MANUAL

DRY GAS SEAL SYSTEMS FOR CENTRIFUGAL COMPRESSORS

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DESIGN AND ENGINEERING PRACTICE

PREFACE

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NOTE: In addition to DEP publications there are Standard Specifications and Draft DEPs for Development (DDDs). DDDs generally introduce new procedures or techniques that will probably need updating as further experience develops during their use. The above requirements for distribution and use of DEPs are also applicable to Standard Specifications and DDDs. Standard Specifications and DDDs will gradually be replaced by DEPs.

TABLE OF CONTENTS

1. **INTRODUCTION** ... 4
1.1 SCOPE ... 4
1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS ... 4
1.3 DEFINITIONS ... 4
1.4 ABBREVIATIONS ... 6
1.5 CROSS-REFERENCES ... 6

2. **GENERAL** ... 7
2.1 PREMISE ... 7
2.2 RESPONSIBILITIES ... 7

3. **DRY GAS SEAL DESIGN AND ARRANGEMENT** ... 9
3.1 INTRODUCTION ... 9
3.2 GENERAL DGS ARRANGEMENT SELECTION ISSUES ... 10
3.3 DGS ARRANGEMENT SELECTION ... 11
3.4 DRY GAS SEAL DESIGN AND CONSTRUCTION ... 14

4. **GAS SEAL SUPPORT SYSTEMS** ... 16
4.1 BASIC OBJECTIVES ... 16
4.2 SEAL GAS SYSTEM ... 17
4.3 LOW PRESSURE LEAK-OFF SYSTEM ... 19
4.4 BUFFER GAS SYSTEM ... 21
4.5 ATMOSPHERIC VENT SYSTEM ... 23
4.6 SEPARATION GAS SYSTEM ... 24

5. **DESIGN AND CONSTRUCTION REQUIREMENTS OF SUPPORT SYSTEMS** 25
5.1 GENERAL ... 25
5.2 ARRANGEMENT ... 25
5.3 MATERIALS ... 25
5.4 PIPING ... 25
5.5 VALVES ... 25
5.6 FILTERS ... 25
5.7 SAFEGUARDING REQUIREMENTS ... 26

6. **REFERENCES** ... 28

APPENDICES

APPENDIX A SELECTION OF DGS ARRANGEMENT ... 29
APPENDIX B SEAL ARRANGEMENTS ... 30
APPENDIX C DRY GAS SEAL SUPPORT SYSTEMS ... 35
APPENDIX D MATERIALS FOR O-RINGS ... 44
APPENDIX E TYPICAL COMPOSITE SCHEMATIC ... 45

1. INTRODUCTION

1.1 SCOPE

This new DEP specifies requirements and gives recommendations for the selection and specification of dry gas seal systems, and their supporting systems, for centrifugal compressors.

1.2 DISTRIBUTION, INTENDED USE AND REGULATORY CONSIDERATIONS

Unless otherwise authorised by SIOP and SIEP, the distribution of this DEP is confined to companies forming part of the Royal Dutch/Shell Group or managed by a Group company, and to Contractors and Manufacturers/Suppliers nominated by them (i.e. the distribution code is “F” as described in DEP 00.00.05.05-Gen.).

If national and/or local regulations exist in which some of the requirements may be more stringent than in this DEP, the Contractor shall determine by careful scrutiny, which of the requirements are the more stringent and which combination of requirements will be acceptable as regards safety, environmental, economic and legal aspects. In all cases the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned with the object of obtaining agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party which carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project, or operation or maintenance of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party which manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party which initiates the project and ultimately pays for its design and construction. The Principal will generally specify the technical requirements. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The **Purchaser** is the party which buys the compressor and its auxiliaries for its own use or as agent for the owner. The Purchaser may either be the Principal or the Contractor.

The term **Vendor** is considered to be synonymous with the term Manufacturer/Supplier defined above.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Buffer gas — Gas (not process gas) which is injected between a pair of dry gas seals, to ensure that any gas leaking from a seal assembly is acceptable to the environment.

NOTE: Apart from the buffer function this gas may also have a cooling function, in which case an additional leak-off may be in place to achieve the minimum required flow rate for cooling.

Continuous flow transfer valve — A valve that can simultaneously divert both inlet and outlet flows from one component to its stand-by component without altering the continuity of full flow through the valve to the equipment.

Cooling gas — An (additional) supply of gas which is injected between a pair of dry gas seals, to ensure that operating temperatures in the seal arrangement stay below design limits.

Dry gas seal (DGS) A seal for a rotating shaft where the sealing is achieved between two essentially flat faces, one of which rotates with the shaft and one of which is stationary, which are held apart in service by the auto-generation of a thin film of gas between them.

Dry gas seal supporting system The arrangement of piping, filters and instrumentation used to control and monitor the pressure or flow of seal gas, cooling gas, buffer gas or separation gas to the equipment shaft end seal arrangements and to safely dispose of and monitor the leakage flows from a seal assembly.

Flammable gas Any substance, in the gaseous state, that will readily burn in air.

Flareable gas Gas which can be flared, vented or otherwise continuously disposed of in a safe and acceptable manner and where a suitable flare, vent or other system is available or can be made available.

High pressure service An application where the gas pressure to be sealed exceeds the proven capability of a single dry gas seal, taking account of the size and speed of the compressor shaft in question.

Hydrogen service An application where the gas being compressed contains hydrogen at a partial pressure greater than 0.7 MPa.

Moderate pressure service An application where the gas pressure to be sealed is within the proven capability of a single dry gas seal, taking account of the size and speed of the compressor shaft in question.

Non-flareable gas Gas which cannot be flared, vented or otherwise continuously disposed of in a safe and acceptable manner, either for environmental reasons or because a suitable system is not available or cannot be made available.

Process gas, sealed gas The main gas stream being compressed and which is to be sealed from the environment.

Sealed pressure The pressure immediately inboard of the innermost seal during any specified static or operating conditions and during start-up and shutdown.

NOTE: In operation, the sealed pressure of a compressor with a normal balanced piston arrangement will typically be close to the suction pressure. In static condition, the sealed pressure may be as high as the settle-out pressure.

Seal gas Gas injected inboard of a seal or the innermost seal of a set, to prevent the seal being damaged by any constituent or contaminant (solids, liquids etc.) present in the process gas.

Separation gas A supply of inert gas or air fed into the region between the seal - or the outermost seal of a set - and the shaft bearing.

Settle-out pressure the maximum pressure the system can come to under static conditions.

Single seal operating pressure limit The sealed pressure above which reliable seal operation and seal integrity cannot be guaranteed with a single dry gas seal (i.e.: the "capability" of a single dry gas seal).

NOTE: This pressure limit is not only dependent on seal size (diameter), but also on the state-of-the-art of the technology. As dry gas seal technology development is still ongoing, the single seal pressure limit should only be fixed in consultation with the seal supplier concerned.

Single seal static pressure limit The maximum differential pressure a single dry gasseal will reliably contain in the stationary condition and from which the seal will reliably “lift-off” and assume its correct operating state when the compressor is started.

Very toxic substance A substance which may produce serious harm to health as a result of a single or short term exposure. Amongst others, the following should be considered very toxic:

- gases containing hydrogen sulphide exceeding 1 000 ml/m^3;
- other substances specified by the Principal to be very toxic

1.4 ABBREVIATIONS

DGS Dry Gas Seal

ED Explosive Decompression

IPF Instrumented Protective Functions

HAZOP Hazard and Operability study

LEL Lower Explosion Limit

PEFS Process Engineering Flow Scheme

QRA Quantitative Risk Assessment

Abbreviations used in this DEP for instrument functions are consistent with (Table 1) of DEP 32.10.03.10-Gen.

1.5 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets. Other documents referenced in this DEP are listed in (6).

2. GENERAL

2.1 PREMISE

There is a wide variety of DGS arrangements and support systems. The final selection depends on the application, but to a certain extent also on user preferences, design and operating philosophy, and the compressor Manufacturer and the DGS Suppliers' standards and experience.

This DEP has been written on the premise that the gas to be sealed is flammable and/or very toxic. Non-toxic, non-flammable gas can generally be sealed using simple seals such as labyrinths.

For exceptional cases (for example where a flammable buffer gas is used to seal a very toxic process gas) the DGS arrangement and support systems should be selected in close consultation with the compressor Manufacturer and DGS Supplier.

2.2 RESPONSIBILITIES

2.2.1 Unit responsibility

In line with DEP 31.29.40.10-Gen., unit responsibility for the total scope of supply of the compressor system (e.g. compressors, gears, drivers and auxiliaries including DGS) should be held by the compressor Manufacturer.

2.2.2 Individual responsibilities

The Principal shall specify the party or parties responsible for each portion of the design, scope of supply, installation, and performance of the DGS system. The following matrix should be considered as a starting point:

Table 1 Typical responsibility matrix for scope of supply

	Purchaser	DGS Supplier	Compressor (system) Manufacturer
Unit responsibility (Section 2.2.1)			X
DGS arrangement and support systems selection *	X	(X)	(X)
DGS arrangement (detailed design and supply)		X	
DGS support systems (design and supply)			X
DGS performance (mechanical running test)			X

NOTE*: Responsibility dependent on approach to equipment specification (See 2.2.3).

2.2.3 Approach to equipment specification

The Principal should decide on the level of detail of equipment specification, ranging from a purely functional approach to a fully technically prescriptive approach. In deciding on the level of specification the Principal should consider the fact that the seal system is an integral part of the compressor package and in turn forms part of the process system. This may require the specification of some design aspects to be made consistent with other components and systems.

In the case of a functional specification, essentially only the following questions have to be answered:

Table 2 Essential questions for selection of DGS arrangement and required support systems

1.	Is the sealed pressure above or below the "single seal operating pressure limit"?
2.	Is the settle out pressure above or below the “single seal static pressure limit”?
3.	Is the combination of pressure, size and speed within proven experience?
4.	Is the seal gas “flareable”; that is can the gas be continuously flared, vented or otherwise disposed of safely and acceptably and is there a system available to do this?
5.	Can a suitable buffer gas be made available? If yes, at what pressure/quantity, and should buffer gas recovery be considered?
6.	Is the seal gas (or when applicable the buffer gas) compatible with the lube oil?
7.	Can separation gas be made available of acceptable composition, pressure, rate?
8.	Does the compressor or driver require to be barred over at low speed for warming up or cooling down purposes?

Data/requisition sheet DEP 31.29.00.95-Gen. should be used to communicate the necessary data. On the data/requisition sheet, entry points are marked “P”, “C” or “D” to indicate the party primarily responsible for providing the data (P = Purchaser, C = Compressor Manufacturer and D = Dry gas seal Manufacturer).

For a functional specification approach, the Purchaser need only provide the data marked “P”. As the level of technical specification increases, the purchaser may also provide data for entries marked “C” or “D”.

3. DRY GAS SEAL DESIGN AND ARRANGEMENT

3.1 INTRODUCTION

3.1.1 DGS arrangements

This section provides guidelines for the selection of one of the following DGS arrangements:

1. Single DGS arrangement;
2. Tandem DGS arrangement:
    - with/without inter-seal labyrinth;
    - with/without cooling or buffer gas injection;
    - with/without controlled pressure leak-off between the two DGSs;
3. Double (face-to-face) DGS arrangement;
4. Triple tandem DGS arrangement;
    - with/without inter-seal labyrinth;
    - with/without cooling or buffer gas injection;
    - with/without controlled pressure leak-off between the inner two DGSs;
5. Triple face-to-face DGS arrangement;
6. Face-to-face triple arrangement.

3.1.2 Applications

The applications in which dry gas seals may be used can be categorised in two ways:

a) Is the application within the proven capability of a single DGS?

Note: This is primarily a function of pressure but also of speed and size. For the purposes of this DEP, applications will be described as “moderate pressure” if they are within the capability of a single DGS or “high pressure” if they are not.

b) Can normal continuous operating leakage flows of the process gas be safely and acceptably disposed of through a flare, vent or other system that is available or can be provided?

