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The Filtration and Drying of Compressed Air

Best Practice Guide 104.

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Foreword

This booklet is part of a series of best practice guides produced by The British Compressed Air Society Ltd.

Compressed air is an essential component in many aspects of manufacturing production and processing, with the ever-increasing demands for clean, dry air from all sectors of industry and commerce.

This guide has been produced to aid in the selection of equipment to meet those demands by providing detailed explanations of the various technologies currently available and their energy efficiencies.

It provides useful guidance to allow informed decisions to be made on which type of compressed air treatment equipment is required, how it should be installed and maintained and importantly, the various levels of air purity (quality) currently achievable.

Acknowledgements

We worked with leading engineers in the field of air treatment and purification to compile this comprehensive overview and our thanks are extended to these and the members of the British Compressed Air Society Ltd who contributed to its production.[1]

BCAS member contributors were:

- BEKO Technologies Ltd
- Donaldson Filtration (GB) Ltd
- Factair Ltd
- Gardner Denver Ltd
- Hi-line Industries Ltd
- Parker Hannifin Manufacturing Ltd

Additional contributions were submitted by the following BCAS members:

- Atlas Copco Compressors Ltd
- D&F Techniek B.V.
- Ingersoll Rand International Ltd
- Michell Instruments Ltd

[1] **Disclaimer**

Introduction

With compressed air often referred to as the fourth utility and the uses for compressed air growing every day, it means that there is a diverse variation in air quality requirements. The concentration of airborne contaminants present during the compression process means that the compressed air will invariably need some form of air treatment before the point of use.

As technology for compressed air treatment continues to evolve, there is now a wide range of equipment available which can satisfy the most demanding of compressed air treatment needs. The selection of the right equipment can be a complex task, affecting everything from maintenance schedules to the ongoing costs associated with achieving the required standards, while avoiding generating excessive purge air and preventing significant pressure drops.

This best practice guide attempts to demystify not only the selection of the right air treatment equipment but explain which contaminants can be present and their impact on the processes the compressed air is being used for.

Most industrial applications for compressed air operate at a pressure of around 7 bar g to 20 bar g (100 – 300 psi), generally considered as low pressure (LP) air. This document is aimed at covering these typical applications.

It is worth remembering though that compressed air can be used at much higher pressures, but other considerations need to be given to these applications and are not generally covered by this document. For applications operating at pressure above 20 bar g, it is advised that operators seek further specialist advice.

Scope

The correct selection of purification equipment is extremely important and there are many factors to consider when designing a purification system. This guide has been developed to provide the end user with an understanding of why purification equipment (filters and dryers) is required, relevant standards that may assist in the development of an air treatment system, an overview of how each different purification technology operates and how they consume energy.

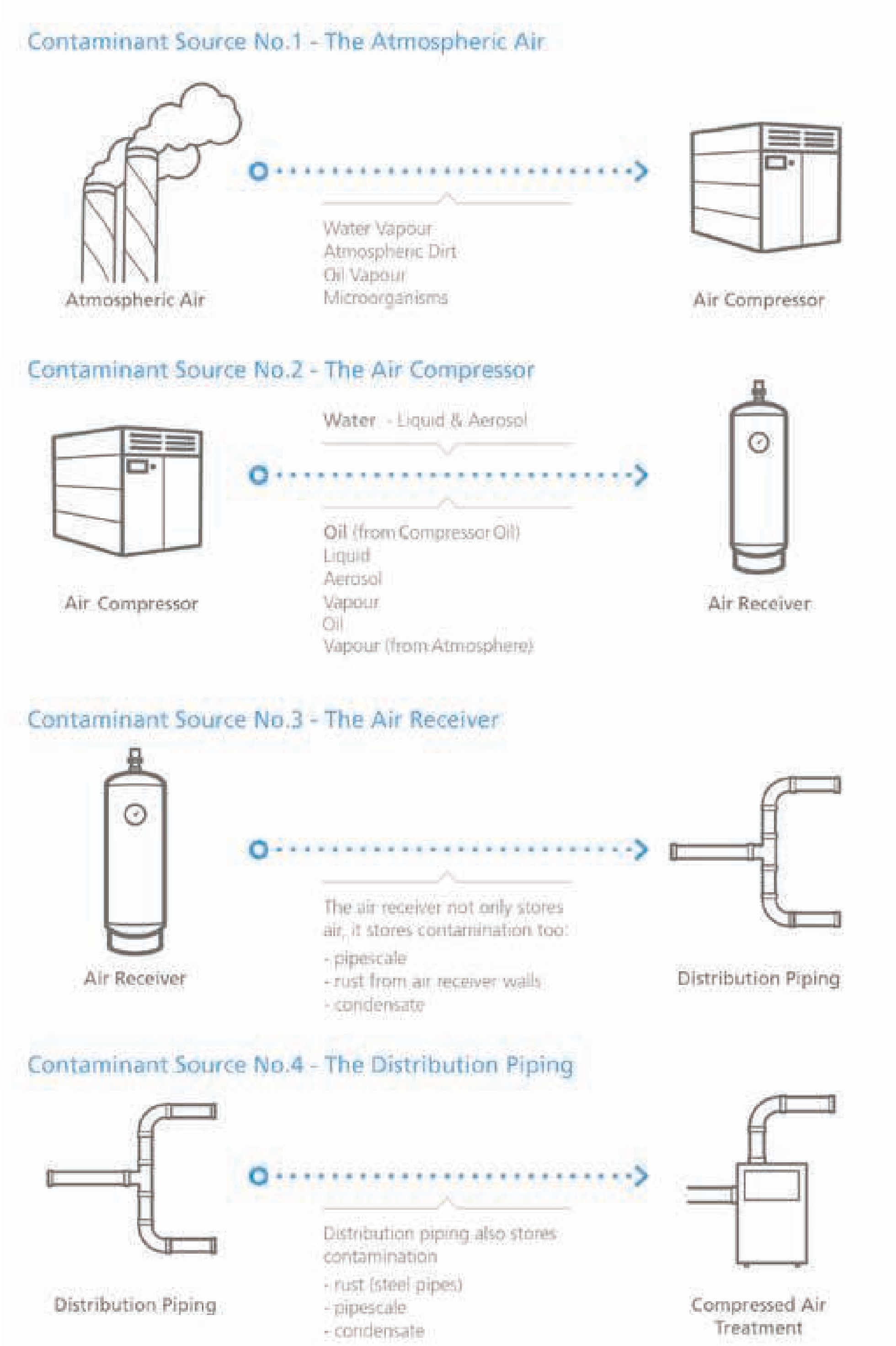
Additional information is given in the BCAS factsheet: 704 'Parameters Needed to Size Compressed Air Treatment Equipment.' Please visit the BCAS website for the most up-to-date fact sheet. **www.bcas.org.uk**

1. Compressed Air Contamination and its Sources

Compressed air is not clean. It contains many hazards in the form of contamination. In a typical compressed air system there are 10 main contaminants that require treatment if the system is to operate safely, efficiently and cost effectively. Contamination in a compressed air system comes from four different sources. Please note, the number of contaminants requiring treatment rises to 15 if the compressed air is used for breathing air or medical air applications.

Figure 1 shows the 4 sources of contamination and the 10 main contaminants of concern.

(Fig 1.)



1.1 Contaminants in Detail

Commonly, compressed air contaminants are combined into three distinct categories for simplicity, these are:

- Particles – (Including viable and non-viable microbiological organisms)
- Water
- Oil

ISO 8573-1, the international standard for compressed air purity (quality), refers to the main contaminants in this format.

Important Note:

When selecting purification equipment, it must be remembered that contaminants will be in one of three different phases (states of matter). For example, water and oil in a compressed air system will be found in liquid form, as an aerosol (fine mist) and in a vapour (gaseous) phase and a different purification technology will be required depending upon the phase of the contaminant (i.e. liquid, aerosol or vapour).

We will now look at the contaminants in further detail.

1.1.1 Solid Particles

Ambient air is subject to contamination which affects the quality of generated compressed air. This can include particulate matter containing viable and non-viable microbiological organisms. For example, in a typical industrial environment there can be more than 140 million dirt particles in every cubic metre of air.

Consider that, when this is then compressed on average to 7 bar g, the contamination is concentrated in line with the pressure increase.

While it is true that the compressor intake filter will remove some of this contamination, the fact remains that around 80 per cent of these particles are smaller than two microns in size and will pass directly into the compressed air system.

1.1.2 Water (Vapour, Liquid and Aerosols)

Water vapour enters the compressed air from the compressor intake. In total volume terms, condensed water vapour is the most prominent contaminant in the compressed air system and on investigation, will form much of the liquid contamination found in a compressed air system. See Table below.

75kW Compressor - 825 m³/hr - 7.5 bar g Discharge Pressure						
Ambient Temp	RH %	Discharge Temp	Water Vapour Entering Compressor (L/hr)	Liquid Water Removed at the Aftercooler (L/hr)	Remaining Water Vapour Entering the Compressed Air System (L/hr)	Total Water Vapour Entering the Compressed Air System Per Year (L)
10°C	65	20°C	4.88	1.67	3.21	28,043
15°C	65	25°C	6.82	2.26	4.56	39,836
20°C	65	30°C	9.41	3.03	6.38	55,736
25°C	65	35°C	12.85	4.03	8.82	77,052
30°C	65	40°C	17.42	5.29	12.13	105,968

If this moisture is not removed from the system, it can cause the pneumatic equipment to fail prematurely, resulting in contamination entering the compressed air stream and the potential for bacterial growth, and adversely affecting final product quality. The more critical the system is to the final production output; the more attention needs to be focused on removing this moisture from the compressed air.

In a compressed air system, water content is measured in terms of dewpoint, which is specified as a temperature. It is the point at which water vapour held in the compressed air is equal to the compressed air's capacity to hold water vapour and the temperature at which condensation will occur.

1.1.3 Oil (Vapour, Liquid and Aerosols)

Oil contamination in the compressed air system can enter from two separate routes.

The first of these is driven by the quality of the intake air. Even before compression begins, the air drawn in through the intake of a compressor contains hydrocarbons and VOC (volatile organic compounds) which when compressed, regardless of compressor type, will cause oil to be present in the compressed air system.

The term 'VOC' is used frequently in media articles in relation to ambient air quality.

Airborne hydrocarbons and VOC are common and are more prevalent in urban and industrial areas. One of the most common sources of hydrocarbons and VOC is fossil fuels, which when condensed and cooled will form a liquid contaminant in the system.

The other source of oil is from the compressor's own lubrication system. While there are several types of compressor available, this document will examine the two most common types; oil lubricated and oil-free.

Please note that this document does not intend to advise on compressor selection. It merely explains the main differences between the technologies and how oil is introduced to the system.

1.1.3.1 Oil Carryover from Lubricated Compressors

'Oil carryover' is the term used to describe the amount of lubricating oil that finds its way downstream of a compressor during its operation. For oil lubricated compressors, oil carryover is due to the efficiency of the air/oil separator in the compressor oil reclamation and recirculation system.

The figures in the table below illustrate typical oil carry over from different types of compressor.

Typical Oil Carryover from Lubricated Compressors	
Reciprocating (Piston)	New: 25 mg/m³ - Old: 100-200 mg/m³
Oil Flooded (Lubricated) Screw	New: <5 mg/m³
Rotary Vane	New: <5 mg/m³

For example, a 425 m³/hr compressor, will add up to 18 litres of oil into an air system over an 8000-hour operation.

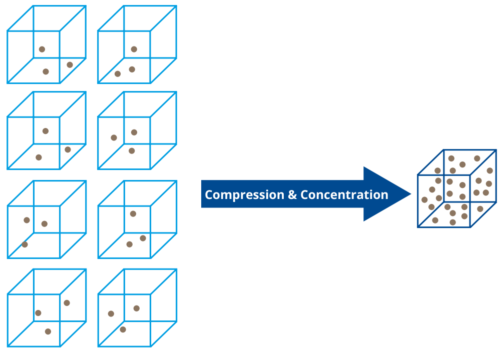
In any compressor, ambient hydrocarbons and VOC enter the intake from the external environment. With an oil-free compressor, the oil is reduced considerably but not removed, due to the presence of the ambient hydrocarbons and VOC (oil vapour).

1.1.3.2 Oil from Oil-Free Compressors

- Oil from an oil-free compressor is dependent upon ambient air quality
- Ambient air typically contains between 0.05 mg/m^3 and 0.5 mg/m^3 of oil vapour (this can be higher or lower and often varies)
- When ambient air is drawn into the compressor intake and compressed, the oil vapour it contains is concentrated.
  - Refer to the appendix in this document to reference DEFRA publications regarding hydrocarbons and VOC present in the ambient air
  - See below for an explanation and example of compression and concentration

In simple terms, to generate one cubic metre of compressed air, the compressor must draw in and compress multiple cubic metres of ambient air (the higher the pressure, the more cubic metres of ambient air are used).

