gas systems – toxicity risks of using non metallic materials” and section 3.2.
Where hoses fitted with distance pieces are used for gases other than oxygen and air, the compatibility of the gas with the material of the distance piece has to be checked, e.g. no copper for acetylene, see EN ISO 11114-1.
The distance piece can be straight or bent depending on the configuration of the system, see Appendix 3.

4.5 Particles

It is good practice to prevent ingress of particles into any gas equipment, but particularly equipment for oxygen service.
To prevent particles being entrained in gas streams, the following have been used within the gases industry:

- Appropriate cleaning procedures.
- Dust caps over the cylinder valves during transport.
- Filters in the line at the point of cylinder connection. (These do need frequent maintenance.)
- In the case of oxygen and compressed air, advising customers to clean the outlet of the valve before connection.

Before connecting a cylinder to a manifold system the user should visibly check that the valve is clean and free from obvious signs of contamination.

4.6 Static electricity

This only applies to plastic lined hoses (see 3.5.2). One method of reducing the risk of static build up in this type of hose is to use an anti-static liner e.g. a carbon loaded PTFE liner.
Another method is to eliminate particles from the gas stream since they are primarily responsible for producing static charges.
As previously mentioned there is no evidence that any ignitions inside plastic lined hoses have been caused by this mechanism.
To prevent the formation of pinholes (see 3.2) the use of an anti-static liner may be beneficial.
The electrical conductivity of a hose should be in accordance with EN ISO 14113.

4.7 Operation, use and maintenance

Before hoses are fitted and used it is essential to ensure that all relevant service conditions have been considered in the hose specification (see 4.1 to 4.6).
The optimum length of the hoses should be selected for each application to prevent undue torsion stresses on the hose. Where torsion stresses cannot be avoided, the use of swivel joints should be considered.
Hoses should be maintained in good mechanical condition and should be regularly inspected for damage or deterioration.
Where hoses are subjected to rough handling, mechanical impact or abrasion some form of protective covering should be fitted.
As deterioration of hoses may lead to failures, hoses should be included in the maintenance programme for the facility. Part of this will require the replacement at regular intervals, e.g. five years as determined by the user and the operating conditions, e.g. frequency of filling, hose dimensions, environmental conditions.
For filling stations, hoses should be visually inspected prior to each day of use.

5 Check list

The checklist in Appendix 2 has been prepared to assist designers in checking the design of an oxygen installation incorporating PTFE hoses.

6 References

1. Anna Norberg

"Electrostatic effects of solid particles in high pressure gas flow in flexible plastic hoses"

Institute of High Voltage Research, Uppsala 1987

2. Barthelemy, H and Vagnard, G

"Ignition of PTFE hoses in high pressure oxygen systems: Test Results and considerations for safe design and use.
Paper presented at ASTM Symposium on "Flammability and sensitivity of Materials in Oxygen Enriched Atmospheres" 1987 ASTM STP 986

3. A.J.Santay, I.D.Becker and B.L.Werley.

"Design Strategies for polymer lined flex-hose Distance/ Volume pieces"
Paper presented at ASTM Symposium on "Flammability and sensitivity of Materials in Oxygen Enriched Atmospheres" 1997 ASTM STP 1319

EN ISO 11114-1 Compatability of cylinder and valve materials with gas contents Part 1 Metallic Materials

EN ISO 11114-2 Compatability of cylinder and valve materials with gas contents Part 1 Non-Metallic Materials

pr EN 11114-4 Compatability of cylinder and valve materials with gas contents Part 4 Test methods for selecting metallic materials resistant to hydrogen embrittlement

Appendix 1 - Adiabatic Compression

When a gas is compressed rapidly it increases in temperature. The theoretical final temperature when oxygen is compressed assuming the process is adiabatic, (no heat loss to the surroundings), is calculated from the following equation:

$$T_2 = T_1 \times (P_2/P_1)^{(\gamma - 1)/\gamma}$$

Where	T_1	=	Initial gas temperature (K)
	T_2	=	Final gas temperature (K)
	P_1	=	Initial gas pressure (bar a)
	P_2	=	Final gas Pressure (bar a)
	γ	=	Ratio of heat capacities, (1.4 for oxygen)

Therefore if oxygen is compressed from 1 bar to 200 bars at 15°C, the adiabatic theoretical temperature would be 1036°C. Fortunately these theoretical temperatures are never reached in practice, due to heat losses to the surroundings, but the temperatures generated are above the ignition temperature of PTFE at pressure ratios normally encountered in high pressure systems.

Reference should be made to the ASTM Paper; Design Strategies for Polymer lined flex hose Distance/Volume pieces. (ref. 3)

Appendix 2 - Check List

This checklist may be used when designing and supplying systems incorporating PTFE lined hoses.

1. Have all the materials been approved in the system for the particular oxygen service conditions, i.e. temperature and pressure?

    a) Non-metallic materials e.g. elastomers, plastics, valve seats and seals.

    b) Metallic materials

2. Has the system been cleaned to the appropriate standard and can the system be easily cleaned once it has been installed?