Note: For the purposes of this DEP the process gas will be described as “flareable” or “non-flareable”

3.2 GENERAL DGS ARRANGEMENT SELECTION ISSUES

The following are applicable to the selection of each and any DGS arrangement:

(i) The simplest, most reliable, arrangement sufficient for the application should be selected.

(ii) The single seal operating pressure limit and/or pressure-velocity limit and the single seal static pressure limit should be determined in consultation with the DGS Supplier(s). For applications with a sealed pressure above 100 bar (ga), and where the DGS Supplier claims that this is still below the single seal operating pressure limit, the DGS Supplier shall provide evidence in support of this claim to the satisfaction of the Principal. This should be done by comparison with at least 3 satisfactory applications in similar service.

(iii) In deciding whether an application is “high pressure service” or “moderate pressure service” all specified static and operating conditions shall be considered, including start-up, shutdown and fault conditions.

(iv) In some cases, particularly with multi-casing compressors, the need to seal pressures above the capability of a single DGS (high pressure applications) can be avoided by providing a leak-off connection from the chamber inboard of the seal assembly to a lower pressure point in the system, such as a lower pressure compressor casing. However the possible effect of such a connection on the settle-out pressure(s) in the system shall be considered.

(v) Unless local discharge of small quantities of process gas (outer DGS leakage) through an atmospheric vent is acceptable, tandem DGSs (double or triple) shall be provided with buffer gas injection inboard of the outer DGS. The buffer gas shall generally be inert gas. However, in exceptional cases, where local discharge of process gas is unacceptable because it is very toxic, rather than because it is flammable, non-toxic hydrocarbon gas may be used as buffer gas.

(vi) Separation gas shall be provided, when required, to prevent gas from migrating from the seal assembly into the bearing chamber, and oil from migrating into the seal assembly, in accordance with (4.6). Separation gas should be inert gas. Where inert buffer gas is provided and the provision of inert separation gas is economically unattractive then air may be used. Air may be considered in other circumstances but requires compliance with the requirements of (4.5.3) and the Principal's agreement.

(vii) If the compressor lubrication system also lubricates an electric motor, except where the motor is pressurised (EX-P type), there shall be a clear space, open to the atmosphere, between the seal chamber and the bearing housing, see (Figure B.10), and separation air or inert gas shall be supplied to the inboard seal of the bearing housing.

(viii) The need for additional cooling in the seal arrangement, whether by separate cooling-gas supply or additional buffer gas supply/leak-off, shall be assessed jointly by the compressor Manufacturer and the DGS Supplier.

3.3 DGS ARRANGEMENT SELECTION

3.3.1 Moderate pressure, flareable gas applications

Note: Most applications will fall into this category.

3.3.1.1 Single DGS (Figure B.1)

3.3.1.1.1 If approved by the Principal, a single DGS arrangement may be considered for moderate pressure service if the process gas is flareable. In addition to its simplicity, this arrangement may be particularly attractive where there is a need to minimise the axial length of the seal assembly for rotor-dynamic reasons. However, the use of a single DGS requires the following additional conditions to be satisfied:

- a proven type of segmented carbon ring or other close-clearance type of seal shall be available for use as secondary seals. (See 3.3.1.1.2);
- a reliable source of inert buffer gas shall be available. (See 3.3.1.1.4);
- a reliable method of detecting failure of the primary DGS shall be installed and such failure shall result in immediate shut-down and depressurisation of the compressor;
- there shall be a flare or vent system within which the pressure under all foreseeable situations, shall be such that in the event of failure of the primary DGS the pressure in the interspace (between the primary and secondary seals) will not exceed the capability of the separation gas / secondary seals to contain the leakage until the compressor can be shut down, isolated and depressurised.

3.3.1.1.2 A single DGS arrangement shall be provided with a secondary/separation seal assembly comprising a pair of segmented carbon ring seals (or other approved close-clearance seals), mounted in a face-to-face configuration with inert buffer gas injected between them. When requested, the DGS/compressor Supplier shall provide evidence of the proven reliability of the proposed secondary seals in similar applications.

3.3.1.1.3 The primary leakage (i.e. the gas leaking outwards from the DGS plus the inward leaking separation gas) shall be conducted to a flare, vent or other suitable disposal system.

3.3.1.1.4 The buffer gas system shall be capable of reliably supplying buffer gas at sufficient pressure and in sufficient quantity to positively prevent outward leakage of process gas under all operating and static conditions including failure of the DGS. In establishing the DGS failure condition, due account shall be taken of the maximum likely flare or vent system pressure, due to simultaneous discharge from other process equipment and pressure loss in the connecting pipework.

3.3.1.2 Tandem DGS arrangement (Figure B.2) and (Figure B.3)

3.3.1.2.1 When specified, or if the additional conditions specified in (3.3.1.1.1) cannot be met, a tandem DGS arrangement shall be provided for moderate pressure, flareable gas service.

3.3.1.2.2 The primary leakage (from the inner DGS) shall be conducted to a flare, vent or other suitable disposal system. The system shall be designed to impose a minimal back pressure on the inner DGS whilst maintaining a sufficient pressure across the outer DGS to prevent "hang-up".

3.3.1.2.3 The outer DGS shall be designed to contain the maximum pressure that may occur under all foreseeable fault conditions. This will generally be with a disintegrated primary DGS with the primary leakage flow limited only by labyrinths and other restrictions, and with the maximum pressure in the flare/vent system resulting from other equipment discharging into it.

3.3.1.2.4 If venting of small quantities of process gas is not acceptable, an intermediate labyrinth shall be provided between the two dry gas seals and buffer gas shall be injected between that labyrinth and the outer DGS, Figure C.3. The buffer gas system shall be capable of supplying buffer gas at sufficient pressure and in sufficient quantity to prevent process gas that leaks through the inner DGS from leaking through the outer DGS. If so stipulated by the compressor Manufacturer and/or the DGS Supplier, it may be necessary to increase the quantity of buffer gas for cooling purposes.

3.3.1.2.5 `Unless otherwise agreed, an intermediate labyrinth shall be provided even if buffer gas is not used. Such a labyrinth will help to prevent debris from a failed inner DGS from precipitating failure of the outer DGS and will also enable a buffer gas facility to be installed at a later date if required. Agreement not to provide such an intermediate labyrinth should only be given if it is essential to minimise the axial length for rotor-dynamic reasons.

3.3.1.2.6 The secondary leakage shall be routed to a separate independent atmospheric vent.

3.3.1.3 Triple face-to-face DGS arrangement, (Figure B.8).

3.3.1.3.1 If discharge of process gas directly to the atmosphere is not acceptable, and it is essential to minimise the quantity of buffer gas required, and provided there is no constraint on axial length, a triple DGS arrangement with the outer seals in a face-to-face configuration may be considered. See (Figure B.8).

3.3.1.3.2 The primary DGS leakage shall be conducted to a flare or vent system.

3.3.1.3.3 Buffer gas shall be provided between the outer face-to-face DGSs and consistently maintained at a pressure greater than the pressure outboard of the primary DGS. However, it may be necessary to provided additional flow for cooling purposes.

3.3.2 High pressure flareable gas applications

3.3.2.1 Where the pressures to be sealed exceed the operating or static capability of a single DGS (high pressure application) and the gas is flareable, a tandem DGS arrangement shall be used. The pressure outboard of the inner DGS shall be controlled at a value in the order of 50% of the sealed pressure. The compressor Vendor in co-operation with the DGS Supplier may offer alternative arrangements for the Principal's approval.

3.3.2.2 Tandem DGS arrangement with controlled pressure leak-off (Figure B.4)

Subject to the additional conditions specified in (3.3.1.1.1), and with the Principal's agreement, a tandem DGS arrangement with two dry gas seals, as shown in Figure B.4, may be used. Such an arrangement shall be provided with a secondary/separation seal arrangement as described in (3.3.1.1).

3.3.2.3 Triple tandem DGS arrangement (Figure B.6)

3.3.2.3.1 When specified or if the additional conditions specified in (3.3.1.1.1) cannot be met a triple tandem DGS arrangement as shown in Figure B.6 shall be used.

3.3.2.3.2 When venting of small quantities of process gas is not acceptable, an intermediate labyrinth shall be provided between the outer two dry gas seals and buffer gas shall be injected between that labyrinth and the outer DGS, (See Figure B.7). The buffer gas system shall be capable of supplying buffer gas at sufficient pressure and in sufficient quantity to prevent process gas that leaks from the middle DGS from leaking through the outer DGS.

3.3.2.3.3 Unless otherwise agreed, an intermediate labyrinth shall be provided between the outer two DGSs, even if buffer gas is not used. Such a labyrinth will help to prevent debris from a failed middle DGS from precipitating failure of the outer DGS and will also enable a buffer gas facility to be installed at a later date if required. Agreement not to provide such an intermediate labyrinth should only be given if is essential to minimise the axial length for rotor-dynamic reasons.

3.3.3 Non-flareable gas applications

3.3.3.1 Where the gas to be sealed cannot be continuously vented, flared or safely disposed of in any other way, or where a suitable vent, flare or other system is not available and cannot be made available, a double face-to-face DGS arrangement such as is shown in (Figure B.5) shall be used.

3.3.3.2 A double face-to-face arrangement shall also be used where the pressure to be sealed can be lower than that in the available vent or flare system.

3.3.3.3 A double face-to-face arrangement should also be considered for applications subject to frequent stops and starts or significant periods at standstill but pressurised, as an alternative to providing an external source of seal gas.

3.3.3.4 Buffer gas shall be injected between the two DGSs at a pressure which is reliably controlled at a level which is always greater than the pressure inboard of the seals under all operational, static and transient conditions.

3.3.3.5 For high pressure, non-flareable gas applications, an additional DGS shall be installed outboard of the face-to-face assembly (a face-to-face triple arrangement) and the pressure between the outer two DGSs, maintained at an intermediate pressure as described in (3.3.2). See Figure B.9.

3.4 DRY GAS SEAL DESIGN AND CONSTRUCTION

3.4.1 Cartridge design

3.4.1.1 For each end of the compressor, the complete DGS arrangement shall be designed as a fully shop-assembled cartridge.

3.4.1.2 Where segmented carbon rings or other types of close clearance seals are used as secondary/separation seals, these shall be included in the cartridge. However the cartridge shall be designed so that such secondary/separation seals can be replaced in-situ without removing the complete cartridge.

3.4.1.3 Unless otherwise agreed DGS cartridges shall be tested at the DGS Supplier's works prior to shipment before assembly into the compressor. For testing scope and procedures, DEP 31.29.40.30-Gen. shall apply.

3.4.1.4 To prevent any accumulation of liquid in the seal assembly, any inlet connections to a seal cartridge, such as seal gas, buffer gas or separation gas, shall be at the top and any outlet connections, such as low pressure leak-off or atmospheric vent, shall be at the bottom.

3.4.1.5 The seal/cartridge design shall be such that secondary sealing devices such as O-rings will not be damaged or dislodged by inadvertent reverse pressure.

3.4.2 Bi-directional or uni-directional design

3.4.2.1 The DGS Supplier shall clearly indicate on the data/requisition sheet whether the offered DGS design is bi-directional or uni-directional.

3.4.2.2 For uni-directional designs, the direction of rotation shall be permanently marked on the outside of each cartridge.

3.4.2.3 In the case of a uni-directional design, the compressor Manufacturer in co-operation with the DGS Supplier shall ensure that inadvertent fitting of a cartridge at the wrong end of a compressor casing is physically impossible.

3.4.2.4 The impact of the directional nature of a particular DGS design on spares interchangeability and hence on the required stocks of spares should be considered. It should also be recognised that the face groove design may affect the ability of the DGS to “lift-off” at elevated pressure and/or low speed and also affect the operating face clearance, which in turn may affect the leakage rate and heat generation.