Example: To generate 1m^3 of air, at a pressure of 7 bar g (8 bar A), then 8m^3 of ambient air will be required. And while the ambient air is squeezed into a smaller volume (compressed), any contaminants it contains will be concentrated. If that ambient air contains oil vapour, with levels between 0.05 mg/m^3 and 0.5 mg/m^3, once compressed to a pressure of 7 bar g (8 bar A) there will now be between 0.4 mg/m^3 and 4 mg/m^3 of oil vapour present after compression and concentration.



Concentration Examples

To highlight the effect of concentration, the table below contains the maximum hourly 'oil vapour concentration values' (averaged from the values recorded over four years).

Recorded Contamination Levels 1 Cubic Metre of Ambient Air Before Compression						
Pressure	Industry Values		Recorded Ambient Values (Average Over 4 Years)			
	Min	Max	Auchencorth Moss	Harwell	Eltham	Marylebone Road
0 bar g	0.05	0.5	0.29	0.14	0.48	0.67

The table below highlights the increased 'oil vapour' contamination levels that 1 cubic meter of compressed air would contain. (at industry typical operating pressures).

Oil Vapour Contamination Levels 1 Cubic Metre of Compressed Air						
Pressure	Industry Values		Effect of Compression on Recorded Ambient Values			
	Min	Max	Auchencorth Moss	Harwell	Eltham	Marylebone Road
7 bar g	0.40	4.00	2.32	1.12	3.84	5.36
10 bar g	0.55	5.50	3.19	1.54	5.28	7.37
13 bar g	0.70	7.00	4.06	1.96	6.72	9.38
40 bar g	2.00	20.00	11.6	5.60	19.2	26.8
All Concentration Values in mg/m^3						

Negligible Values

So, what may appear as negligible values in the ambient air, are no longer negligible once the concentrating effects of compression is taken into consideration.

2. Standards

2.1 Selecting the Correct Air Purity (Quality)

Depending on the application for which the compressed air is to be used, there are number of different compressed air standards and best practice guidelines which can assist the end user. Prior to the purchase of new compressed air treatment equipment, the user should assess carefully the air purity (quality) requirements of the system or application. The air purity (quality) required should be specified to all suppliers to assist product selection.

An overview of the most commonly used standards and best practice guidelines are summarised below, however for further detail on each of these standards, you should refer to the full standard or contact BCAS for guidance - **technical@bcas.org.uk**

2.1.1 International Standards - ISO8573 Series

ISO8573 series is the most commonly used standard for compressed air (excluding breathing air or medical air). It is made up of nine separate parts. Part 1 refers to air purity (quality), while parts two to nine provide details on the equipment and methodology to be used to measure for different contaminants in a compressed air system (and meet the air purity (quality) classifications shown in part one).

2.1.2 ISO8573-1 – International Standard Relating to Compressed Air Purity (Quality)

ISO8573-1 provides the user a way of specifying an air purity (quality) required for the entire compressed air system and/or for individual usage points, based upon application requirements. It also allows equipment manufacturers to show product performance easily and specify purification equipment to meet the end users air purity (quality) specification.

In ISO8573-1, compressed air contaminants are grouped into particulate, water and total oil. Different levels of contamination are then assigned 'purity (quality) classes.' When using ISO8573-1 to define the air quality required at a usage point, the specification should be written as follows:

First the standard (ISO8573-1) must be written, then the year (revision) stated then the purity (quality) classes (separated with a colon), e.g. **ISO8573-1:2010 [A: B: C:]**

Where:

A is the purity (Quality) class for particles; see Table 1
B is the purity (Quality) class for humidity and liquid water; see Table 2
C is the purity (Quality) class for oil; see Table 3

Table 1 - Compressed Air Purity (Quality) Classes for Particles

SOLID PARTICULATE			
Class	Maximum Number of Particles per Cubic Metre as a Function of Particle Size, *d*		
	0.1 µm < d ≤ 0.5 µm	0.5 µm < d ≤ 1.0 µm	1.0 µm < d ≤ 5.0 µm
0	As specified by the equipment user or supplier and more stringent than class 1		
1	≤ 20,000	≤ 400	≤ 10
2	≤ 400,000	≤ 6,000	≤ 100
3	Not specified	≤ 90,000	≤ 1,000
4	Not specified	Not specified	≤ 10,000
5	Not specified	Not specified	≤ 100,000

Table 2 – Compressed Air Purity (Quality) Classes for Humidity

Class	WATER	
	Vapour Pressure Dewpoint °C	Liquid g/m³
0	As specified by the equipment user or supplier and more stringent than class 1	
1	≤ -70	-
2	≤ -40	-
3	≤ -20	-
4	≤ +3	-
5	≤ +7	-
6	≤ +10	-
7	-	≤0.5
7	-	≤0.5 – 5
9	-	– 10
X	-	>10

Table 3 – Compressed Air Purity (Quality) Classes for Total Oil

Class	OIL
	Total Oil (Liquid, Aerosol and Vapour) mg/m³
0	As specified by the equipment user or supplier and more stringent than class 1
1	≤ 0.01
2	≤ 0.1
3	≤ 1
4	≤ 5

2.2 Other Compressed Air Related Standards / Best Practice Recommendations

2.2.1 Food Grade Air

The Food Grade Compressed Air Best Practice Guideline 102 was prepared by the British Compressed Air Society Ltd with advice from the British Retail Consortium Trading Ltd.

In all instances The British Compressed Air Society Ltd advises full consideration of this guide and the information contained within.

The Food and Beverage Grade Compressed Air Best Practice Guideline 102 is available to download from **www.bcas.org.uk**

It details the HACCP process and enables informed decisions to be made on the type of compressed air equipment that is required, how it should be installed as well as maintained and importantly the requirements for the air purity (quality).

2.2.1.1 Direct Contact Recommendation

Compressed air that comes in to direct contact with food or beverage products should meet or exceed the following classification:

Table 1, as identified in the ISO 8573-1:2010 Compressed Air Purity (quality) Designation ISO 8573-1:2010 [2:2:1], which translates to;

Class	Maximum Number of Particles Per m³ For Particle Sizes, d (μm) (At Reference Conditions see 7.3.1)		
	0.,1 < d ≤ 0,5	0,5 < d ≤ 1,0	1,0 < d ≤5,0
2	≤ 400 000	≤ 6 000	≤ 100

Class	Pressure Dewpoint (°C)
2	≤ -40

Class	Concentration Total Oil (Liquid, Aerosol, and Vapour) (mg/m³) (At Reference Conditions)
1	≤ 0,01

2.2.1.2 Indirect Contact Recommendation

Compressed air that comes in to indirect contact with food or beverage products should meet or exceed the following classification:

Table 2 as identified from ISO 8573 1:2010 Compressed Air Purity (quality) Designation, ISO 8573-1:2010 [2:4:2], which translates to:

Class	Maximum Number of Particles per m^3 For Particle Sizes, d (µm) (At Reference Conditions see 7.3.1)		
	0.,1 < d ≤ 0,5	0,5 < d ≤ 1,0	1,0 < d ≤5,0
2	≤ 400 000	≤ 6 000	≤ 100

Class	Pressure Dewpoint (°C)
4[1]	≤ +3

Class	Concentration Total Oil (Liquid, Aerosol and Vapour) (mg/m^3) (At Reference Conditions)
2	≤ 0,1

[1] See Annex C.2.1.3 for information on the drying of compressed air

[1]Extract from Annex C 2.1.3:

“Microbiological contaminants such as bacteria require water to maintain viability.”

To reduce the viability for microbiological contaminants to be present in the compressed air system, it is recognised that the humidity of the compressed air needs to be reduced.

Typically, adsorption dryers (commonly described as desiccant dryers) provide the highest levels of compressed air dryness and are best suited for reducing the humidity to levels that are low enough to suppress microbiological activity within the system.

2.2.1.3 Microbiological Contaminants

Hazard analysis shall establish the risk of contamination by microbiological contaminants from compressed air. The presence of microbiological contaminants shall be established by the test method specified in ISO 8573-7.

The best practice guideline recommends that compressed air purity (quality) shall be tested and verified at least twice per year, unless otherwise identified in the HACCP (Hazard analysis critical control point) process.

You are reminded that a full copy of the Food and Beverage Grade Compressed Air Best Practice Guideline 102 is available to download from the BCAS website. **www.bcas.org.uk**

2.2.2 Medical and Surgical Air

In the UK, Health Technical Memorandum HTM02-01 is a purity (quality) specification for medical gas pipeline tests (working gases). It specifies the following limits: (See Fig 6.).

(Fig 6.)

Gas and source	Particulates	Oil	Water	CO	CO_2	NO and NO_2	SO^2	Polytest tube (Optional)	Odour
Medical and Surgical Air	Free from visible particles in a 75L sample (for medical air) and 175L sample (for surgical air)	≤0.1 mg/m³	≤67 vpm (≤0.05 mg/L, atmospheric dewpoint of -46°C)	≤5mg/m³ ≤5 ppm v/v	≤900 mg/m³ ≤500 ppm v/v	≤2 ppm v/v	≤1 ppm v/v	No discoloration	None

In Europe, the European Pharmacopoeia 5.0 for medicinal air applies the following limits: (See Fig 7.)

(Fig 7.)

Gas and source	Particulates	Oil	Water	CO	CO_2	NO and NO_2	SO^2	Odour
Air, Medicinal	20.4% v/v to 21.4% v/v	≤0.1mg/m³	≤67 ppm v/v*	≤5 ppm v/v	≤ 500 ppm v/v	≤2 ppm v/v	≤1 ppm v/v	None

*- Except where the competent authority decides a maximum of 870 ppm v/v shall apply at pressure not greater than 10 bar g and a temperature not less than 5°C.

Reference should be made to each document for the testing methods.

2.2.3 Dental Air

In the UK, dental practices covered by NHS requirements should follow the recommendations in Health Technical Memorandum HTM2022 Supplement 1 (See Fig 8.).

(Fig 8.)

Gas and Source	Oxygen	Nitrogen	CO^2	CO	Oil	Water	Particulates	SO^2	NO and NO^2	Odour
Dental Compressed Air	20.9 ± 0.5%	78.0% by inference	≤500 ppm v/v	≤5 ppm v/v	≤0.1 mg/m³	≤1020 vpm (≤0.78 mg/L, at-mospheric dewpoint of - 20°C)	Free from visible particles in a 75-litre sample (taken at 150 litres/min)	≤1 ppm v/v	≤2 ppm v/v	None

For other dental practices, the British Dental Trade Association and British Compressed Air Society Ltd jointly prepared a code of practice with an air purity (quality) specification as follows: (See Fig 9.)

A full copy of The British Compressed Air Society Ltd - Dental Compressed Air - A Code of Practice is available to download via the BCAS website **www.bcas.org.uk**

(Fig 9.)

Contaminant	Purity (Quality) Specification (see Note 1)
Water	Maximum +5°C or lower dewpoint measured at pressure with a minimum line temperature of 10°C
Oil	<0.5mg/m³ (Total oil content)
Particles (see Note 2)	Free from visible particles in a 75 Litre sample (taken at 150 L/min)
Bacteriological contaminant	Removal of particles down to 0,01 µm is sufficient to remove airborne bacteria, viruses and bacteriophage. (see Note 3)
NOTE 1: Air purity (quality) class as per ISO 8573-1: [6:4:3]. NOTE 2: Particle removal to less than 5µm will satisfy the sampling quoted. NOTE 3: A point of use sterile air filter is recommended, consult filter supplier for details of application, installation and use.	

2.2.4 Breathing Air

The specified standard for breathable air is EN 12021: 2014 - 'Respiratory protective devices: Compressed gases for breathing apparatus.' It is now the only standard to indicate maximum permitted contaminant levels for breathing air both in the UK and in the EU.

Additional information is given in BCAS factsheet 304. Please check the BCAS web site for the up-to-date factsheet - **www.bcas.org.uk**

Extract from BS EN 12021 – Clause 6

'Compressed gas for breathing shall not contain contaminants at a concentration which can cause toxic or harmful effects. In any event, all contaminants shall be kept as low as possible and shall be less than one tenth of a national 8 hr exposure limit. For breathing air only, the limit shall be less than one sixth of a national 8 hr exposure limit. For breathing at hyperbaric pressures greater than 10 bar or exposure times greater than 8 hr, the levels shall be revised to consider the effects of pressure and exposure times.' (See Fig 10.)