3. Have the following been considered to the possibility of adiabatic compression occurring:-

    a) Are there any dead ends in the system?

    b) Have any fast opening valves been installed in the system, e.g. ball valves, quick action globe valves or automatic valves?

    c) Can the equipment resist adiabatic compression, e.g. hoses, valves, pipe work, gauges?

    d) Are there procedures to specify the sequence for opening valves?

4. Can the system tolerate particles?

5. Has the build up of static electricity been considered and has it been eliminated?

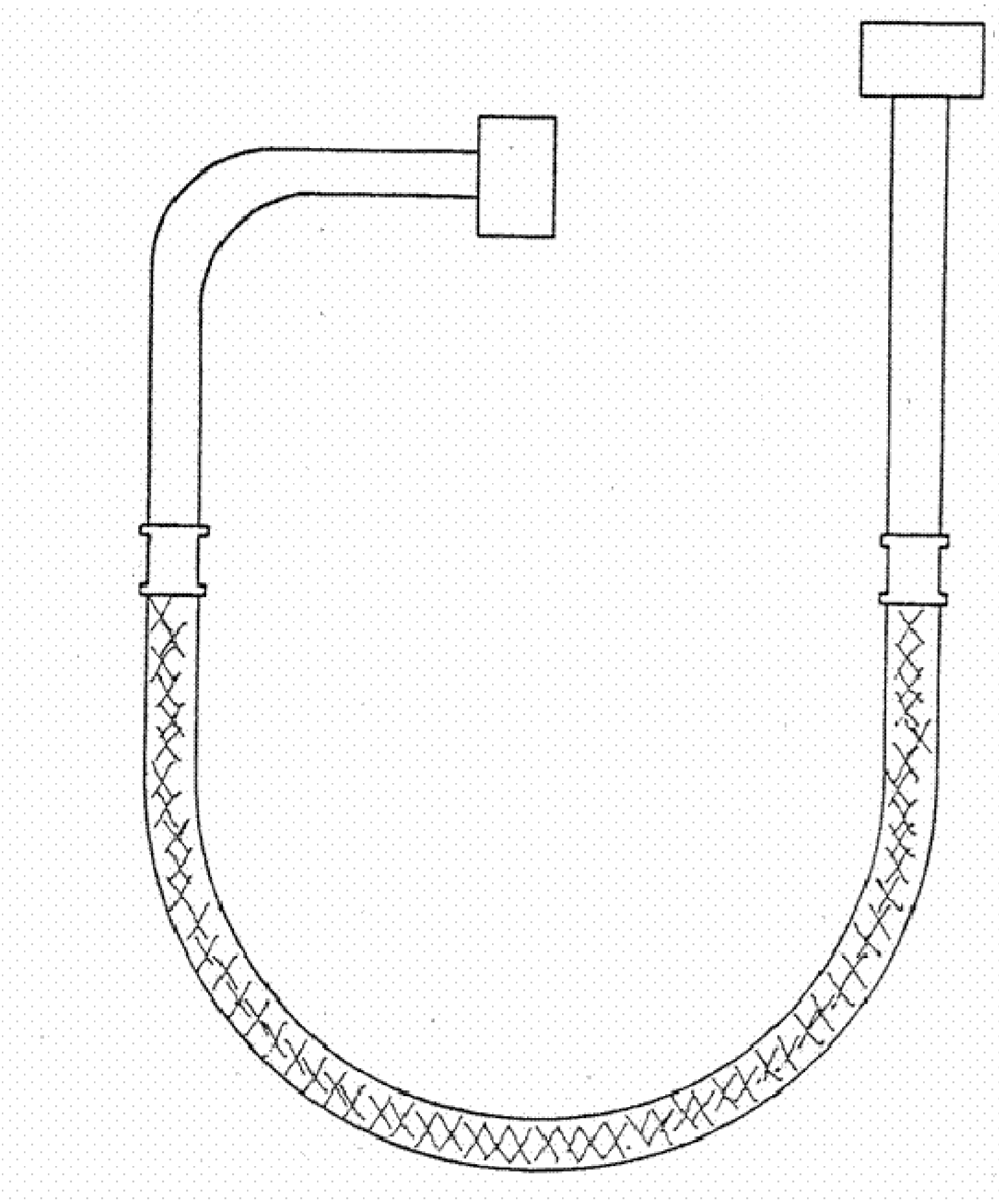
6. Has sufficient care been taken to ensure that mechanical damage to the hoses can be reduced to a minimum? Have the following been considered?

    a) Can the hose be damaged by impact?

    b) Are the hoses of optimum length and diameter for the particular application?

7. Has sufficient information been supplied to person who is to operate the equipment to enable them to operate it in a safe manner?

Appendix 3 - Example of a hose with a bent and straight distance piece



Note: Any additional connection parts may act in similar way as distance pieces, (absorbing heat) e.g. quick connection handles, hose ends.