3.4.3 Materials selection for O-rings and other static seals

3.4.3.1 Explosive decompression (ED):

3.4.3.1.1 Above a sealed pressure of 60 bar (ga), O-rings shall be made of ED-resistant materials and the section dimensions should be less than 7 mm maximum.

NOTE: Examples of suitable (1996 state-of-the-art) ED materials are provided in (Appendix D).

3.4.3.1.2 The alternative, i.e. slow depressurisation while still using conventional elastomer materials, should only be considered if process and operational considerations allow a depressurisation period of the order of 24 hours.

NOTE: The maximum depressurisation rate often proposed by a Supplier of 20 bar/min is therefore considered insufficient.

3.4.3.1.3 For applications where ED is possible, particular attention to O-ring materials is required where the gas contains H_2S, methanol or aromatics, or the operating temperature can be below minus 20 °C.

3.4.3.2 For extremely high (e.g. above 175 °C) or low (e.g. below minus 20 °C) seal operating temperatures, the suitability of the proposed elastomer material at the expected operating temperatures shall be confirmed.

3.4.3.3 Particularly at low seal operating temperatures, the use of self-energised (spring-assisted) seal designs should be considered.

3.4.3.4 Self-energised (spring-assisted) PTFE seals may be preferred for applications subject to frequent starts, as they may be less prone to resist axial movement and to cause hang-up of the DGS.

3.4.4 Machines requiring barring

If the compressor or the driver needs to be rotated at low speed for the purpose of warming up or cooling down (barring), the Vendor shall confirm that the dry gas seals will not be damaged by such operation and/or shall warn the Principal of any special precautions that must be taken.

4. GAS SEAL SUPPORT SYSTEMS

4.1 BASIC OBJECTIVES

The objectives of the dry gas seal support systems are:

- to maintain the conditions necessary for reliable operation of the seals (i.e. pressures, temperatures and gas quality) during all anticipated static and operating conditions and during transients such as start-up and shut-down;
- to contain and dispose of the normal leakage from the seals in a safe and acceptable manner and prevent it from contaminating the compressor oil system or other facilities;
- to facilitate the monitoring of the performance of the seals and in particular provide warning of a seal failure;
- to contain the leakage from a failed seal long enough for the compressor to be safely shut-down and, if necessary, depressurised.

The support systems required for each DGS type are shown in Table 3 below.

Table 3 Required dry gas seal support systems

		DGS arrangement								
		S	T	TB	TL	D	TT	TTB	TF	FT
Support system	Fig No	B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9
Seal gas	C.1or C.2	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Low pressure leak-off	C.3	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No
Controlled pressure leak-off	C.4	No	No	No	Yes	No	Yes	Yes	No	Yes
Buffer gas - for tandem DGSs	C.5	Yes	No	Yes	Yes	No	No	Yes	No	No
Buffer gas - for face-to-face DGSs	C.6	No	No	No	No	Yes	No	No	Yes	Yes
Atmospheric vent	C.7	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Separation gas (see Note)	C.8	No	Yes	Yes	No	No	Yes	Yes	No	No

Where:

S = Single DGS

T = Tandem DGS

TB = Tandem DGS with intermediate labyrinth and buffer gas supply

TL = Tandem DGS with controlled pressure leak-off

D = Double, face-to-face DGS

TT = Triple tandem DGS

TTB= Triple tandem DGS with buffer gas supply

TF = Triple face-to-face DGS

FT = Face-to-face triple DGS

NOTE: The above table indicates that separation gas is not required for DGS face-to-face arrangements. This is because in such arrangements there is no risk of process gas entering the bearing housing. However, separation gas may still be required for these arrangements to prevent lubricant entering the seal assembly.

4.2 SEAL GAS SYSTEM

4.2.1 Purpose

The seal gas system shall be designed to:

- ensure that the gas at the seal remains free from any contaminants (solids or liquids) that may be present in the process gas;
- assist in maintaining acceptable temperatures in the seal area;
- in conjunction with the primary leak-off system, maintain a pressure difference across the primary DGS in the correct direction and of an appropriate magnitude under all predictable steady-state and transient conditions.

Seal gas is required for all DGS arrangements except face-to-face arrangements where the flow through the innermost DGS is inwards.

4.2.2 Source of seal gas

4.2.2.1 For most applications, seal gas shall be obtained from:

- the discharge from the compressor casing in question;
- the discharge from the final casing of a multi-casing compressor (in this case the one seal gas system may serve all the casings in the train: however the possible effect of such an interconnection between casings on settle-out pressures should be considered);
- an intermediate stage of the compressor casing in question where a suitable connection is available.

4.2.2.2 If a compressor is subject to frequent starts (say more than 20 per year) or is expected to stand stationary but pressurised for significant periods, the availability of seal gas at an adequate pressure shall not be dependent on the compressor running. This should be achieved by obtaining the seal gas from a process source that can be expected to be available whenever there is a positive pressure in the compressor. Where this is not possible, an auxiliary source of seal gas shall be provided together with an automatic changeover system which introduces the auxiliary seal gas whenever the normal seal gas supply is not available at an adequate pressure. This requirement may not be necessary for compressors handling gas which is known to be clean (e.g. LPG refrigeration service).

4.2.2.3 However this requirement to provide seal gas when the compressor is not running is satisfied, the possible effects on the pressures in the system prior to compressor start-up shall be considered.

4.2.3 Quality of seal gas

4.2.3.1 If an external source of seal gas is used, either permanently or temporarily, the gas shall be compatible with the process and with the materials of construction of the compressor and downstream equipment.

4.2.3.2 Seal gas shall be filtered such that all solid particles greater than 2 μm are removed. Two filters in parallel shall be provided, with the necessary valving, so that one filter can be taken out of service, depressurised and its element replaced with the compressor on line.

4.2.3.3 The temperature of the seal gas shall be not less than 10 ^{o}C above the dewpoint at the pressure prevailing in the seal assembly, under all identified operating conditions.

4.2.3.4 Unless the dew point of the seal gas can be confidently expected to be below ambient temperature, and for compressors which need to be liquid washed or otherwise have liquid regularly injected, coalescers shall be provided in addition to or in combination with the filters. Also seal gas piping shall be insulated, kept as short as possible and provided with drainage facilities.

4.2.4 Control of seal gas supply

4.2.4.1 A sufficient quantity of seal gas shall be supplied, at the necessary pressure, to prevent outward flow of unfiltered process gas into the seal chamber. Where the seal chamber and the body of the compressor are separated by a simple labyrinth, the seal gas pressure shall be sufficient to result in a mean inward velocity through the smallest gap of not less than 7m/s with the compressor in operation in order to prevent outward migration of process gas due to the highly turbulent, circumferential flow regime in the labyrinth. In the stationary condition, the mean inward velocity shall be not less than 3m/s. Where separation is by some other type of seal, an alternative criterion may be appropriate.

4.2.4.2 The simplest and therefore most reliable method of controlling the supply of seal gas is to let it down from the source pressure through suitable restriction orifices see Figure C.1. This method shall therefore be used provided the criteria of (4.2.4.1) can be satisfied under all specified compressor operating and static conditions. It shall be possible to adjust the flow to each seal assembly with manual regulating valves and/or by changing the orifice size.

4.2.4.3 Where the criteria of 4.2.4.1 cannot be satisfied by the simple system described in (4.2.4.2), due for example to widely varying compressor operating conditions, the seal gas supply shall be controlled by a differential pressure controller as shown in (Figure C.2). Where the compressor design is such that the sealed pressure at the two ends is substantially the same, one common differential pressure controller can be used for the seal gas supply to the two ends. Otherwise a separate differential pressure controller shall be provided for each seal assembly.

4.2.4.4 During start-up and shut-down of a centrifugal compressor, significant transient differential thermal expansion can occur between the shaft and the casing. During such transients it is essential that an adequate positive pressure difference is maintained across each DGS, otherwise, the DGS may separate and fail to reseat. Where necessary, this problem can be avoided by supplying seal gas at a higher pressure than would otherwise be required. If necessary the control of the seal gas supply should be integrated with the control of the low pressure leak-off.

4.2.5 Seal gas monitoring

4.2.5.1 The supply of seal gas to each seal assembly shall be provided with a suitable flow indicator. These flow indicators can be used to adjust the system during initial commissioning and to indicate deterioration of the inboard labyrinth or other device.

4.2.5.2 A differential pressure alarm should be provided to warn of loss seal gas pressure.

4.2.5.3 A differential pressure alarm should also be fitted across the filters/coalescers.

4.2.6 Safeguarding

Since failure to supply adequate seal gas will not immediately result in a hazardous situation unless allowed to persist, it is not considered essential to provide automatic shut-down of the compressor except perhaps for remote unmanned installations.

4.3 LOW PRESSURE LEAK-OFF SYSTEM

4.3.1 Purpose

4.3.1.1 The low pressure leak-off system shall be designed to:

- dispose of the seal gas that inevitably leaks through the DGS in a single DGS arrangement or the inner DGS in a tandem or triple-tandem arrangement, in a safe and acceptable manner, under all conditions including seal failure;
- control the pressure outboard of the inner DGS of a tandem arrangement in order to maintain an acceptable pressure difference across both DGSs under all operating, static and transient conditions;
- provide suitable signals which can be used both to monitor the condition of the DGSs and for safeguarding purposes.

4.3.2 Disposal

4.3.2.1 Where the composition of the sealed gas is such that direct discharge to the atmosphere is acceptable (typically if the density is less than that of air) and local regulations permit such a discharge, the low pressure leak-off may be conducted to atmosphere either through a separate dedicated vent or into a common vent system. Where this not acceptable the low pressure leak-off shall be conducted to a flare.

4.3.2.2 If the low pressure leak-off is conducted to a common flare system or a common vent system that serves other equipment, the maximum pressure that can exist in the system must be allowed for in deciding the required seal gas pressure and the method of control of the seal gas, the low pressure leak-off and the buffer gas (if provided).

4.3.3 Control of low pressure leak-off

4.3.3.1 In a single DGS arrangement, it is essential that the line to the flare (or vent) system imposes minimum resistance to flow. In most cases it is not necessary to control the leak-off in any way but merely let it ride on the flare (or vent) system pressure. See (Figure C.3).

4.3.3.2 For tandem DGS arrangements, consideration shall be given to maintaining a positive pressure difference across each DGS, under all predictable operating, static and transient conditions. The simplest way of achieving this is to insert a suitably sized restriction orifice in the leak-off line. However, this is not recommended because if the orifice is sized for the normal flow when the DGSs are in good condition, any deterioration in the inner DGS or a tendency for the seal faces to open due to differential thermal expansion during start-up or other transients will cause an increase in flow resulting in a large increase in the pressure outboard of the inner DGS. For this reason, if it is necessary to restrict the leak-off flow, this should be done with a back-pressure controller as shown in (Figure C.4). This controller should be of a simple proportional type, without integral (reset) action. The size of the control valve and the associated pipework shall be based on the maximum flow under seal failure conditions.

4.3.4 Monitoring the low-pressure leak-off

4.3.4.1 A flow meter shall be provided in the low-pressure leak-off line from each seal assembly. This flow meter shall be of a type capable of measuring the normal flow when the DGSs are in good condition (reproducibility is important but high accuracy is not required) to enable the condition of the DGSs to be monitored. However, it is essential that this flow meter does not impose a significant pressure drop on the system in the event of failure of the inner DGS.

NOTE: A possible type of flow meter which may satisfy the above requirements is the type which operates on the principle of measuring the convective heat loss from a heated element.

4.3.4.2 The pressure in the chamber outboard of the inner DGS shall be measured. A significant increase in this pressure will indicate a failure of the inner DGS.

4.3.5 Safeguarding

4.3.5.1 In a single DGS arrangement, failure of the DGS shall immediately result in the compressor shutting down and being depressurised. This can most reliably be detected by a rapid and substantial increase in the low pressure leak-off flow. The shut-down level should be set at a value several times the normal flow so that it is not activated by variations in buffer gas flow.