(Fig 10.)

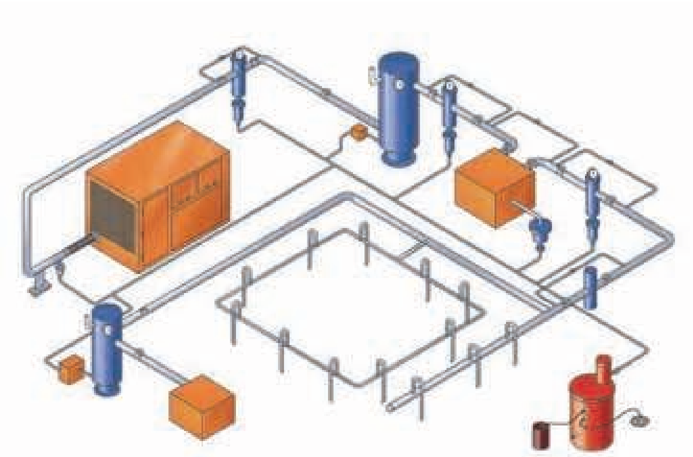
<table>
<tr><th>Oxygen</th><td colspan="2">(21 ± 1) % By Volume</td></tr>
<tr><th>Carbon Monoxide</th><td colspan="2">≤ 5ml/m^3 (ppm)</td></tr>
<tr><th>Carbon Dioxide</th><td colspan="2">≤ 500ml/m^3 (ppm)</td></tr>
<tr><th>Oil</th><td colspan="2">≤ 0.5 mg/m^3</td></tr>
<tr><th>Water (Vapour)</th><td colspan="2">Compressed breathing air shall have a dewpoint sufficiently low to prevent condensation and freezing. Where the apparatus is used and stored at a known temperature the pressure dewpoint shall be at least 5 °C below the likely lowest temperature.

Where the conditions of usage and storage of any compressed air supply is not known the pressure dewpoint shall not exceed -11°C.</td></tr>
<tr><th rowspan="4">Water (Vapour) Content of High Pressure Breathing Air</th><td>Nominal Maximum Supply Pressure bar</td><td>Maximum Water Content of Air at Atmospheric Pressure and 20°C mg/m^3</td></tr>
<tr><td>40 to 200</td><td>≤ 50</td></tr>
<tr><td>>200</td><td>≤ 35</td></tr>
<tr><td colspan="2">The water content of the air supplied by the compressor for filling 200 bar or 300 bar cylinders should not exceed 25 mg/m^3.</td></tr>
<tr><th>Odour / Taste</th><td colspan="2">The gas shall be free from unsatisfactory odour or taste.</td></tr>
</table>

BS EN 12021:2014, the UK National Annex NA.4.2, states: 'Samples should be taken and analysed at least every three months or more frequently if there has been a change in, or concerns relating to, the production process.'

3. Specifying Air Treatment Equipment

Whether designing new systems, or reviewing existing systems, the first step should be to define the precise compressed air purity (quality) requirements, ideally using the ISO8573-1 standard. To achieve the degree of air purity (quality) specified by ISO8573-1, a careful approach to system design, commissioning and operation must be adopted.



It is recommended that compressed air is treated:

- Prior to entry into the distribution system
- At critical usage points and applications (this ensures that contamination already in the distribution system is removed).

Purification equipment should ideally be installed where the air is at the lowest possible temperature, i.e. downstream of air receivers (but also protected from freezing). Point-of-use purification equipment should be installed as close as possible to the application.

To allow correct sizing and selection of purification equipment, the following primary operating parameters must be obtained from the user's site:

- The MAXIMUM compressed air flow rate into the filters/dryer
- The MINIMUM operating pressure into the filters/dryer
- The MAXIMUM operating temperature into the filters/dryer
- The MAXIMUM ambient air temperature where the equipment is to be installed (required for some dryer technologies)
- The required dewpoint (dryers)

Individually, each of the primary operating parameters can influence product sizing, however collectively they can have a major impact on product sizing and performance (always seek the manufacturer's advice).

Many manufacturing plants only need a proportion of the compressed air to be treated to a very high purity (quality). In these cases, excellent savings are achievable by treating all the generated air to the minimum acceptable level and improving the purity (quality) to the desired level at the usage point.

If most of the compressed air is needed at a high purity (quality), it can make sense to treat all the compressed air to the level required by the highest purity (quality) application.

It should be noted that adding low dewpoint dryers to piping, which previously had no dryer or positive dewpoint dryers installed, can result in an increase of rust and pipe scale particles downstream as the piping dries out. Point of use particulate filters are always recommended.

4. Compressed Air Treatment

As previously mentioned in Clause 2 of this guide; in a typical compressed air system, there are a minimum of 10 contaminants that require treatment. It takes a combination of different purification technologies to reduce these 10 contaminants to acceptable levels (See Fig 11.).

(Fig 11.)

Purification Technologies	Contaminants									
	Atmospheric Particles	Rust	Pipe scale	Micro-organisms	Liquid Water	Water Aerosols	Water Vapour	Liquid Oil	Oil Aerosols	Oil Vapour
Water Separator					•			•		
Coalescing Filter	•	•	•	•		•			•	
Adsorption Filter										•
Dryer							•			
Dry Particulate Filter	•	•	•	•						
Sterile Filter				•						

4.1 Using ISO 8573-1 Air Purity (Quality) Classifications to Specify Compressed Air

Many organisations define their own internal specifications for the purity (quality) of compressed air in their facility. These typically refer to 'purity (quality) classifications' from ISO 8573-1.

Using ISO 8573-1 classifications allows purification equipment suppliers to match treatment equipment to the requirements of the specification and location.

The classifications can be quoted for an individual contaminant or for all contaminants.

There are currently three revisions of ISO 8573-1 and these are identified by their release year.

The revision date must always be specified.

For the following sections, ISO 8573-1:2010 will be used. (See Fig 12.).

(Fig 12.)

ISO8573-1:2010 CLASS	Solid Particulate				Water		Oil
	Maximum Number of Particulates Per m^3			Mass Concentration mg/m^3	Vapour Pressure Dewpoint	Liquid g/m^3	Total Oil (Aerosol Liquid and Vapour) mg/m^3
	0.1 - 0.5 micron	0.5 - 1 micron	1 - 5 micron				
0	As specified by the equipment user or supplier and more stringent then Class 1						
1	≤ 20,000	≤ 400	≤ 10	-	≤ - 70 °C	-	0.01
2	≤ 400,000	≤ 6,000	≤ 100	-	≤ - 40 °C	-	0.1
3	-	≤ 90,000	≤ 1,000	-	≤ - 20 °C	-	1
4	-	-	≤ 10,000	-	≤ + 3 °C	-	5
5	-	-	≤ 100,000	-	≤ + 7 °C	-	-
6	-	-	-	≤ 5	≤ + 10 °C	-	-
7	-	-	-	5 - 10	-	≤ 0.5	-
8	-	-	-	-	-	0.5 - 5	-
9	-	-	-	-	-	5 - 10	-
X	-	-	-	≤ 10	-	≤ 10	≤ 10

Important Note:

ISO 8573-1 releases do not supersede previous editions. For example, if a facility is using the ISO 8573-1:2001 revision, it can continue to do so, however it must ensure equipment suppliers provide equipment to the 2001 revision.

The classes change between revision years and therefore the classification of purification equipment may also differ.

Classifications shown in the following sections are representative of industry norms, however it is always recommended to consult with the manufacturer’s literature.

If ISO 8573-1:2010 Class 0 is required or specified:

- A value must always be included for the level of contamination required.
- The contaminant must be stated i.e. particulate / water / total oil.
- It must be more stringent that Class 1 (i.e. cleaner).
- It must be measurable using the test methods of ISO 8573 parts 2 to 9 (the international standards for measuring contaminants in compressed air).
- ISO 8573 parts 2 to 9 describe the test methods for these classes as well as gaseous contaminant and viable microbiological contaminant.
- **Simply stating that Class 0 is required is not in accordance with the ISO 8573-1 standard and is therefore meaningless.**

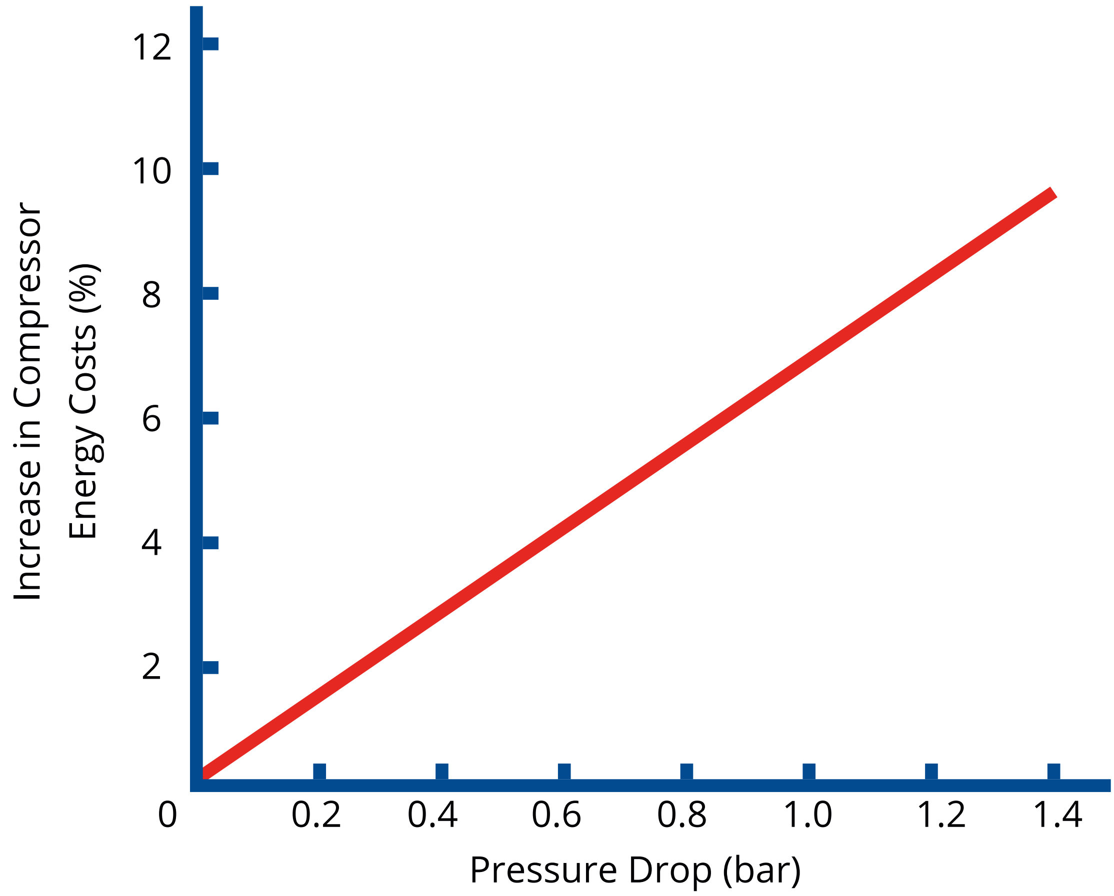
5. Pressure Loss

Compressors are often found to be generating at a pressure above that required for the application, to cater for pressure losses in the compressed air system.

These pressure losses can arise from leaks, poor system design, incorrectly dimensioned distribution piping and of course the purification equipment. As there is a cost associated with generating compressed air at a higher pressure it is worth assessing the system routinely.

On average, it is found that for every 1 bar g additional generation pressure there is a loss of 7 per cent in specific energy, therefore keeping pressure losses low helps reduce operating costs.

(See Fig 13.)



6. The Compressed Air Treatment System – Purification Technologies

The following section will now examine each component part found in a typical compressed air treatment system, with an emphasis on how each technology operates, typical ISO8573-1 classifications associated with that technology and how the technology consumes energy.