Alternatively, failure of the DGS can be detected by a rapid and substantial increase in the low pressure leak-off pressure. However, for relatively low sealed pressures, the safeguarding system may need to be able to differentiate between a true increase in leakage and an increase in the pressure in the flare (or vent) system to which the leak-off is connected.

4.3.5.2 With a tandem DGS arrangement, failure of either DGS shall initiate a shut-down. Failure of the inner DGS can be detected by a rapid and substantial increase in the low pressure leak-off flow or by an increase in the intermediate pressure. Failure of the outer DGS can be detected by a decease in intermediate pressure or by an increase in demand for buffer gas where this is provided and is differential pressure controlled. As above it may be necessary to engineer a system which can differentiate between a seal failure and variation in the flare (or vent) system pressure.

NOTE: Since, in a tandem arrangement, the outer DGS will normally be designed to contain any leakage from a failed inner DGS, the shut-down and depressurisation initiated by such a failure may be of a controlled rather than emergency nature.

4.4 BUFFER GAS SYSTEM

4.4.1 Purpose

The buffer gas system shall be designed to provide positive separation between the process and the local environment.

4.4.2 Source of buffer gas

4.4.2.1 Except where hydrocarbon buffer gas is used solely to avoid discharging very toxic gas into a vent or flare system, buffer gas shall be inert gas (normally nitrogen).

4.4.2.2 For face-to-face DGS arrangements it is essential for the source of buffer gas to be reliable since if the buffer gas pressure falls below the sealed pressure (inboard of the inner DGS), the inner DGS faces will separate and may fail to re-seat.

4.4.3 Quality of buffer gas

4.4.3.1 Since the buffer gas will pass though at least one DGS, the quality of buffer gas shall be as defined for seal gas in (Section 4.2.3).

4.4.3.2 Buffer gas shall not contain more than 10% oxygen under any foreseeable condition.

Note: In some cases it may be necessary to impose more stringent limits; for example to avoid corrosion in the vent or flare system.

4.4.4 Control of buffer gas

4.4.4.1 Where the buffer gas is supplied between a pair of face-to-face DGSs, see (Figure B.5), (Figure B.8) and (Figure B.9), it is essential for the pressure to be maintained at a prescribed differential above the pressure inboard of the inner DGS of the pair (or the pressure outboard of the outer DGS in vacuum applications). The required differential will be specified by the compressor Manufacturer/DGS Supplier (normally 1 or 2 bar). The pressure differential should therefore be controlled as shown in (Figure C.6).

4.4.4.2 Where the buffer gas is supplied inboard of a DGS for the purpose of ensuring that the leakage through that DGS is free of process gas, see (Figure B.3) and (Figure B.7), the buffer gas shall be controlled to achieve a minimum axial velocity through the inboard labyrinth of 7m/s under operating conditions and a minimum axial velocity of 3m/s under static conditions. This can be achieved by controlling the pressure at which the buffer gas is supplied at a fixed differential above the inboard pressure. The pressure difference should be adjusted to achieve the required minimum flow with the labyrinth(s) in new condition. Maintaining a constant pressure differential will automatically compensate for wear of the labyrinth.

4.4.4.3 Where buffer gas is supplied between a pair of close clearance seals as shown in (Figure B.1), differential pressure control should also be used, since the inboard pressure, normally the pressure in the flare system, may vary.

4.4.5 Monitoring buffer gas supply

4.4.5.1 With face-to-face DGS arrangements, the flow rate of the buffer gas should be continuously monitored. This will facilitate initial setting up of the buffer gas system. Also, an increase in flow is indicative of deterioration of one of the DGSs.

4.4.6 Safeguarding

4.4.6.1 With the following DGS arrangements, primary containment of the process gas is dependent on the buffer gas being supplied at the appropriate pressure:

- double (face-to-face) DGS;

- face-to-face triple DGS.

In such cases, therefore, it is essential that failure to maintain the required pressure shall result in the compressor shutting down and being immediately depressurised.

4.4.6.2 With a single DGS arrangement, where the buffer gas also serves as separation gas, failure to maintain the buffer gas at an adequate differential pressure will result in local leakage of process gas and/or contamination of the oil system. Unless otherwise agreed, this shall also initiate a compressor shut-down. Where separation gas is also supplied to the inboard seal of the adjacent bearing housing (see 3.2 (vii) and 4.6.2), it may be acceptable for failure of buffer gas pressure to result in an alarm only, provided any leakage from the seal assembly is conducted to a safe location.

4.4.6.3 With the following DGS arrangements, primary containment is not dependent on the continued supply of buffer gas; however buffer gas is necessary to avoid local venting of process gas:

- tandem DGS with buffer gas supply;
- triple tandem DGS with buffer gas supply.

In these cases failure to maintain the required buffer gas pressure should initiate an alarm. The decision whether such failure should also result in a compressor shut-down and depressurisation depends on whether the local venting of small quantities of process gas is acceptable.

4.5 ATMOSPHERIC VENT SYSTEM

4.5.1 Purpose

The atmospheric vent system shall be designed to safely dispose of the leakage from the outer DGS of a multi-seal arrangement.

4.5.2 Disposal

The leakage gas from each seal assembly shall be separately conducted to a safe location. The pipework shall be arranged and sized to present the minimum resistance to flow, shall be designed to avoid the entrapment of liquid and shall be provided with flame traps.

4.5.3 Monitoring atmospheric vents

Where both flammable gas and air may be present, either in normal operation or following a fault, each vent shall be provided with a proven type of flammable gas detector. Conditions resulting from multiple faults need not be included provided facilities are provided for the detection of likely faults. By agreement this requirement may be relaxed where it can be shown that the seal assembly and the whole of the vent system can withstand the effects of an internal explosion resulting from ignition of the vent gas.

4.5.4 Safeguarding

Where flammable gas detectors are required in accordance with (4.5.3), detection of increased flammable gas content in the vent shall initiate an alarm Consideration should be given to arranging for a further increase to initiate a compressor shut down.

4.6 SEPARATION GAS SYSTEM

4.6.1 Purpose

The separation gas system shall be designed to prevent process gas from entering the bearings and lubricant from entering the seal assembly.

4.6.2 Arrangement

The separation gas shall be injected between two labyrinth seals located between the seal cartridge assembly and the bearing chamber. If agreed, an approved type of segmented carbon ring or other close-clearance seal may be used in place of the labyrinths.

Where the lubricant system also serves an electric motor it is particularly imperative that the lubricant is not contaminated with flammable process gas, to avoid the possibility of explosions in the motor. In such a case, except where the motor itself is pressurised (EX-P type), there shall be a clear space open to atmosphere between the seal assembly and the bearing chamber and a further supply of separation gas (air or nitrogen) shall be provided to the inboard seal of the bearing housing. See (Figure B.10).

4.6.3 Control of separation gas

To effectively prevent migration of buffer or process gas into the bearing housing or oil-containing air into the seal cartridge, the separation gas system shall be designed to achieve a mean velocity of 7 m/s through the labyrinths in normal operation. This is most conveniently achieved by supplying the separation gas at a predetermined controlled pressure. See Figure C5.

4.6.4 Monitoring separation gas

The pressure of the separation gas at each seal assembly shall be monitored.

4.6.5 Safeguarding

In cases where there is no buffer gas supply and flammable gas detectors are provided in the atmospheric vents (4.5.3), failure of the separation gas will be detected by an increased flammable gas content in the atmospheric vent which will initiate a shut-down, see (4.5.4).

In other cases, separation gas failure will not immediately result in a hazardous situation hence it is not necessary to initiate a trip.

5. DESIGN AND CONSTRUCTION REQUIREMENTS OF SUPPORT SYSTEMS

5.1 GENERAL

Dry gas seal support systems should be designed and built to similar standards as those specified in DEP 31.29.60.32-Gen. for special purpose oil systems.

5.2 ARRANGEMENT

Dry gas seal support systems should be designed as compact modules. These can be mounted on and supported from the compressor baseplate, or supplied as separate skids (stand-alone or combined with the lube-oil system).

As far as possible, the layout should be such that the function of control valves and change-over valves for spared items is readily apparent.

The location and arrangement of the module or modules shall not impede normal operation and maintenance of the compressor. Normal maintenance, particularly of the compressor bearings and seals, shall be possible with a minimum of disconnections.

The appropriate level of isolation (e.g. double-block-and-bleed, if required by the pressure) shall be provided for all components, particularly filters, if it is desired to service such items without isolating and depressurising the compressor.

5.3 MATERIALS

All systems which supply gas into the compressor seal assemblies shall be completely made entirely of austenitic stainless steel.

5.4 PIPING

Piping shall be fabricated by welding or bending and with the minimum number of flanged joints (flanges only where required to facilitate maintenance).

Piping connections shall not be threaded.

All instrument impulse lines shall be stainless steel. Impulse lines after the first isolation valve may be stainless steel tubing with stainless steel compression fittings of an approved make and type.

5.5 VALVES

Valves shall conform to the applicable piping classes. All valves shall have stainless steel trim.

5.6 FILTERS

Guidance on filter sizing is provided in API 614.

The collapsing pressure of the filter elements shall not be less than 3.5 bar (ga).

The gas flow to be used for sizing purposes shall be three times the gas flow determined to be required for seal gas in accordance with (4.2) or three times the gas flow determined to be required for buffer gas in accordance with (4.4). In each case the maximum design labyrinth clearances shall be assumed. The pressure drop across a clean filter shall not be greater than 10 mbar. The system shall still function with a dirty filter pressure drop of up to 250 mbar.

Dual filters shall be provided, equipped with continuous-flow transfer valves and vents to enable the off-line filter to be isolated and depressurised, and have its elements replaced with the compressor in service.

Additional isolation valves between the transfer valves and the filters are required when the service and gas supply pressure level dictate double isolation for maintenance.

The layout of the sealing-gas filtration system should be such that the filters can be replaced with better or larger ones (e.g. one size up) without major piping reworks, should this prove necessary at a later date.

Instrumentation on the filtration system should allow for monitoring of differential pressure (PDI), and provide an alarm on the same parameter (PDA-H).

5.7 SAFEGUARDING REQUIREMENTS

The number of shut-down functions should be kept to a minimum.

The final arrangement of the dry gas seal support systems should be subject to an IPF review in accordance with DEP 32.80.10.10-Gen.

The minimum alarms and shut-downs for each DGS arrangement considered acceptable in most applications are shown in Table 4.

Table 4 Alarm and shutdown requirements

	DGS arrangement								
	S	T	TB	TL	D	TT	TTB	TF	FT
Figure No	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9
Seal gas system									
Low differential supply pressure	A	A	A	A		A	A	A	
High filter differential pressure	A	A	A	A		A	A	A	
Low pressure leak-off system									
High pressure	AX(1)	AX(1)	AX	A		AX(1)	AX	A	
Low pressure	A	A	AX	A		A	AX	A	
High flow	AX(1)	AX(1)	A	AX		AX(1)	A	AX	
Controlled pressure leak-off									
High pressure				AX		AX			
Low pressure				AX		AX			
High flow				A		A			
Buffer gas system									
Low differential pressure	AX(2)		A		AX		A	A	AX
High flow	A				A				A
High filter differential pressure	A		A		A		A		A
Atmospheric vent system									
High flammable gas content		A				A			
Separation gas system									
Low differential pressure		A		A		A			

Where:

S = Single DGS
T = Tandem DGS
TB = Tandem DGS with intermediate labyrinth and buffer gas supply
TL = Tandem DGS with controlled pressure leak-off
D = Double, face-to-face DGS
TT = Triple tandem DGS
TTB = Triple tandem DGS with buffer gas supply
TF = Triple face-to-face DGS
FT = Face-to-face triple DGS

A = Alarm X = Shut-down (trip)

NOTES:

1. Shutdown on both high pressure and high flow will generally not be required.
2. Shutdown may not be required if separation gas is provided to the inboard seal of the bearing housing and any leakage from the seal assembly is conducted to a safe location.

6. REFERENCES

In this DEP reference is made to the following publications:

NOTE: Unless specifically designated by date, the latest edition of each publication shall be used together with any amendments/supplements/revisions thereto.

SHELL STANDARDS

Index to DEP publications and standard specifications	DEP 00.00.05.05-Gen.
Compressors - selection, testing and installation	DEP 31.29.40.10-Gen.
Symbols and Identification Systems - Instrumentation (Part I - Process (Engineering) Flow Schemes)	DEP 32.10.03.10-Gen.
Classification and Implementation of Instrumented Protective Functions	DEP 32.80.10.10-Gen

AMERICAN STANDARDS

Lubrication, Shaft-Sealing, and Control-Oil Systems and Auxiliaries for Petroleum, Chemical and Gas Industry Services	API 614
Centrifugal Compressors for Petroleum, Chemical, and Gas Service Industries	API 617

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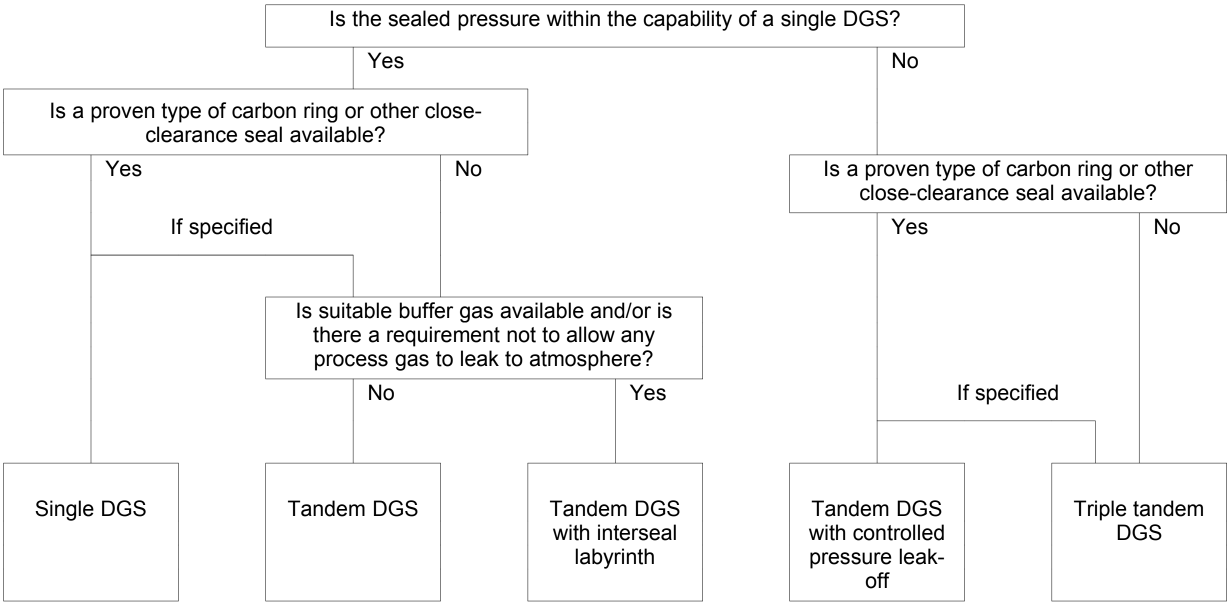
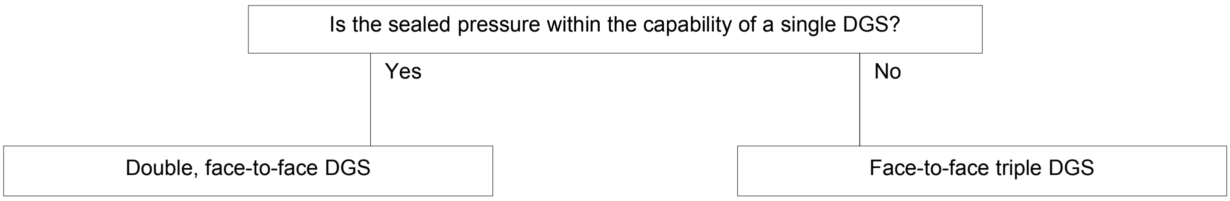
APPENDIX A SELECTION OF DGS ARRANGEMENT

(a) DGS arrangements for flareable gas applications



(b) DGS arrangements for non-flareable gas applications



APPENDIX B SEAL ARRANGEMENTS

FIGURE B.1 SINGLE DGS

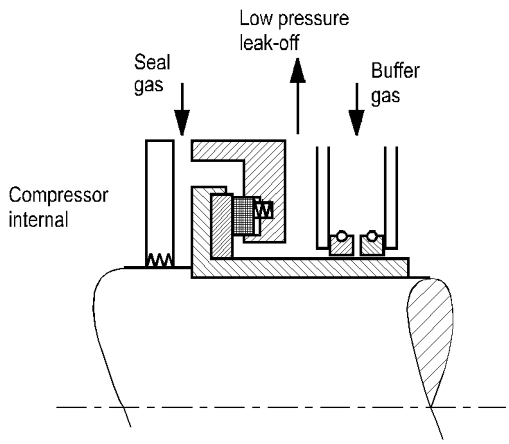


FIGURE B.2 TANDEM DGS

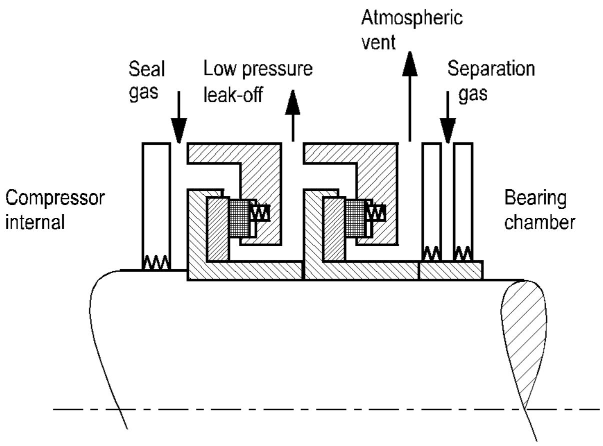


FIGURE B.3 TANDEM DGS WITH INTERMEDIATE LABYRINTH AND BUFFER GAS

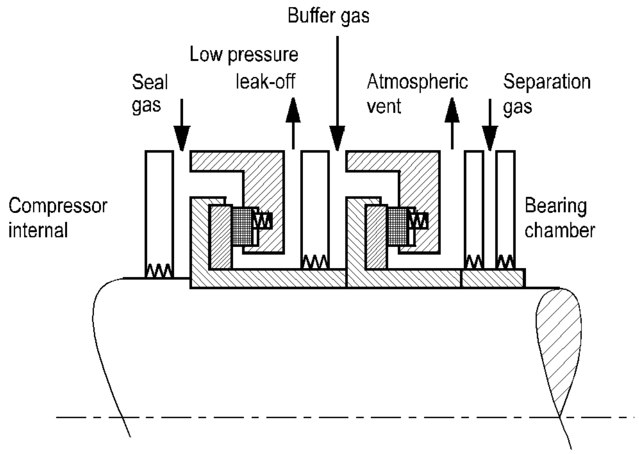


FIGURE B.4 TANDEM DGS WITH CONTROLLED PRESSURE LEAK-OFF

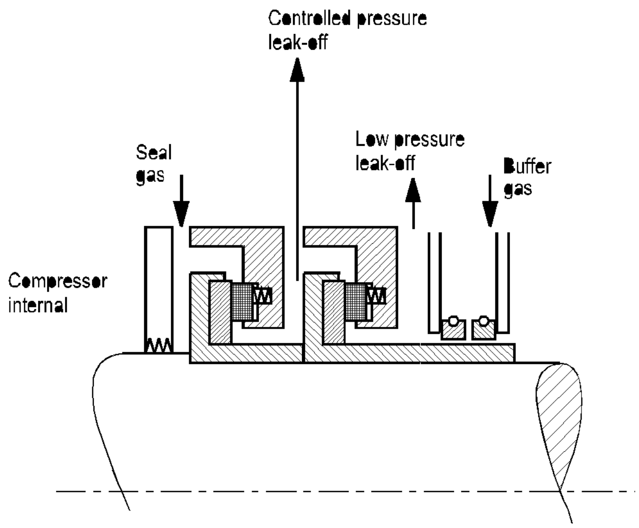
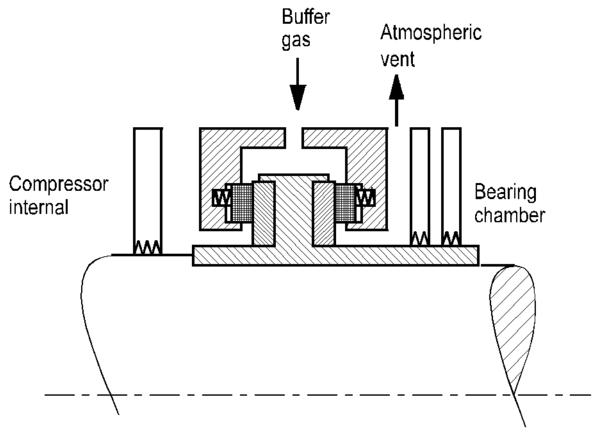


FIGURE B.5 DOUBLE (FACE-TO-FACE) DGS



NOTE: Where the buffer gas is flammable, the atmospheric vent should be replaced with a low pressure leak-off.