Compressor Intake Filtration

After-Cooling

Air Receivers

Filtration

- Water Separators
- Coalescing Filters
- Dry Particulate Filters
- Adsorption Filters
- Catalyst Systems
- Sterile Air Filters

Drying

- **Refrigeration dryers**
  - Direct Expansion
  - Thermal Mass
  - Variable Speed
  - Regenerative Refrigerant Dryers
- **Membrane Dryers**
- **Adsorption (Desiccant) Dryers**
  - **Heatless Regeneration**
    - Standard Heatless Regeneration
    - Heatless Vacuum Assisted
  - **Heat Regenerated**
    - Internally Heated Purge
    - Externally Heated Purge
    - Blower Regeneration
    - Vacuum Regeneration
- **Tandem (Hybrid) Technology**
- **Heat of Compression Dryers**

Condensate Management

- Oil Water Separators
- Condensate Drains

Filtration Associated with the Compressed Air System

6.1 Compressor Intake Filtration

To protect the compressor from incoming dirt, it is generally supplied with an air intake filter. In the case of piston, vane and screw machines these filters have a dirt-retention capacity of between 5 μm and 50 μm. Centrifugal machines are more sensitive to incoming dirt and air intake filtration is normally in two stages, the final filtration level being around 0.2 μm.

Some additional power is required to overcome the pressure drop of the air intake filter. This is considered within the compressor package performance figures. However, as the air intake filter becomes contaminated with the many particles contained in atmospheric air, the pressure drop, and hence the power required, will increase. Increases in specific power consumption of three per cent are not uncommon due to this problem.

To help overcome this issue, consult the compressor service manual and change the air intake filters in line with manufacturers recommendations.

6.2 After-Cooling

The first step in removing water and some oil vapour, through condensing, is in the after-cooler, which is a standard fitting on most compressors. In practice 68 per cent of the water is removed in the after-cooler where the air temperature is typically reduced to between 10 and 15°C above ambient.

The after-cooler power requirement is normally included in the total package electrical consumption of the compressor.

Important Note:

Ventilation for air cooled after-coolers is critical. Poor ventilation will prevent condensation occurring and result in high-temperature saturated air, overloading downstream purification equipment.

For water cooled after-coolers, always ensure that the cooling water is at the correct temperature and circulation pumps are operating. Removal of condensed liquid is also critical as failure to remove condensed liquids will result in liquid carryover, overloading downstream purification equipment.

6.3 Air Receiver

Following the after-cooler, the air is normally fed in to an air receiver, the volume of which is normally some 10 per cent of the compressor rated output in volume-per-minute terms. The receiver should, wherever possible, be placed outside in a cool location, which will further reduce the temperature of the compressed air and so more water and oil will condense.

A receiver also creates a quiet zone where the turbulence is considerably reduced. Some moisture can pass through the after-cooler condensate removal separator at high velocity and the receiver can help to trap this.

Important Note:

Be aware that receivers should not be placed in locations where the temperatures will consistently fall below 0°C. Where this is likely trace heating or inside locations should be considered. Additional information is given in BCAS factsheet 851. Please check the BCAS web site for the up to date factsheet - **www.bcas.org.uk**

6.4 Filtration

Filtration is important in a compressed air system. Compressed air filters are required to treat nine of the 10 main contaminants.

Selection of filtration is important and there are many factors to consider.

1. Sizing. For example, can the filter handle the compressed air flow rate at the minimum system pressure and maximum system temperature?
2. Grade of filtration. Depending on your application single or multi stage filtration may be required. It is essential that you understand the air purity (quality) and efficiency required when specifying the grade of filtration necessary to meet your application. **Note, are you specifying at the compressor house or at the point of use?**
3. Cost. Filters are often seen as a commodity and purchased on price. Although filters may look similar and claim comparable performance, the cost to operate and maintain the filter can vary significantly. When considering cost, always use total cost of ownership rather than initial purchase price.

6.4.1 Filtration Grades and Types

6.4.1.1 Water Separators

Although called water separators, this equipment reduces the volume of all liquids at the point of installation. Liquid in a compressed air system is usually a mixture of oil and water.

Water separators are usually the first piece of purification equipment installed downstream of an aftercooler or air receiver and should be used to protect coalescing filters from liquid contamination. It is worth noting that they are not always necessary, for example, if coalescing filters are installed immediately after the air receiver and the air temperature is unchanged. This is because no condensation will occur between the air receiver and the filters, which means no liquid requires removal.

If variable speed compressors are used, ensure the water separator selected can work at the variable flow condition. Many are designed for optimum efficiency only at their maximum flow conditions and, reducing air flow reduces the velocity of the air in the separator and therefore the separation efficiency. A water separator would be classified typically as ISO 8573-1:2010 Class 6 for water.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Water Separator	✔	✕	✕

6.4.1.2 Coalescing Filters

Coalescing filters treat multiple contaminants, including atmospheric particulate, rust, pipe scale, micro-organisms and aerosols of oil and water. More importantly, they protect refrigeration and adsorption (desiccant) air dryers from contamination.

They are usually installed close to where the compressor is located, either in the compressor room on larger installations or on the actual compressor itself for smaller fixed or portable units.

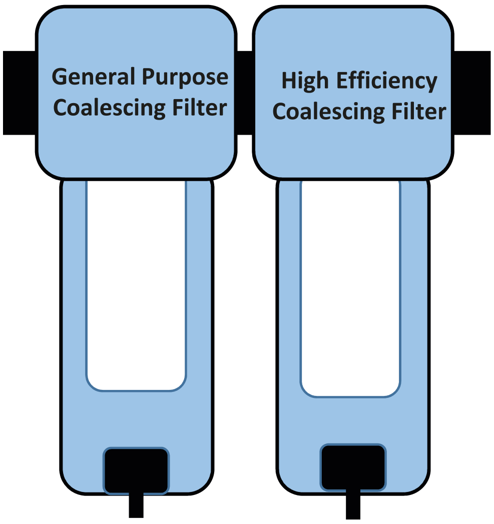
These will typically be installed in pairs, with one being a general purpose (pre-filter) filter, the other being a high efficiency filter. This is the most cost-effective method of installation as the general purpose (pre-filter) filter protects the high efficiency filter from heavy contamination, extending the life of both elements up to twelve months.

Important Note:

It is not uncommon to see one of these filters removed when an oil-free compressor is installed. There is a common misconception that the first is a particulate filter and the second is an oil removal filter and, because the compressor is classified as oil-free, the oil filter is not required. This is an incorrect assumption and can lead to air quality issues and loss of dryer dewpoint. Coalescing filters should always be installed in pairs or in multiple stages.

6.4.1.3 General Purpose (pre-filter) Coalescing Filters

A general purpose coalescing filter will typically provide particle reduction down to 1 µm and an oil aerosol reduction around 0.5 mg/m^3 / 0.5 ppm (w). A single general purpose filter would be classified as ISO 8573-1:2010 Class 2.-.3.



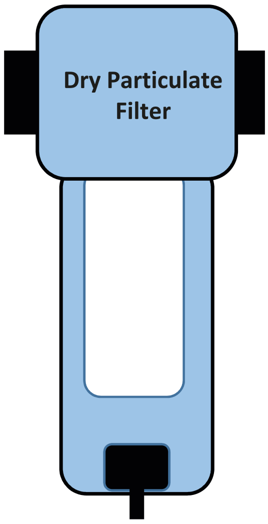
6.4.1.4 High Efficiency Coalescing Filters

When preceded by a general purpose coalescing filter, a high efficiency coalescing filter will typically provide particle reduction down to 0.01 µm and an oil aerosol reduction to around 0.01 mg/m^3 / 0.01 ppm (w). A combination of general purpose (pre-filter) and high efficiency coalescing filters would typically be classified as ISO 8573-1:2010 Class 1.-.2.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Coalescing Filter	✔	✔	✕

6.4.1.5 Dry Particulate Filters



Dry particulate filters are very similar in construction and operation to that of some coalescing filters, however as their name suggests, they are not suitable for the treatment of oil or water aerosols and are therefore installed downstream of the coalescing filters and dryer.

Adsorption dryers use granular desiccant materials and dry particulate filters. These are usually installed on the outlet of such dryers to prevent excessive particulates entering the distribution system.

They will also be installed to protect point-of-use applications from particulate already in the distribution system such as rust and pipe scale and micro-organisms.

A general purpose (pre-filter) dry particulate filter will provide particle reduction down to 1 µm with an efficiency rating around 99.9 per cent typically. A single general purpose(pre-filter) filter would typically be classified as ISO 8573-1:2010 Class 2.-.-.

When proceeded by a general purpose (pre-filter) dry particulate filter, a high efficiency dry particulate filter will provide particle reduction down to 0.01 µm with an efficiency of 99.9999 per cent (limit of accurate measurement) typically. A combination of general purpose(pre-filter) and high-efficiency coalescing filters would be classified as ISO 8573-1:2010 Class 1.-.-.

Important Note:

Although coalescing and dry particulate filters help to reduce the quantity of particulate and micro-organisms in compressed air, they do not remove 100 per cent of these, therefore the compressed air cannot be classified as sterile. For this, a sterile air filter, must be used.

As adsorption dryers can add particulate into the system, the particulate specification provided by a coalescing filter is reduced and should be stated, downstream of the dry particulate after filter.

Purification Equipment	**ISO 8573-1:2010 Classification**
General Purpose (pre-filter) Coalescing Filter	2.-.3
High Efficiency Coalescing Filter	1.-.2
Dryer (-40°C PDP)	-.2.-
Dryer (-40°C PDP) Plus General Purpose (pre-filter) and Dry Particulate Filter	2.2.2

In the example, the coalescing filter combination has provided a classification of ISO 8573-1:2010 Class 1 for particulate however, as the adsorption dryer adds particulate and the outlet dry particulate filter is only down to one micron, the classification changes to ISO 8573-1:2010 Class 2 for particulate.

Should an application require ISO 8573-1:2010 Class 1 particulate, then it is more cost effective to supply this only to the application(s) that need it by installing high-efficiency, dry particulate filters at the point of use (as close to the application a possible or on the equipment or process itself). This also ensures any contamination in the piping system has been reduced and the entire compressed air system has not been over treated.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Dry Particulate Filter	✔	✔	✕

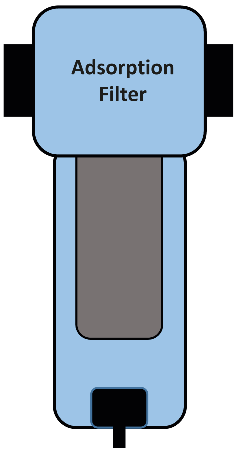
6.4.1.6 Oil Vapour Removal Filters (Activated Carbon Filters)

The previously mentioned stages of filtration will treat liquid water, water aerosols, liquid oil, oil aerosols, and particulate. However, oil vapour will not be removed by these stages, which is often evident by the smell of oil from compressed air.

Oil vapour can cool and condense in the downstream piping and once again, form liquid oil and oil aerosols. Additionally, if the compressed air is to be used for breathing, or will come in to contact with food, beverage, pharmaceutical, specialist electronic products or other such duties, oil vapour reduction must be included.

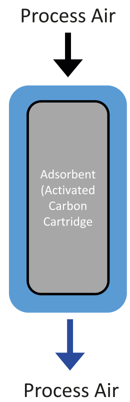
A combination of general purpose (pre-filter) and high-efficiency coalescing filters plus an oil vapour removal filter would typically be classified as ISO 8573-1:2010 Class 1.-.1. Some manufacturers are also able to meet ISO 8573-1:2010 Class 0 for total oil.

Adsorption filters are available in a variety of designs and can be classified into the in-line type, carbon tower and modular system.



In-line oil vapour filters are installed in a similar or identical housing to a coalescing filter. They are usually matched to the pipe size of the system and therefore have a small volume of adsorbent material inside. This requires frequent element changes, maybe even monthly, to achieve the desired air quality continually. This type of filter is best suited for small flow, point-of-use applications, not compressor rooms.

Carbon towers are constructed like air receivers and are loose filled with granular adsorbent material. They offer greater life expectancy of up to twelve months however, due to their loose fill, they can be prone to adsorbent attrition and blockage of downstream dry particulate filters. Due to their large size, carbon towers are usually only installed in the compressor room.



Modular adsorption filters are often smaller than carbon towers and have adsorbent filled cartridges for easy maintenance. Sized to match the inlet conditions of the compressed air system, this type of filter provides up to twelve months' protection.

They are suitable for installation either in the compressor room (for full system protection) or at critical point-of-use applications to ensure that the compressed air is not over treated.

Important Note:

Oil vapour removal filters do not operate in the same manner as coalescing or dry particulate filters (although sometimes they may use the same housings).

Care must therefore be taken when selecting oil vapour removal filters, especially the in-line type, as they are often only matched to the pipe size of the distribution piping and the adsorption bed is not sized for the many parameters that affect lifetime and performance.

A correctly specified oil vapour removal filter will size the adsorption bed to meet system demand, contamination levels and to provide adequate adsorption lifetime.

Always consult with the manufacturer to ensure correct selection.

If only a limited number of applications require ISO 8573-1:2010 Class 1 or Class 0 for total oil, then it is more cost effective to supply this classification to those application(s) that need it, by installing the oil vapour removal filters at the point of use (or as close to the application as possible or on the equipment or process itself). Again, like high-efficiency, dry particulate filters, this ensures the entire compressed air system has not been over treated.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Adsorption Filter	✔	✕	✕

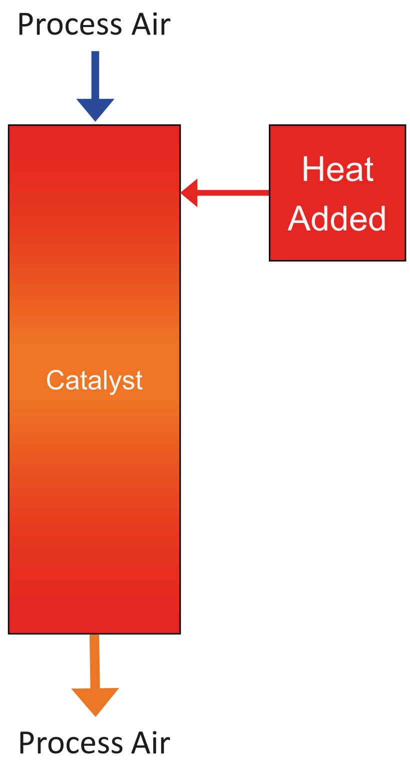
6.4.1.7 Catalytic Converter

Oil is a mixture of hydrocarbon molecules built with various lengths of hydrocarbon chains. A catalytic convertor reduces oil vapour by means of a chemical reaction inside the catalytic converter chamber.

Compressed air is passed over a catalyst material where heat is added. The catalyst uses the heat and oxygen in the compressed air to break down or 'crack' hydrocarbon molecules, which are chemically transferred into water and carbon dioxide.

Regardless of the catalytic conversion process, various heating systems are used:

- Electrical heating system inside the reactor vessel
- Electrical heating system outside the reactor vessel
- Electrical heating system inside the compressed air inlet pipe
- Electrical heating system outside the reactor vessel



Important Note:

To guarantee both chemical cracking of hydrocarbon molecules and to ensure safety, the catalytic converter is temperature controlled. Once the minimum or the maximum temperature value set by the controller is exceeded, the compressed air flow is interrupted by closing the valves.

For 24/7 operation, a full functional bypass or redundant system is mandatory.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Catalytic Convertor	✔	✔	✔

6.4.1.8 Technically Oil-free Air to ISO8573-1 Class 1 and Class 0 for Total Oil

Technically oil-free air can be delivered by both an 'oil-free' or lubricated compressor with the correct purification equipment installed downstream.

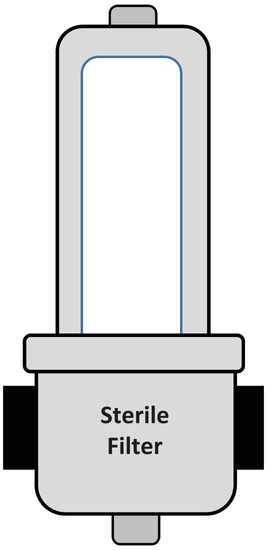
If an application requires air purity (quality) to ISO 8573-1:2010 Class 1 for total oil (down to 0.01 mg/m^3) or ISO 8573-1:2010 Class 0 for total oil (user specified between 0.01mg/m^3 and 0.003mg/m^3), coalescing filters (used for the reduction of oil aerosols) will need to be supported by an additional oil vapour reduction filter. The requirement for water separators, general purpose (pre-filter) and high-efficiency coalescing filters would be identical for both oil-lubricated and oil-free compressor types.

The additional oil vapour removal filter, required to achieve ISO8573-1 Class 1 or Class 0 for total oil, may be slightly smaller on the oil-free compressor installation as it does not need to remove oil vapour added by a lubricated compressor.

A combination of general purpose (pre-filter) and high-efficiency coalescing filters plus an oil vapour removal filter would typically be classified as ISO 8573-1:2010 Class 1.-.1. Some manufacturers are also able to meet ISO 8573-1:2010 Class 0 for total oil.

6.4.1.9 Sterile Air Filters

Micro-organisms in compressed air can be a serious problem. Not normally visible to the naked eye (some can be as small as 0.02 μm), they are drawn into the compressor intake in huge quantities and multiply rapidly in the compressed air system under the right conditions.



The passage of even a few viable organisms into a clean area, process or system causes contamination. This can result in reduced product quality, complete rejection or serious infection.

Some applications, typically in the food, beverage or pharmaceutical industries, require a degree of control over micro-organisms or even sterile compressed air. For this, a combination of dry air (-40°C pressure dewpoint to inhibit the growth of micro-organisms) and point-of-use sterile air filters are used.

The growth of micro-organisms can be controlled, as low compressed air dewpoints are known to inhibit the growth of micro-organisms. For example, the BCAS Food and Beverage Grade Compressed Air Best Practice Guideline 102 recommends a pressure dewpoint of -40°C for direct contact applications or indirect applications where micro-organisms may still present a risk.

By controlling the multiplication or growth of micro-organisms in the compressed air system, high-efficiency, dry particulate filters can be used to remove almost all as a particulate. For critical applications needing 100 percent particulate removal and applications that require sterile compressed air, sterile air filters can also be used.

The benefit of these filters is that they not only provide sterile compressed air, but they are designed such that they can be sterilised in place with steam.

Unlike standard coalescing and dry particulate filters, sterile air filters are usually of the sieve-retention membrane type. They provide absolute removal of particulates and micro-organisms and the housing and element design and construction materials allow for the entire system to be steam sterilised using 'Steam in Place' (SiP) techniques.

Important Note:

Coalescing and dry particulate filter performance will include an efficiency rating typically. This is because they are 'mechanical' filters and are unable to remove 100 per cent of the incoming contaminant. The higher the concentration of inlet contamination, the greater the contaminant carryover downstream. For critical applications where 100 per cent particulate or micro-organism removal is required, a sieve retention membrane filter is normally used. This is not a normal requirement for most compressed air systems or applications. The life expectancy of a sterile filter can be impacted by temperature and the number of sterilisation cycles.

On this type of filter, energy is consumed through:

Filter Type	Initial Pressure Drop	Pressure Drop as Filter Blocks During Operation	Electrical Energy for Heaters
Sterile Air Filter	✔	✔	✕

6.4.2 Energy Consumption Associated with Filtration

In a compressed air filter, pressure losses are created from a combination of fixed pressure loss and incremental pressure loss. Fixed pressure losses are designed into the filter from the outset and transfer from the filter housing and element endcap designs.

Many manufacturers offer filters with flow management built into the design and while a little more expensive to purchase, they offer significant savings when in operation.

Incremental pressure losses on the other hand come from the filter element as its starts operating.

Pressure loss in compressed air purification equipment is often stated as differential pressure (dp).

Coalescing filter technical specifications will tend to show both a dry differential pressure and/or a wet or saturated differential pressure. The dry dp figure can be largely ignored. This is due to the way coalescing filters 'wet out' with oil and water aerosols.

Important Note:

If the dp of a coalescing filter does not indicate the differential pressure as wet or saturated, then clarification should be sought from the manufacturer.

Technical specifications for dry particulate filters will only have a dry differential pressure, as oil and water aerosols will have already been removed.

To reduce pressure losses while ensuring the high levels of compressed air purity (quality) required by many industrial applications, a combination of filters is often used. The combination of a general purpose (pre -filter) and high-efficiency filter is common practice, as the general purpose (pre-filter) filter protects the fine media of the high-efficiency filter from contaminant carryover, rapid blockage, high pressure losses and frequent element changes.

6.4.3 Calculating Energy Consumption and Operational Costs

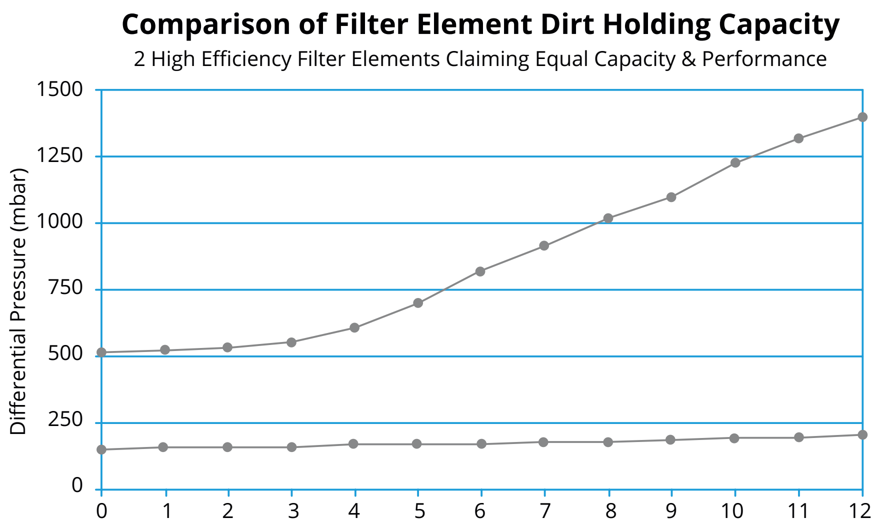
It is worth noting that manufacturers performance data for differential pressure will be indicative of a filter in an 'as-new' condition and this data should therefore not be used to calculate operational costs.

As coalescing and dry particulate filters operate, they capture atmospheric particulate, rust, pipe scale and micro-organisms, resulting in a more tortuous path for the compressed air as it passes through the filter media. This progressively increases the differential pressure across the filter, the longer the filter is used.

Instead, for a more accurate indication of potential operational costs, the blockage characteristics (dirt holding capacity) of the filter should be used (if available) as this provides an indication as to the filter's dirt holding capacity.

The graph below (highlighting differential pressure over time) demonstrates a comparative test of two high-efficiency coalescing filters with equal claims of flow capacity and performance. The filters are first wetted out for 24 hours with oil aerosol (in accordance with ISO 12500-1) and then tested with twelve equal amounts of particulate to simulate twelve months of operation. (See Fig 14.)

(Fig 14.)



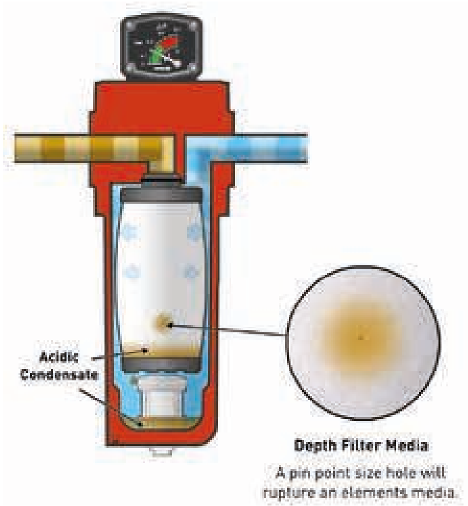
While the initial performance of the two filters may look similar or identical (both quoted 200mbar wet dp) in literature, the testing indicates that one filter has an element with a higher dirt-holding capacity than the other and, would therefore have lower operational costs.

6.4.3.1 Filter Element Changes

Coalescing and dry particulate filters may have a dp gauge or dp monitor fitted and it is often assumed, incorrectly, that this is an accurate, calibrated instrument which should be used to indicate when a filter element requires changing.

Compressed air filters are installed for contamination reduction and there are many factors which affect their performance and therefore the lifetime of the filter element.

Differential pressure gauges or indicators should not be used solely to indicate when to change a filter element, and they should only be used to indicate premature blockage of the filter element.



Important Note:

This type of indicator/gauge/monitor will not indicate the true blockage state of a filter element in low flow conditions, such as varying shift patterns, or when used with a variable speed compressor. More importantly it will show little or no movement if an element has been left in too long and has ruptured, effectively allowing all the contamination to travel downstream.

To ensure both the air quality and energy efficiency of the original filter is maintained, filter elements should always be changed in accordance with the manufacturer's recommendations and only proprietary parts should be used.

6.4.3.2 Point-of-Use Filters and Pressure Loss

Point-of-use filters are necessary for almost all compressed air systems. They deal with the contamination that is already in the distribution piping, such as rust, pipe scale, particulates, oil vapour and micro-organisms, especially in ageing systems. When it comes to high pressure losses in existing systems, it can often be traced back to point-of-use filtration.

As facilities change or expand, demand for air increases and system pressure subsequently drops.

Compressed air filters must be sized for the minimum system operating pressure. Remember lower pressure equals more air volume which will require a larger filter. Incorrect sizing will result in too great an air flow, which increases pressure losses (dp) significantly, increases costs and results in contamination carryover to the application.