FIGURE B.6 TRIPLE TANDEM DGS

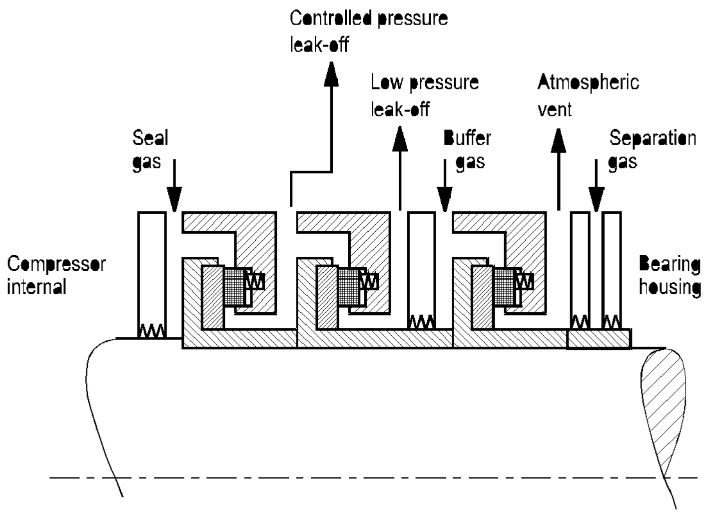


FIGURE B.7 TRIPLE TANDEM DGS WITH INTERMEDIATE LABYRINTH

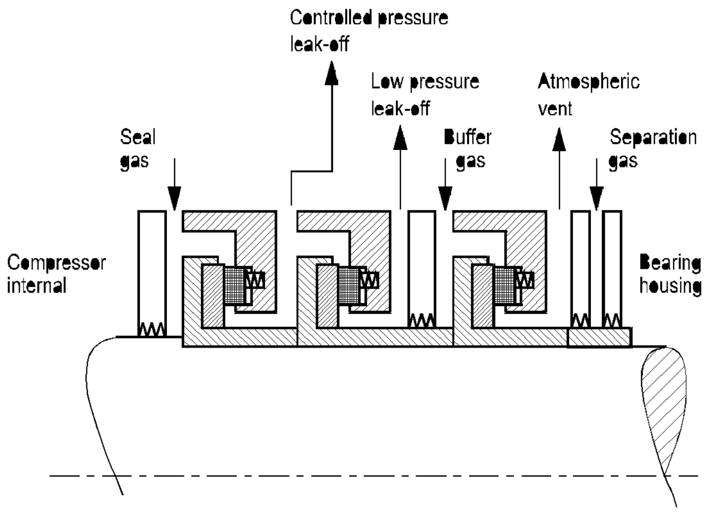


FIGURE B.8 TRIPLE FACE-TO-FACE DGS

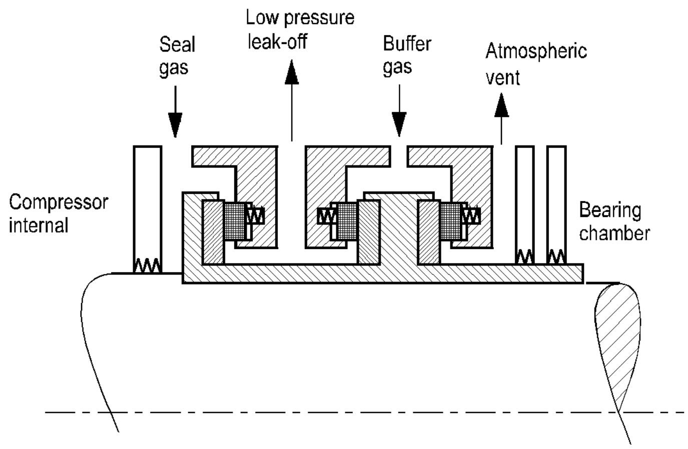


FIGURE B.9 FACE-TO-FACE TRIPLE DGS

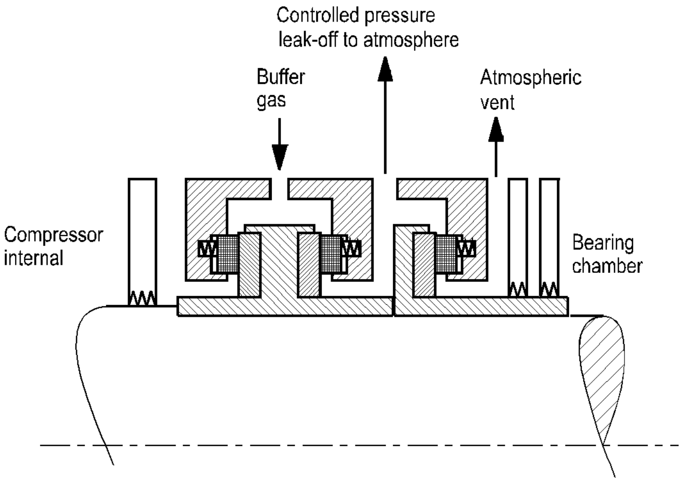
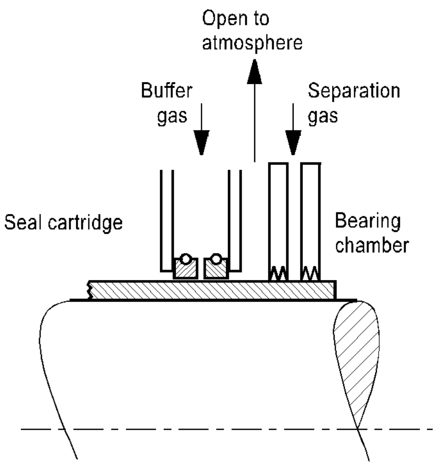
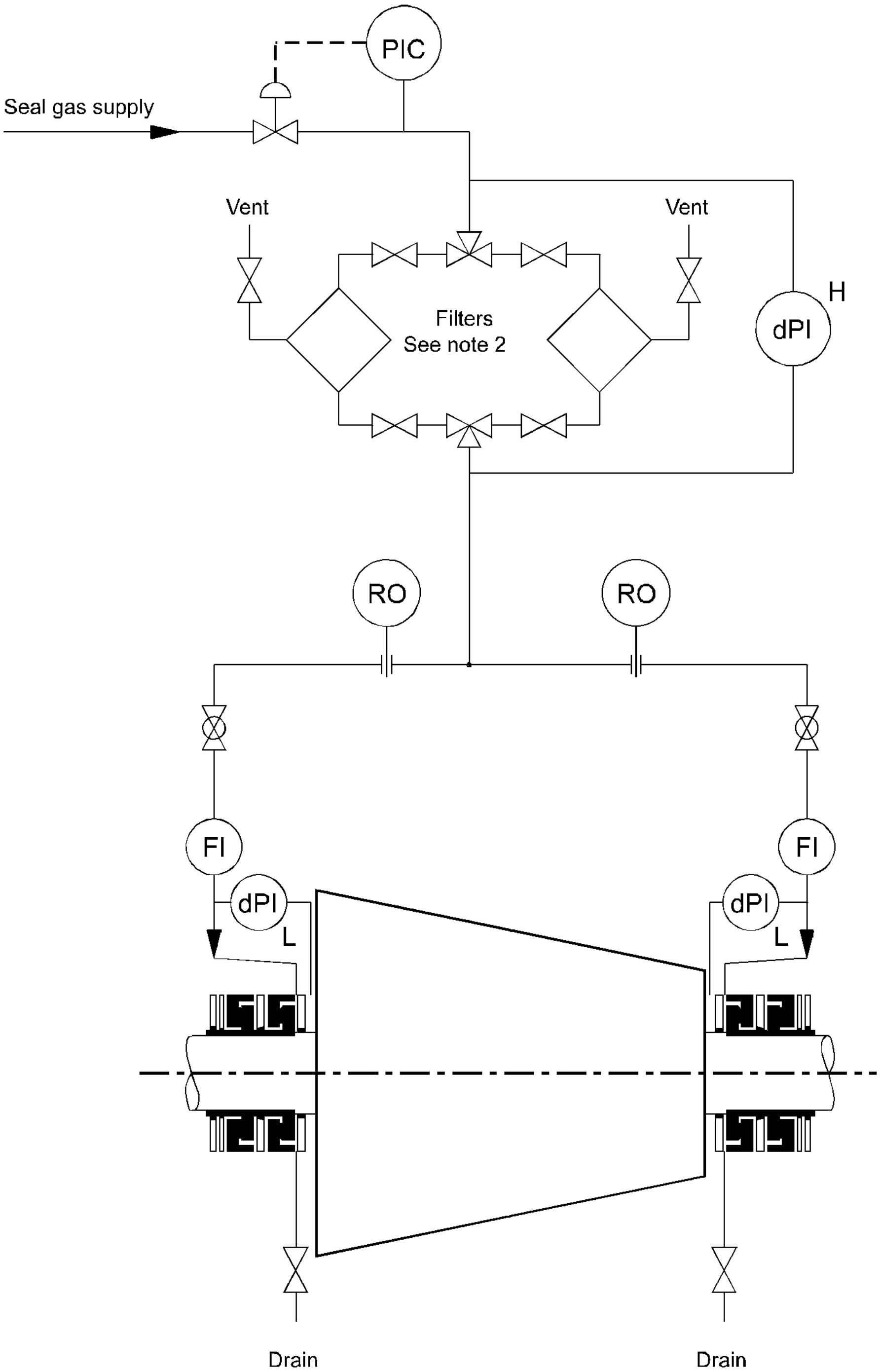


FIGURE B.10 SEPARATION GAS ARRANGEMENT WHERE THE OIL SYSTEM ALSO SERVES AN ELECTRIC MOTOR



APPENDIX C DRY GAS SEAL SUPPORT SYSTEMS

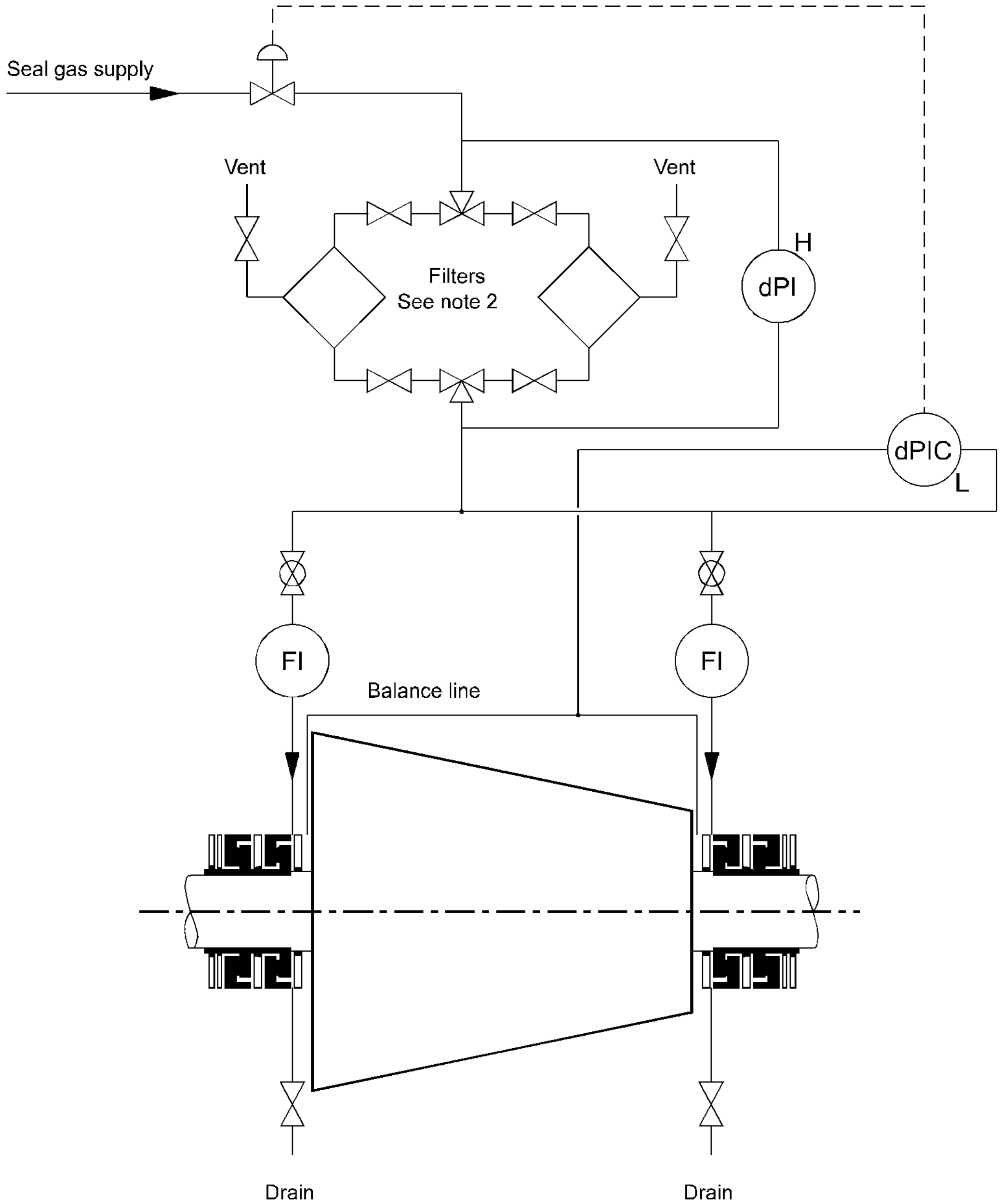
FIGURE C.1 SEAL GAS SYSTEM (UNCONTROLLED)



NOTES: 1. The pressure control of the seal gas supply may not be necessary if seal gas is available at a suitable pressure.

2. Additional isolation valves at the filters are only required if double-block-and-bleed isolation is necessary.

FIGURE C.2 SEAL GAS SYSTEM (DIFFERENTIAL PRESSSURE CONTROLLED)



NOTES: 1. Separate differential pressure control should be provided for each seal assembly if the sealed pressures at the two ends of the compressor are significantly different.