When sizing point-of-use equipment, always check how the pressure changes when equipment is operating. It is not uncommon for pneumatically-operated processes to drop the system pressure significantly when using compressed air. Never size the filtration equipment based upon the compressor discharge pressure.

Correctly sizing a point-of-use filter can save significantly on pressure losses and energy consumption.

6.5 Drying

Many users are unaware just how much water can be produced when operating a compressed air system. Water in a compressed air system is in one of three phases (states) - liquid, aerosol and vapour.

Large volumes of wet atmospheric air are drawn constantly into the compressor intake and following compression and subsequent cooling, the now compressed air exits the compressor after-cooler 100 per cent-saturated with water vapour. As compressed air is stored in the air receiver and travels around the piping network, it cools down, condensing the water vapour into liquid water, which in turn, also forms aerosols or mists of water.

The installation of water separators will reduce the liquid water in the compressed air flow and coalescing filters will reduce the aerosols of water, however, relying on filtration alone for water reduction is simply not enough. If only water separators and filters are installed, the best ISO8573-1 classification possible is Class 6 for water and this classification will only be at the outlet of the final filter. Further condensation and production of liquids and aerosols will occur downstream of the filter and at each point of use. This is the result of rapidly cooling air as it expands.

To reduce water, it requires all three phases (states) to be treated and for water vapour reduction, a dryer is used. Regardless of type, dryers only reduce the water vapour content so pre-filtration is always required.

6.5.1 Dewpoint

A dryer's performance is usually expressed as a pressure dewpoint and represented in either °C or °F. Dewpoint is the temperature at which condensation occurs and in theory, if you reduce the dewpoint below the minimum temperature of the compressed air in the facility, you will see no more condensation occur, and liquid water will be eliminated.

Important Note:

A pressure dewpoint is a measurement taken when the air pressure is above atmospheric pressure (i.e. the pressure of the compressed air system) and will typically be denoted as PDP. Atmospheric dewpoint is a measure of the compressed air after it has been expanded back to atmospheric pressure and will be denoted as ADP.

PDP and ADP for the same compressed air system will be different. For example, a 7-bar g compressed air system with a PDP of -40°C will have an ADP reading of around -57°C. This is because the volume of water remains fixed while the volume of air increases due to expansion (See Fig 15.).

In the past, dewpoint selection was often based upon whether the piping was installed indoors or outdoors, with refrigeration dryers and positive dewpoints selected for internal applications and adsorption dryers for external applications. Today, there are many more critical applications for compressed air, more sensitive equipment using this air and a greater understanding of how dewpoint can control the growth of micro-organisms in the compressed air.

Point-of-use dryers are now very common and allow a cost-effective way to dry compressed air. For example, it is quite common to achieve +3°C dewpoint for general purpose applications and -40°C pressure dewpoint for more important or critical applications.

ISO 8573-1: 2010 Class 1		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	-70	-88
15	-70	-87
14	-70	-87
13	-70	-86
12	-70	-86
11	-70	-85
10	-70	-85
9	-70	-84
8	-70	-84
7	-70	-83
6	-70	-82
5	-70	-81
4	-70	-80
3	-70	-79
2	-70	-77
1	-70	-74
0	-70	-70

ISO 8573-1: 2010 Class 2		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	-40	-63
15	-40	-62
14	-40	-62
13	-40	-61
12	-40	-61
11	-40	-60
10	-40	-59
9	-40	-59
8	-40	-58
7	-40	-57
6	-40	-56
5	-40	-55
4	-40	-53
3	-40	-52
2	-40	-49
1	-40	-46
0	-40	-40

ISO 8573-1: 2010 Class 3		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	-20	-46
15	-20	-46
14	-20	-45
13	-20	-45
12	-20	-44
11	-20	-43
10	-20	-42
9	-20	-42
8	-20	-41
7	-20	-40
6	-20	-39
5	-20	-37
4	-20	-36
3	-20	-34
2	-20	-31
1	-20	-27
0	-20	-20

ISO 8573-1: 2010 Class 4		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	+3	-28
15	+3	-28
14	+3	-27
13	+3	-27
12	+3	-26
11	+3	-25
10	+3	-24
9	+3	-23
8	+3	-22
7	+3	-21
6	+3	-20
5	+3	-18
4	+3	-16
3	+3	-14
2	+3	-10
1	+3	-6
0	+3	3

ISO 8573-1: 2010 Class 5		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	+7	-26
15	+7	-25
14	+7	-25
13	+7	-24
12	+7	-23
11	+7	-22
10	+7	-21
9	+7	-20
8	+7	-19
7	+7	-18
6	+7	-17
5	+7	-15
4	+7	-13
3	+7	-10
2	+7	-7
1	+7	-2
0	+7	7

ISO 8573-1: 2010 Class 6		
System Pressure	Pressure Dewpoint	Atmospheric Dewpoint
bar g	°C	°C
16	+10	-24
15	+10	-23
14	+10	-22
13	+10	-22
12	+10	-21
11	+10	-20
10	+10	-19
9	+10	-18
8	+10	-17
7	+10	-16
6	+10	-14
5	+10	-13
4	+10	-11
3	+10	-8
2	+10	-4
1	+10	0
0	+10	10

6.5.2 Dryer Types

There are many different types of compressed air dryer available (examples are highlighted in this document). While it is known that different technologies deliver different outlet dewpoints (for example, refrigeration dryers typically deliver outlet dewpoints above 3°C and adsorption dryers dewpoints below 0°C), they also differ in the consistency of the outlet dewpoint delivered.

Manufacturers design dryers to deliver either a constant outlet dewpoint (which has little variation), or a dewpoint suppression (which has large dewpoint variations).

6.5.3 Understanding the Difference Between Constant Dewpoint and Dewpoint Suppression

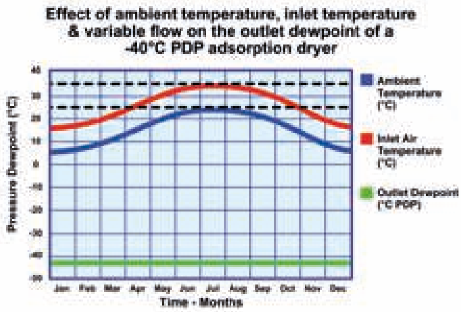
6.5.3.1 Constant Dewpoint

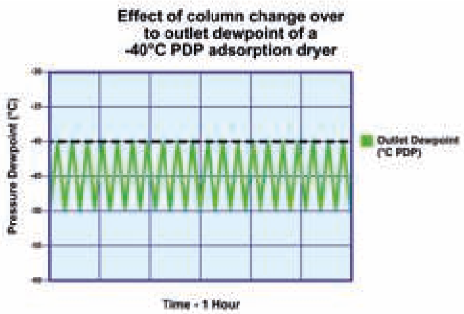
To deliver a constant outlet dewpoint, a dryer is first 'sized' to match worst case inlet and ambient conditions of the user's site (maximum water vapour loading). This ensures the adsorption bed is large enough and capable of handling the maximum water vapour loading of the system while being able to deliver a consistent outlet dewpoint.

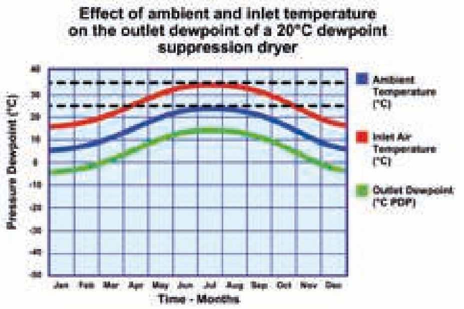
A dryer delivering a constant outlet dewpoint will see small fluctuations but will always deliver a minimum pressure dewpoint.

For example, if an adsorption dryer is selected to deliver a ≤-40°C PDP, then -40°C PDP will be the worst dewpoint delivered.

Typically, the outlet dewpoint will fluctuate between, say, -50°C and -40°C (due to the way the adsorption dryer operates). Initially, dewpoint will be low (-50°C) as compressed air flows over the newly-regenerated adsorbent material after column changeover, dropping towards the minimum acceptable dewpoint (-40°C in this case) as the adsorbent material adsorbs the water vapour in the air. The dryer will change automatically from the active, on-line column to the regenerated column to always achieve the -40°C PDP.







6.5.3.2 Dewpoint Suppression

There are also dryers available that are designed to provide dewpoint suppression. These are typically not sized to match ambient conditions resulting in a smaller amount of adsorption material for drying. The advantage of not sizing for all conditions is that they can be fitted in places where larger, constant dewpoint dryers cannot (for example, railway braking systems). The disadvantage is that the outlet dewpoint delivered by a suppression dryer can vary significantly.

Dewpoint suppression dryers are affected by changes in ambient air temperature and inlet temperature (water vapour loading). If a dryer is designed to provide a dewpoint suppression of -20°C, then it will reduce the dewpoint to 20 degrees below the compressed air temperature (this figure of -20°C should not be confused as a constant outlet dewpoint).

Example: If the ambient temperature in summer is 25°C and the compressed air temperature into the dryer is 35°C, then the dewpoint delivered from a -20°C dewpoint suppression dryer will be +15°C not -20°C.

6.5.3.3 How do I Know if a Dryer is a Constant Dewpoint or a Dewpoint Suppression Dryer?

Manufacturers should always state if their dryer delivers a constant outlet dewpoint or a suppression dewpoint. If in doubt, ask for clarification. Alternatively check if the dryer manufacturer states a dewpoint classification in accordance with ISO8573-1 for water.

Pressure Dewpoint	Dewpoint Band	ISO8573-1:2010 Classification for Water
≤ -70°C PDP	-80°C to -70°C	Class 1
≤ -40°C PDP	-69°C to -40°C	Class 2
≤ -20°C PDP	-39°C to -20°C	Class 3
≤ +3°C PDP	-19°C to +3°C	Class 4
≤ +7°C PDP	+4°C to +7°C	Class 5
≤ +10°C PDP	+8°C to +10°C	Class 6

The ISO8573-1 standard includes six dewpoint classifications, in bands from -70°C to +10°C and to comply with an ISO8573-1 classification, a dryer must always deliver the outlet dewpoint within the band of the chosen classification.

A constant outlet dewpoint dryer will typically state an ISO8573-1 classification, as the dewpoint can clearly fall within a defined band, whereas a dewpoint suppression dryer typically does not state an ISO8573-1 classification as the outlet dewpoint varies too greatly.

Dewpoint is the easiest compressed air contaminant to measure and a dryer fitted with a dewpoint hygrometer or a separate dewpoint hygrometer fitted downstream of the dryer will allow the user to verify easily that the dryer is delivering the agreed outlet dewpoint.

For critical applications, for example those with direct contact between compressed air and manufacturing equipment, products or packaging in the food, beverage, pharmaceutical, cosmetic, and electronic industries, where water vapour reduction and control over the growth of micro-organisms are of extreme importance, a constant outlet dewpoint dryer will inhibit the growth of micro-organisms.

Important Note:

Once the required pressure dewpoint (air quality) has been selected, it is then a case of selecting the best technology to provide that dewpoint. All compressed air dryers have their own advantages and disadvantages and there is not currently one single technology that is suitable for every system and application.

6.5.4 Refrigerated Air Dryer Technologies

6.5.4.1 Refrigerated Air Dryers (+3°C/+7°C/+10 °C Pressure Dewpoints)

Refrigeration dryers cool the compressed air causing condensation of the water vapour into liquid water and then, use a built-in water separator to remove that liquid. The dewpoint of a refrigeration dryer is dictated by its ability to cool the air to the desired dewpoint temperature and then the efficiency of the liquid removal separator. If the dewpoint temperature cannot always be achieved and/or the liquid separation is not always 100 percent efficient, for example in varying flow conditions, then the dewpoint cannot be guaranteed.

Typical pressure dewpoints quoted for refrigeration dryers are +3°C / +7°C / +10°C. These are always above freezing to prevent the condensed liquid water from freezing within the dryer. Refrigeration dryer dewpoints will provide the following ISO 8573-1:2010 classifications for water when general purpose (pre-filter) and high-efficiency coalescing filters are included. (See Fig 16.)

Additional filtration before and after the refrigerant dryer may be required to meet the ISO 8573-1 purity (quality) standards for particulate and total oil.

(Fig 16.)

Pressure Dewpoint	Dewpoint Band	ISO8573-1:2010 Classification for Water
≤ +3°C PDP	-19°C to +3°C	Class 4
≤ +7°C PDP	+4°C to +7°C	Class 5
≤ +10°C PDP	+8°C to +10°C	Class 6

Important Note:

As explained previously, refrigeration dryers are not always able to provide a consistent outlet pressure dewpoint and the classifications shown above are to be viewed as best-case only.

On- board measurement devices are usually temperature probes and therefore do not measure actual pressure dewpoint.

For accurate measurement of dewpoint, a downstream hygrometer should always be used. See ISO 8573-3.

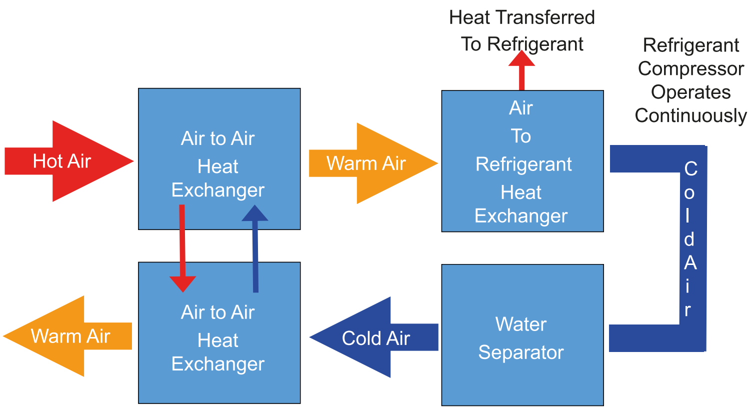
6.5.5 Refrigeration Dryer Types

Refrigeration dryers consume energy through pressure drop, through electricity for the refrigeration compressor and via condenser fans or chillers and pumps on water-cooled variants. Below is an overview of the types of refrigeration dryers available.

6.5.5.1 Direct Expansion Refrigeration Dryers

Direct expansion dryers are the most common type of refrigeration dryer. The refrigerant compressor is running constantly and of the three main types of refrigeration dryer, can be the costliest to run.

However, although refrigeration dryer dewpoints can vary in line with ambient temperatures and system demand, direct expansion dryer dewpoints are often more stable than, for example, those delivered by a thermal mass dryer.

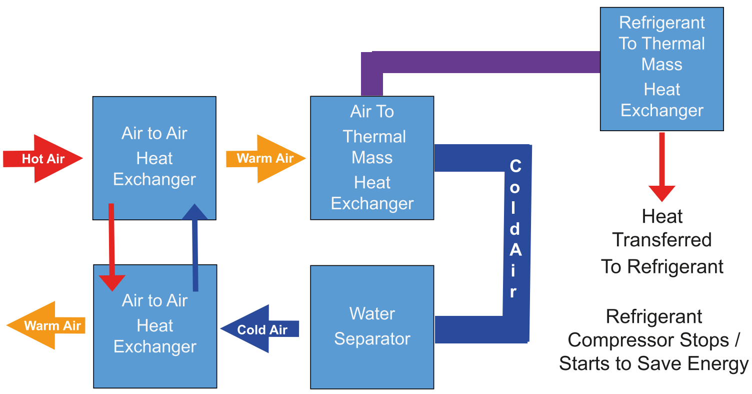


On this type of dryer, energy is consumed through:

Refrigeration Dryer Type	Pressure Drop	Electrical Energy for Refrigeration Compressor	Electrical Energy for Air Cooled Condenser	Electrical Energy for Thermal Mass Water / Glycol Pump	Electrical Energy for Water Cooled Condenser Pump	Electrical Energy for Water Chiller
Direct Expansion	✔	✔	✔	✕	Optional	Optional

6.5.5.2 Thermal Mass Refrigeration Dryers

Unlike direct expansion dryers that have a direct heat exchange between the air circuit and the refrigerant circuit, as their name suggests, thermal mass dryers have a large mass, typically a glycol/water tank or sand, which is cooled by the refrigeration circuit. The heat exchange with the compressed air then takes place between the air circuit and the thermal mass.



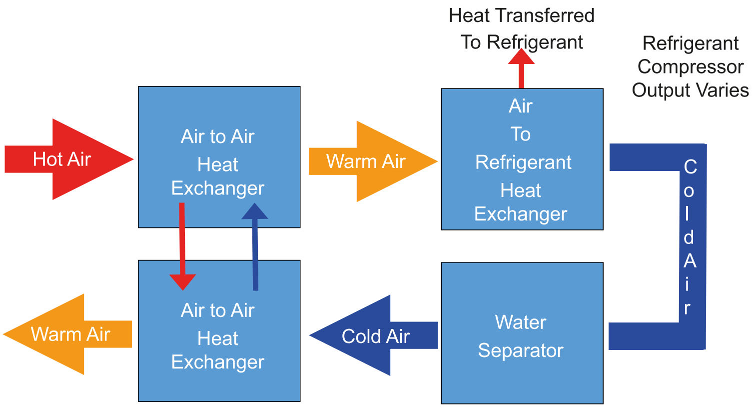
Once the thermal mass has been cooled, the refrigeration compressor can be switched off to save energy. While the energy saving is positive for this type of dryer, the refrigeration compressor is limited to a small number of stop/start sequences per hour to ensure compressor longevity. This means that as air demand or temperature increases, the thermal mass temperature rises and if the refrigeration compressor is unable to come online, then the dewpoint of the compressed air will also increase. For this reason, thermal mass dryers are associated typically with fluctuating dewpoints.

On this type of dryer, energy is consumed through:

Refrigeration Dryer Type	Pressure Drop	Electrical Energy for Refrigeration Compressor	Electrical Energy for Air Cooled Condenser	Electrical Energy for Thermal Mass Water / Glycol Pump	Electrical Energy for Water Cooled Condenser Pump	Electrical Energy for Water Chiller
Thermal Mass	✔	✔	✔	✔	Optional	Optional

6.5.5.3 Variable Speed Refrigerant Dryer

This type of refrigeration dryer uses invertor technology to vary the speed of the refrigeration compressor to match the cooling requirements of the dryer to the water vapour loading of the incoming compressed air. While such technology can be more energy efficient than an equivalent direct-expansion dryer, the cost of the inverter technology and complexity means it is often only available for larger compressed air flows. Dewpoint can still be variable due to the efficiency of the liquid separation device at all flow conditions.



On this type of dryer, energy is consumed through:

Refrigeration Dryer Type	Pressure Drop	Electrical Energy for Refrigeration Compressor	Electrical Energy for Air Cooled Condenser	Electrical Energy for Thermal Mass Water / Glycol Pump	Electrical Energy for Water Cooled Condenser Pump	Electrical Energy for Water Chiller
Variable Speed	✔	✔	✔	✕	Optional	Optional

Important Note:

Refrigeration dryers have been in use for many years and are probably the most widely used type of dryer, usually giving few problems in service if properly installed and maintained. However, problems do occur which can affect performance, and hence energy consumption.

These include:

- Poor dewpoint due to internal contamination. Pre-filtration is always required
- High inlet air temperatures
- Poor ventilation in the compressor room
- Dirty condensers
- Faulty condensate drains allowing the passage of the condensed liquids downstream of the dryer
- Loss of refrigerant

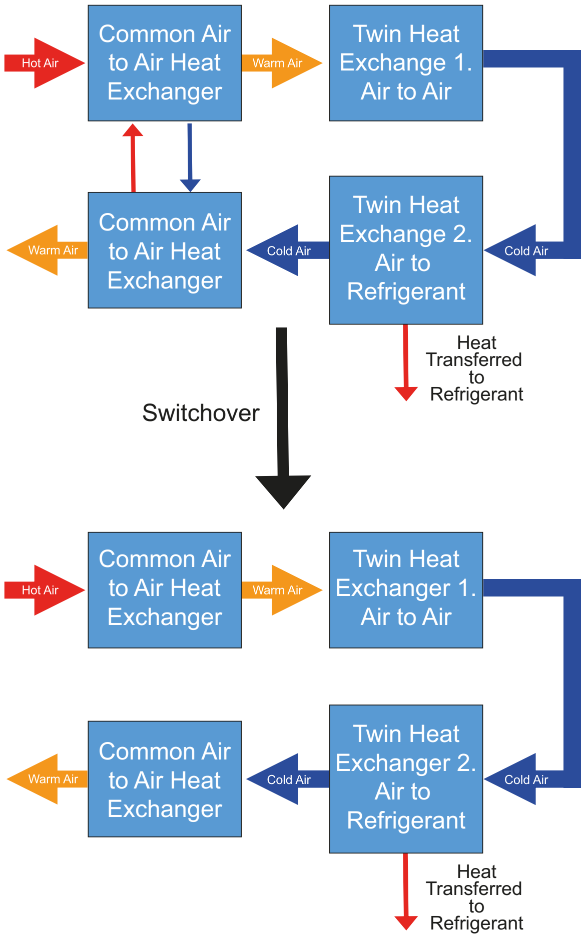
6.5.5.4 Regenerative Refrigerant Dryers

Regenerative refrigerant dryers use a refrigerant circuit and a saturation/regeneration cycle to provide -20 deg C (PDP) air quality for water content.

They do not waste compressed air or use any external heat for regeneration, which reduces the energy consumption.

The energy consumption will be slightly higher than traditional refrigerated direct expansion dryers operating at +3 ^{0}C (PDP) and higher.

ISO 8573-1 2010 class 3 classification for water Is possible with this type of refrigerant dryer.



Operation

Three different heat exchangers will ensure the performance while maximizing the air-to-air heat exchange to reduce energy usage.

The first drying takes place in the common pre-cooler/re-heater where the incoming air is cooled/dried by the outgoing air, with heat exchanger in the middle.

The still warm incoming air is used to regenerate the heat exchanger that has frost build-up from the previous cycle regeneration.

The air is routed to the third heat exchanger where it reaches the -20 deg C PDP.

Exiting the dryer, the air is re-heated in two stages via the upper portion of the working heat exchanger and the first common pre-cooler/re-heater.

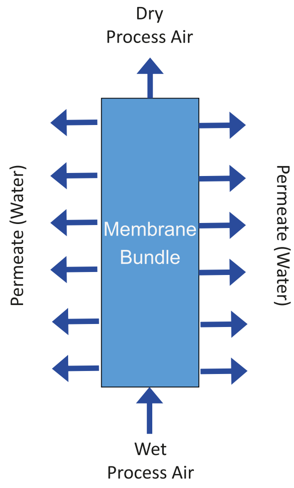
As the third heat exchanger is saturated with frost, the cycle will switchover and the air flow will be redirected so that the freshly-regenerated heat exchanger will now dry and the saturated heat exchanger will be regenerated.

On this type of dryer, energy is consumed through:

Refrigeration Dryer Type	Pressure Drop	Electrical Energy for Refrigeration Compressor	Electrical Energy for Air Cooled Condenser	Electrical Energy for Thermal Mass Water / Glycol Pump	Electrical Energy for Water Cooled Condenser Pump	Electrical Energy for Water Chiller
Regenerative Refrigeration	✔	✔	✔	✕	Optional	Optional

6.5.6 Membrane Dryers (Dewpoint Suppression)

This type of dryer uses hollow-fibre membranes, which diffuse the moisture from the compressed air to atmosphere. To remove the permeated moisture from the membrane they generally require a constant flow of compressed air called 'sweep air.' Where permanent sweep is used these units can use up to 50 per cent of the dryer-rated capacity. Where this is uneconomical, there is also a version with sweep air switch. Three versions are explained below.



There are three derivatives of membrane dryers:

1. **Membrane dryers with permanent sweep air consumption**
   These are for general purpose (pre-filter), with no energy-saving potential.

2. **Membrane dryers with a sweep air switch**
   These adjust sweep air flow either to match compressor operation or application duty.

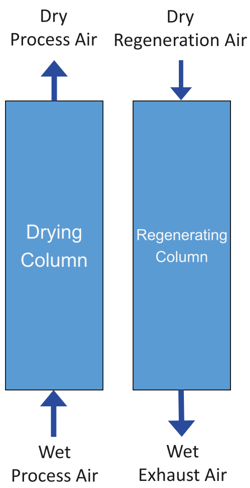
3. **Membrane dryers with variable sweep air control**
   These provide dewpoint suppression at constant and/or various operating conditions. They can also provide a constant pressure dewpoint regardless of fluctuating operating conditions. The lowest pressure dewpoint available is -26°C.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air Purge	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Refrigeration Circuit
Membrane	✔	✔	✕	✕	✕	✕

6.5.7 Adsorption (Desiccant) Dryers (-20°C/-40°C/-70°C Pressure Dewpoint)

When lower dewpoints are required than those which can be achieved from refrigerated air dryers, adsorbent (desiccant dryers) are used.