2. Additional isolation valves at the filters are only required if double-block-and-bleed isolation is necessary.

FIGURE C.3 LOW PRESSURE LEAK-OFF SYSTEM (UNCONTROLLED)

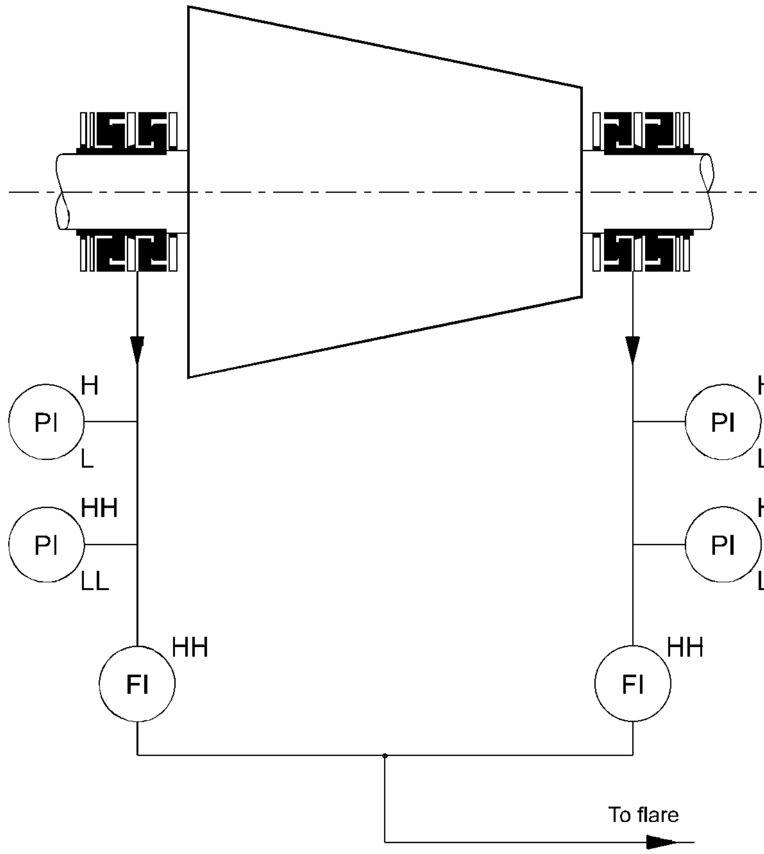
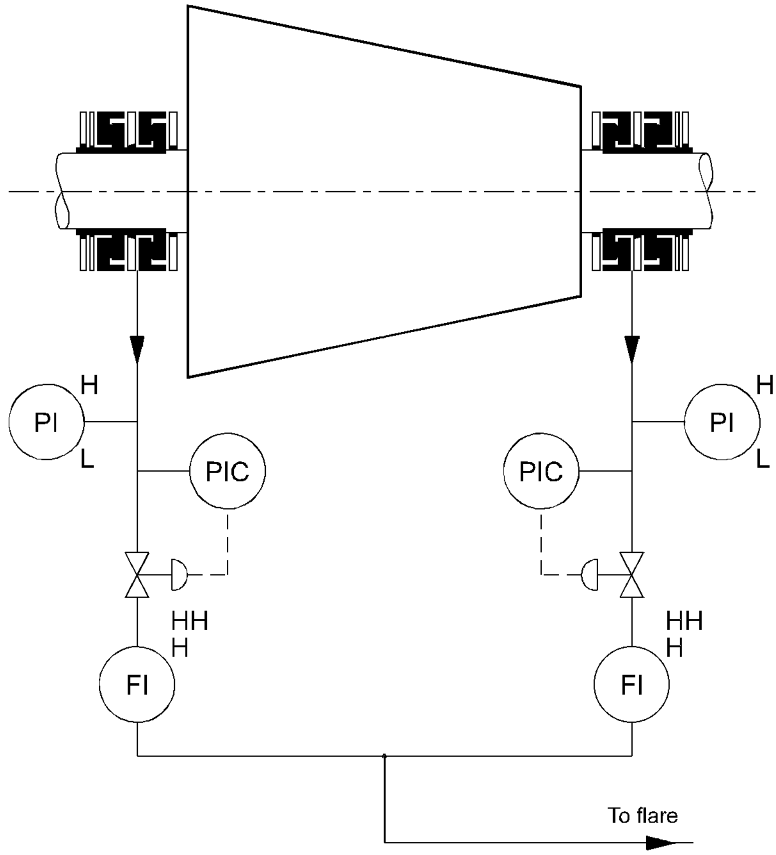
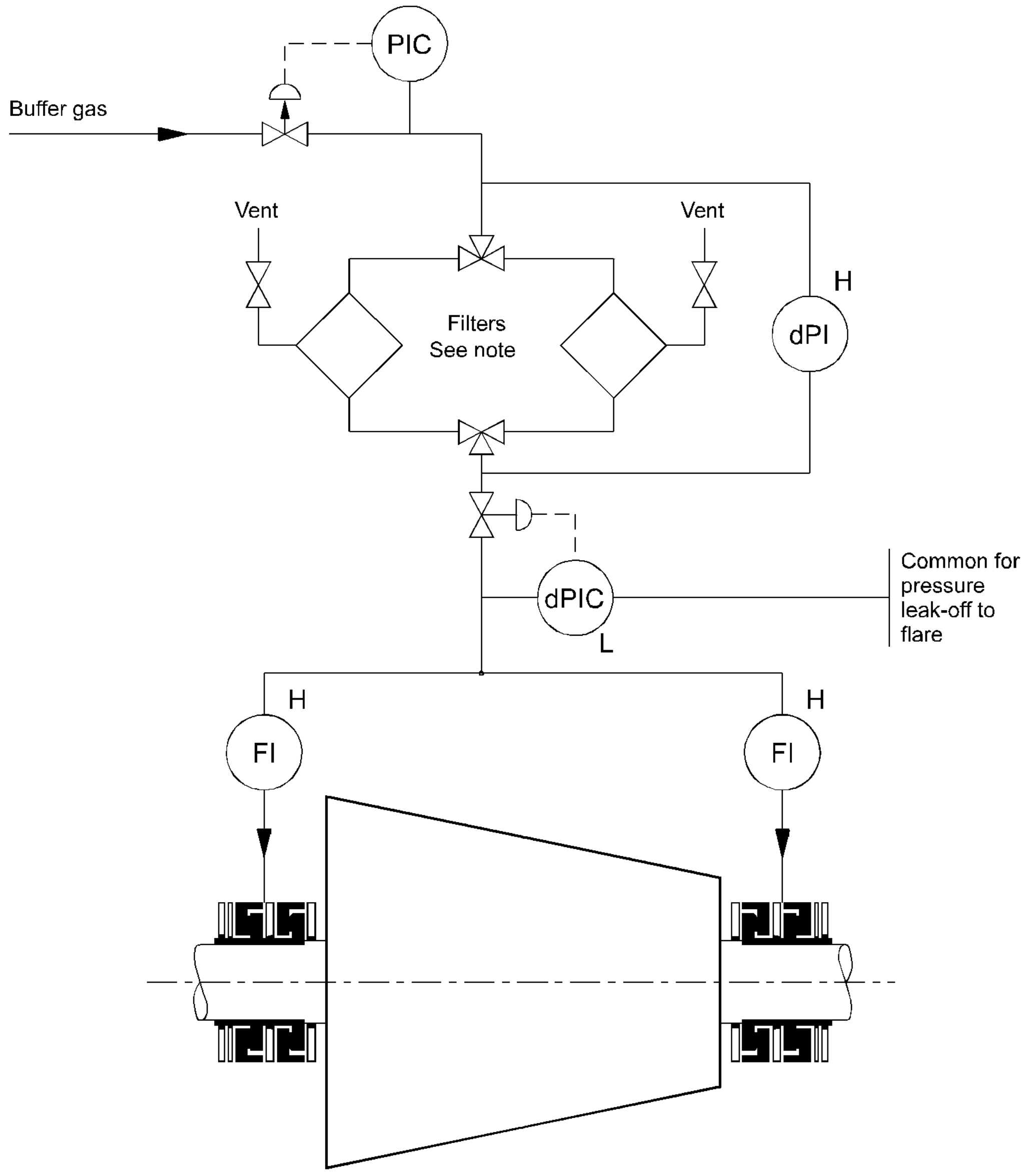


FIGURE C.4 LOW PRESSURE LEAK-OFF SYSTEM (PRESSURE CONTROLLED)



NOTES: The pressure control valves shall be sized to pass the expected leakage from a failed inner DGS.

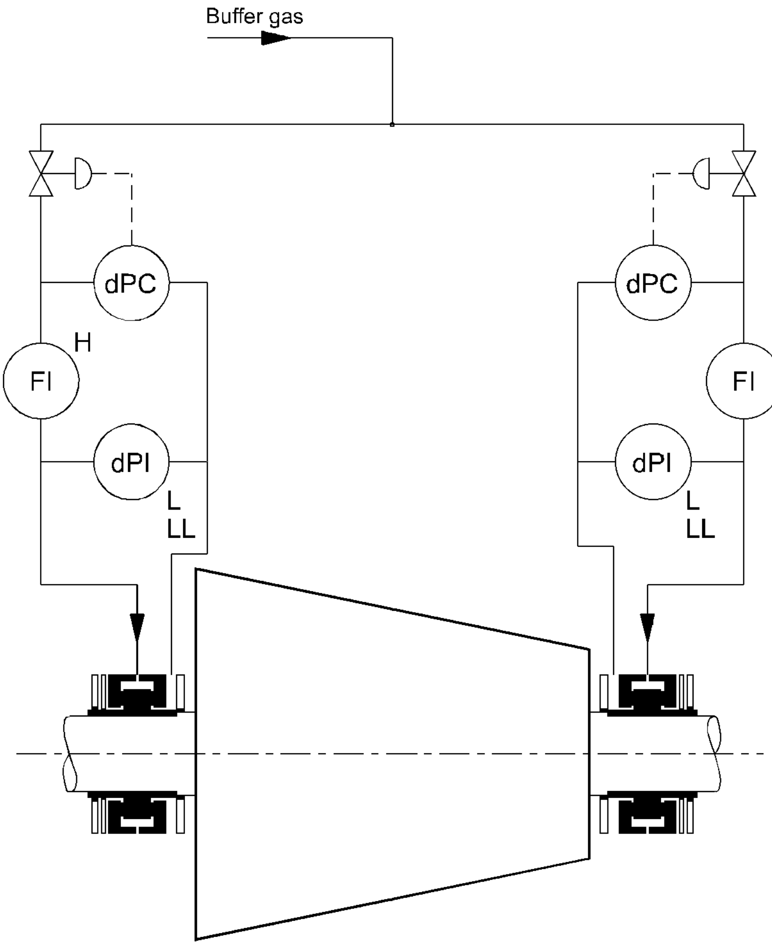
FIGURE C.5 BUFFER GAS SUPPLY SYSTEM FOR TANDEM DGSs



NOTES: 1. The initial pressure controller may not be necessary if the buffer gas is available at a suitable pressure.

2. Filters may not be necessary if the buffer gas can be relied upon to be clean and dry.

FIGURE C.6 BUFFER GAS SYSTEM FOR FACE-TO-FACE DGS



NOTE: Filters may not be necessary if the buffer gas can be relied upon to be clean and dry.

FIGURE C.7 CONTROLLED PRESSURE LEAK-OFF SYSTEM

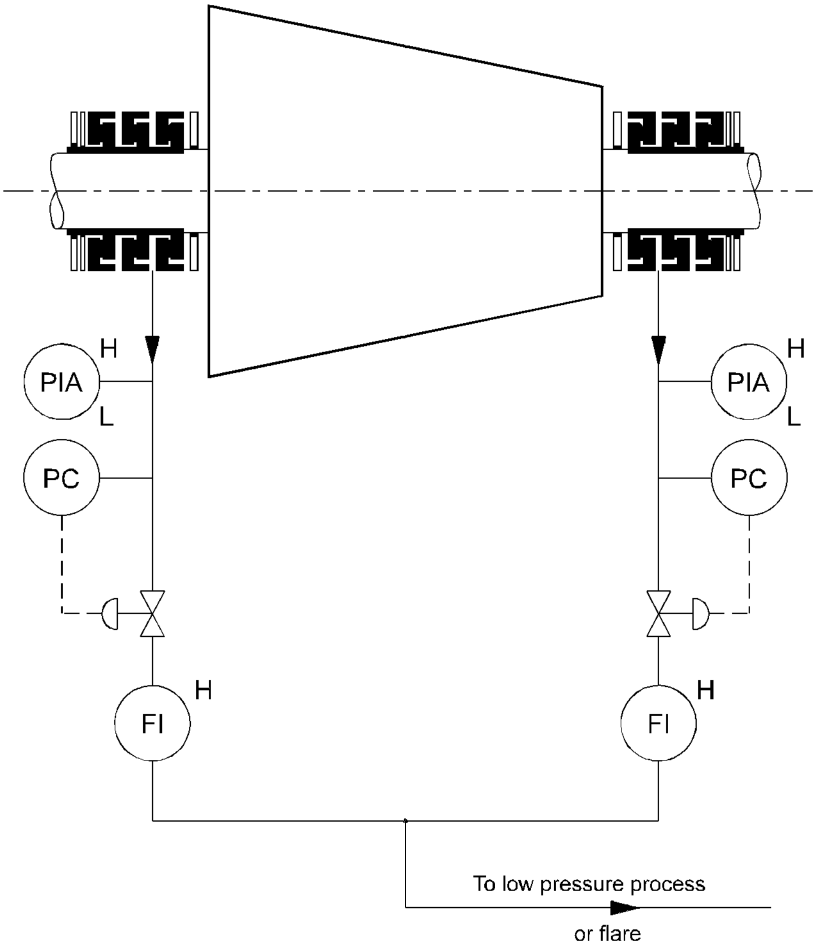


FIGURE C.8 ATMOSPHERIC VENT SYSTEM

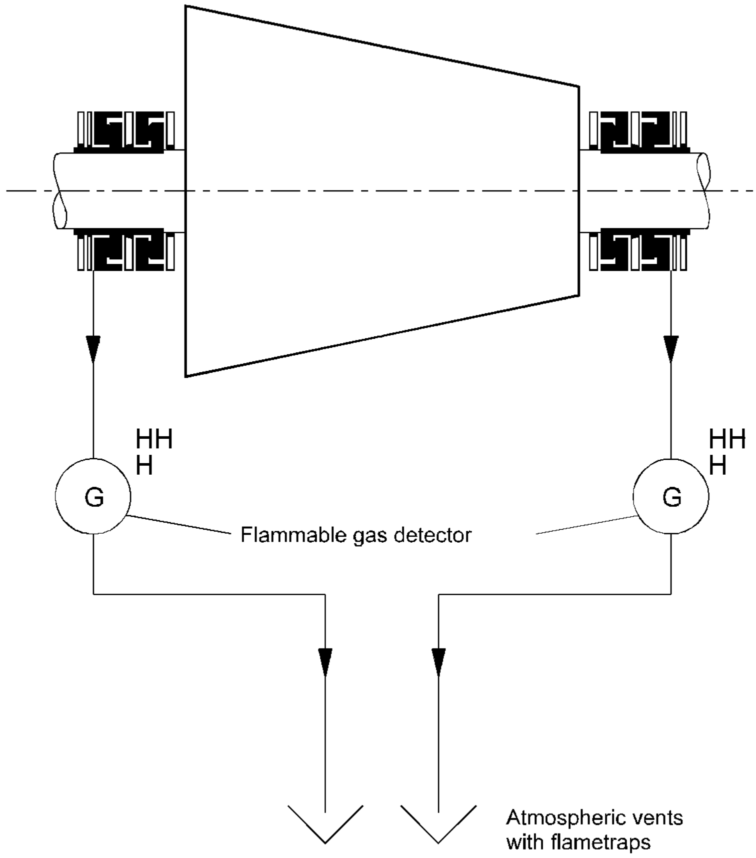
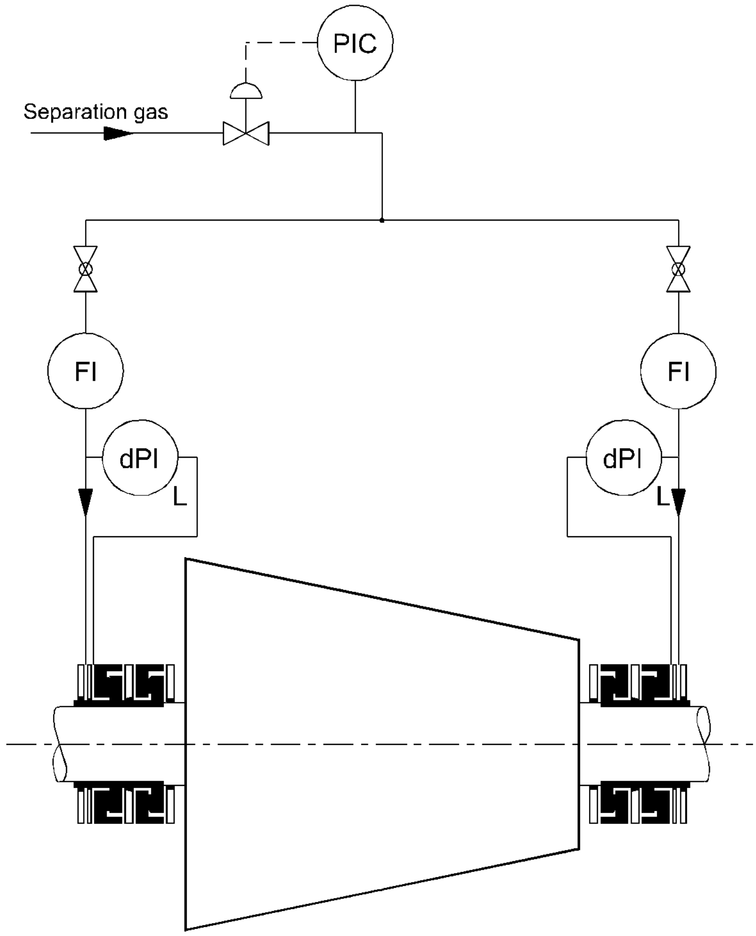


FIGURE C.9 SEPARATION GAS SYSTEM



APPENDIX D MATERIALS FOR O-RINGS

Materials selection for O-rings and other static seals

Explosive decompression (ED) damage is caused when gas trapped in voids in the elastomer cannot diffuse out fast enough.

Above a sealed pressure of 60 bar (ga), (ED)-resistant materials should be selected, with section dimensions less than 7 mm. The alternative, slow depressurisation while still using conventional elastomer materials, should only be considered if the available/allowable depressurisation period is in the order of 24 hours.

Caution: Vendors often propose conventional elastomers in combination with a maximum depressurisation rate in the order of 20 bar/min., and/or claim that these materials were tested (often, however, with nitrogen as test gas, which has smaller molecules, thus giving a false sense of security where the risk of ED is concerned). These proposals/claims should not be accepted without challenge.

Examples of suitable ED-resistant elastomers include (but are not limited to):

- James Walker FR58/90 or -FR58/98
- Dowty 9730
- Greene Tweed 926
- Oldrati EDG

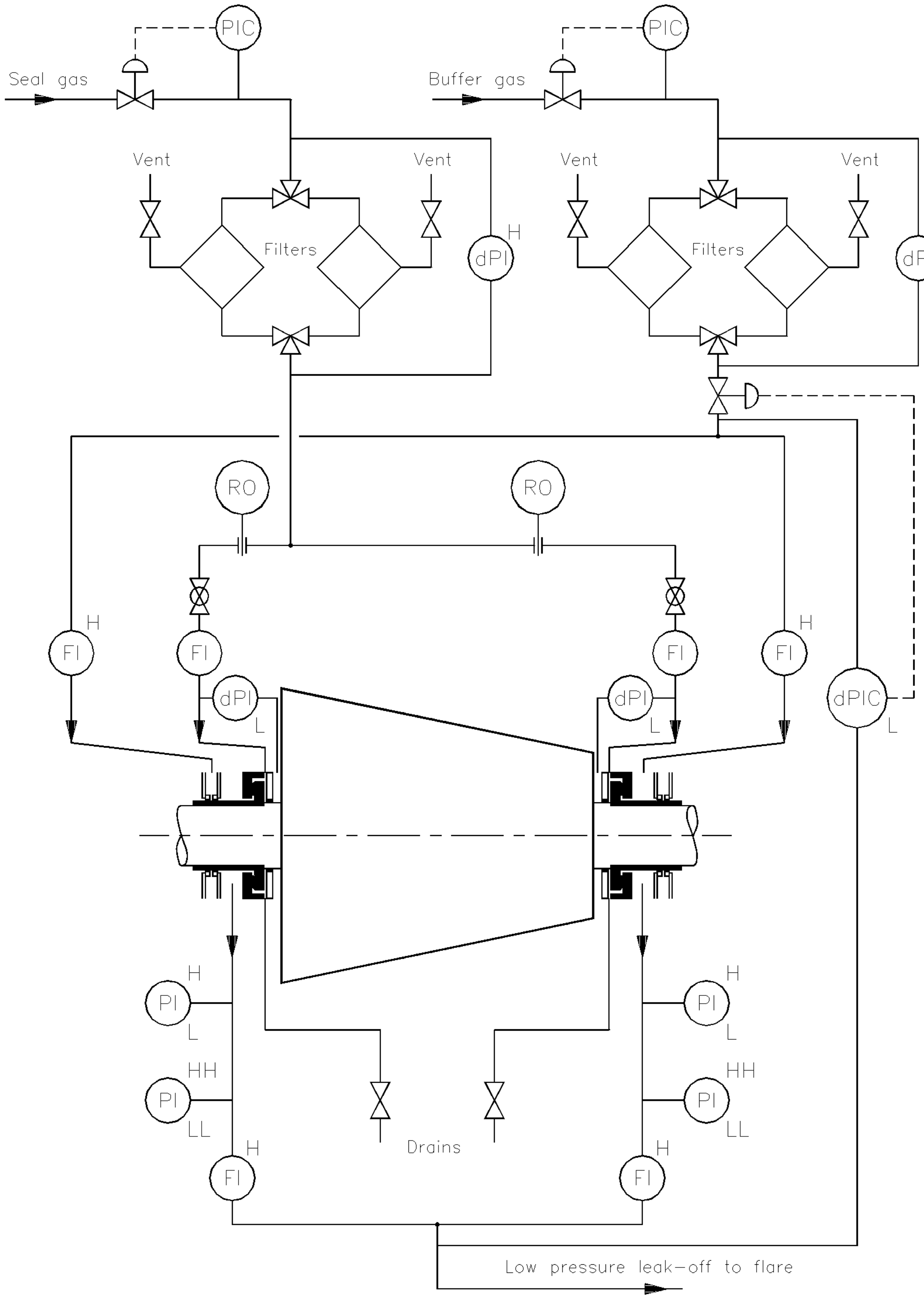
None of these materials, however, are particularly suitable for applications in gases with high concentrations of H_2S, methanol or aromatics. Oldrati EDG is based on a low-temperature elastomer but its suitability for service below 20 °C should be demonstrated.

Particularly for extremely high (e.g. above 175 °C) or low (e.g. below minus 20 °C) seal operating temperatures, the suitability of the proposed elastomer material in relation to the expected operating temperatures shall be confirmed:

- special Viton grades or PTFE should be considered at operating temperatures below minus 20 °C;
- at these low temperatures PTFE may lose flexibility, and the need for self-(spring-) energised seal designs should be considered;
- Viton can be considered up to around 180 °C, PTFE up to around 250 °C

APPENDIX E TYPICAL COMPOSITE SCHEMATIC

FIGURE E.1 TYPICAL OVERALL OUTLINE SCHEMATIC FOR A SINGLE DGS APPLICATION



NOTES: 1. This figure is a typical composite and should not be used as a basis for design.
2. The schematic is based on a fixed seal gas supply pressure. Depending on the source of the seal gas, differential pressure control may be preferred (see 4.2.4), Figure C.1 and Figure C.2.
3. The buffer gas control system is based on Figure C.5 and the requirements of (4.4.4.3). Differential pressure control is used since the inboard pressure of the secondary sealing device (normally the pressure in the flare/vent system) may vary.