The basic principle of an adsorbent dryer is to pass compressed air saturated with water vapour (not liquid or aerosols) over a bed of adsorbent desiccant material. The longer the air is in contact with the desiccant, the drier the air becomes. This is known as contact time.

The desiccant material can only adsorb a certain amount of moisture before becoming saturated and therefore it must be regenerated if a constant dewpoint is to be supplied.

Two pressure vessels, also referred to as chambers or columns, are employed; one to dry the process air while the other is being regenerated. At a pre-set time, the vessel being regenerated will be re-pressurised and brought on stream to ensure a constant dewpoint and pressure is always maintained. While the process of drying is identical for all adsorption dryer types, they vary in the method and technology used to regenerate the adsorbent desiccant material.

Important Note:

Adsorption dryers will only remove water vapour and require adequate pre-filtration. This can be in the form of water separators, if liquids are present and general purpose (pre-filter) coalescing filters and high-efficiency coalescing filters for oil and water aerosols, rust, pipe scale and micro-organisms. Failure to remove these contaminants before the dryer will damage the adsorbent material and result in loss of dewpoint.

Typical pressure dewpoints quoted for adsorption dryers are -70°C/-40°C/-20°C. Adsorption dryer dewpoints will provide the following ISO 8573-1:2010 classifications for water when general purpose (pre-filter) and high-efficiency coalescing filters and general purpose (pre-filter) dry-particulate filters are included. See (Fig. 17).

(Fig. 17.)

Pressure Dewpoint	Dewpoint Band	ISO8573-1:2010 Classification for Water
≤ -70°C PDP	-80°C to -70°C	Class 1
≤ -40°C PDP	-69°C to -40°C	Class 2
≤ -20°C PDP	-39°C to -20°C	Class 3

6.5.7.1 Adsorption (Desiccant) Dryer Types

Adsorption dryers consume energy through pressure drop and the methods used for regeneration of the desiccant material. The regeneration methods can consume energy in the form of purge air taken from the process air, cooling air again taken from the process air or from the ambient air and direct electrical requirements for heaters, blowers or vacuum pumps. Below is an overview of the different types of adsorption dryers currently available.

- **Adsorption (Desiccant) Dryers**
    - Heatless Regeneration
        - Standard Heatless Regeneration
        - Heatless Vacuum Assisted
    - **Heat Regenerated**
        - Internally Heated Purge
        - Externally Heated Purge
        - Blower Regeneration
        - Vacuum Regeneration
- **Tandem (Hybrid) Technology**
- **Heat of Compression Dryers**

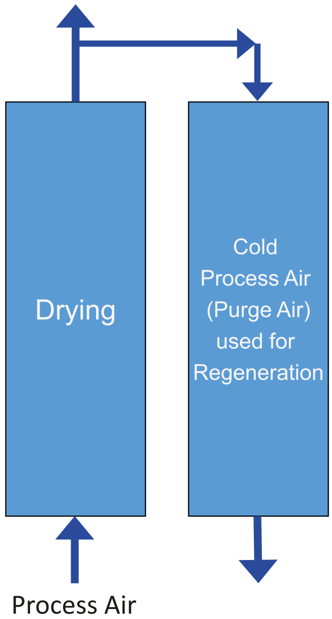
6.5.7.2 Adsorption (Desiccant) Dryers – Standard Heatless Regeneration

The simplest, and most commonly used type of adsorption dryer is the heatless dryer. It has typically the lowest capital costs of all adsorption dryer types and due to its simplicity, the lowest maintenance cost.

Heatless dryers are available to suit all compressed air flow rates from small to large, whereas the more complicated regeneration methods are often only found on higher flow rates due to cost.

The basic principle of a heatless dryer is that it takes a small proportion of the dry process air, known as purge air, expands this purge air back to atmospheric pressure where it becomes even drier and then passes it over the off-line desiccant bed undergoing regeneration. The dry air strips the moisture from the desiccant material.

After a pre-set time, the exhaust valve will close, and the purge air will re-pressurise the off-line vessel. Following re-pressurisation, the vessels will changeover and the process air flow will be redirected over the newly-regenerated desiccant bed, allowing the wet material to be regenerated.



On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Sweep)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Refrigeration Circuit
Heatless	✔	✔	✕	✕	✕	✕

Important Note:

Purge air is often expressed as a percentage of the dryer's rated inlet flow; however, this can cause confusion for those selecting a dryer. Therefore, users should always refer to the purge volume figure used by a dryer. This will ensure that the actual purge loss is known and can be factored into sizing.

Never rely on average purge loss figures as these are not indicative of actual air loss when the dryer is in its regeneration cycle.

Manufacturer's testing a dryer in accordance with ISO7183, the international standard for the testing of compressed air dryer, should always be able to provide the instantaneous purge loss volume.

It was commonly perceived that the heatless dryer was very inefficient and therefore other regeneration technologies were developed to reduce energy consumption. However, it should be noted that many manufacturers can now install energy saving technology on to the heatless dryer, which optimises the drying and regeneration cycles to match the incoming water vapour loading precisely and significantly reduce air loss and energy consumption.

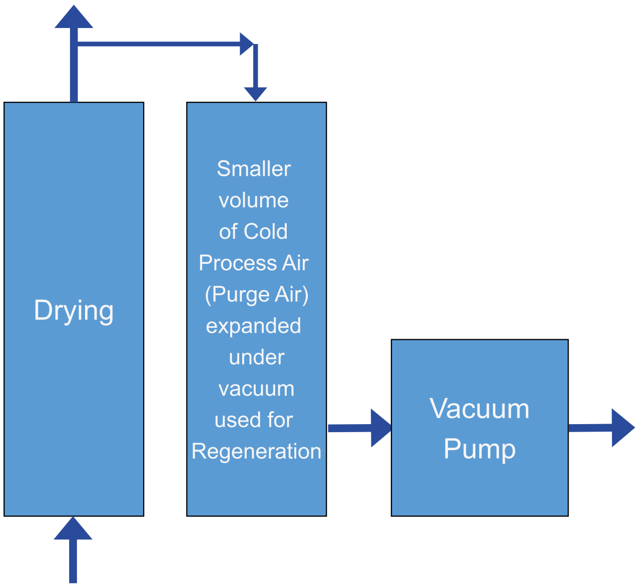
Heatless regeneration, when fitted with energy saving controls still offers a very competitive total cost of ownership.

6.5.7.3 Adsorption (Desiccant) Dryers – Heatless Vacuum Assisted

Heatless dryers are very robust and reliable and have the added benefit that they do not use heat for regeneration. If heat is added, cooling of the bed must also be carried out to maintain outlet dewpoint.

One method to reduce the energy consumption of the heatless dryer is to install a vacuum pump to assist the purge.

Purge is typically three – five per cent of the dryer's literature reference conditions. The energy reductions from reducing the purge air offset the energy required to operate the vacuum pump and still provide significant energy savings overall.



On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Electrical Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Heatless Vacuum Assist	✔	✔	✕	✕	✕	✔	✕

6.5.8 Heat

The remaining technologies all use heat to assist regeneration, however it should be noted that by adding heat, cooling is also required, and some technologies require specific ambient conditions to operate efficiently.

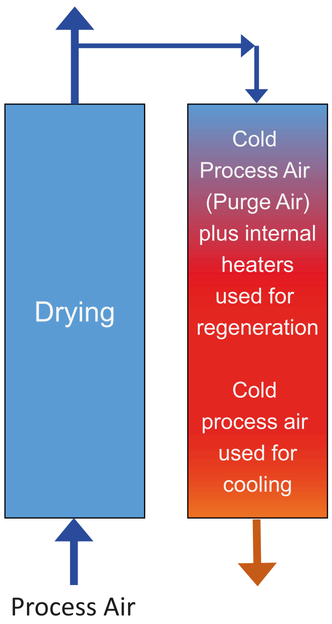
6.5.8.1 Adsorption (Desiccant) Dryers – Internally-Heated Purge

One way to reduce energy consumption from purge air is to add heat and reduce the amount of purge air used.

Internally heated purge dryers reduce the purge percentage to around 7.5 per cent and then heat this purge air to around 200°C. The heaters are located inside the drying vessel.

This heated purge air regenerates the desiccant material in a similar way to the heatless dryer. Heat however, although helping with regeneration, significantly reduces the adsorption capacity of the desiccant material. If the dryer was to change over with the desiccant material at an elevated temperature, the desiccant would not adsorb the incoming water vapour and outlet dewpoint would be lost.

Therefore, before changeover, the desiccant must be cooled. So, at a pre-set time, heaters are switched off and the purge air cools the desiccant material to a usable temperature.



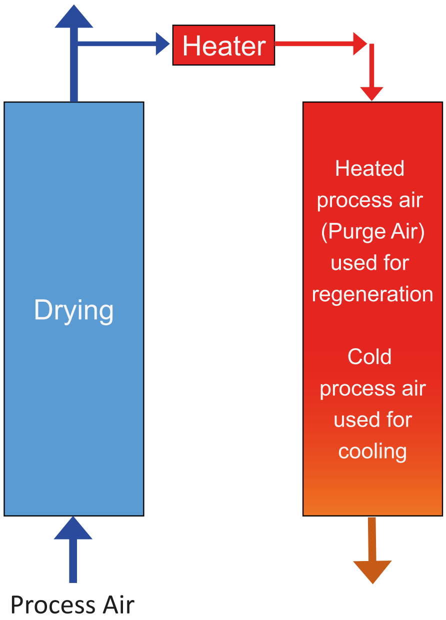
On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Internally Heated Purge	✓	✓	✕	✓	✕	✕	✕

6.5.8.2 Adsorption (Desiccant) Dryers – Externally-Heated Purge

These are very similar in principle to the internally-heated purge dryers; however, the heater is located externally to the pressure vessels.

Purge percentage for this technology is around 8-10 per cent. As with any dryer using heat, a cooling phase is also included in the operational cycle.



On this type of dryer, energy is consumed through:

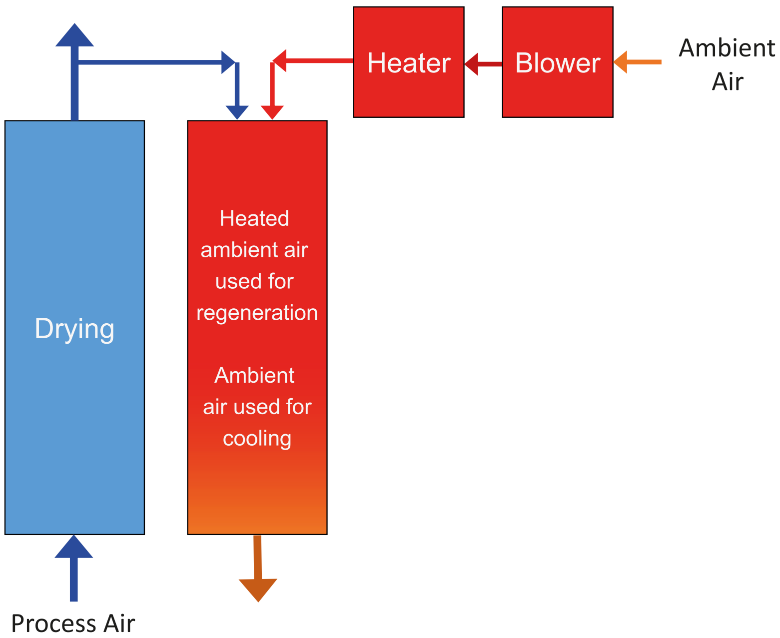
Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Externally Heated Purge	✓	✓	✕	✓	✕	✕	✕

6.5.8.3 Adsorption (Desiccant) Dryers - Blower Regeneration Standard

The ideal for any adsorption dryer is to eliminate the need for process air (purge air) during regeneration and, the principle of the blower dryer is to use ambient air instead of process air.

When the off-line bed has depressurised and is ready to undergo regeneration, a low-pressure blower is used to pass ambient air over a heater and then over the desiccant material requiring regeneration. Once the desiccant has been regenerated, as with any heated dryer, it must be cooled before use.

Turning off the heater alone does not provide sufficient cooling as the blower can add up to 25°C of heat to the ambient air temperature and pushes wet, ambient air back onto the dry desiccant bed. The solution is to use a proportion of the process air for cooling.



Ambient air temperature is very important and adequate ventilation is required at the point of installation.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Blower Regeneration	✔	✕	✔	✔	✔	✕	✕

Important Note:

Unlike heatless and heated purge dryers that use clean, dry process air, blower dryers use contaminated ambient air, which can, in some instances, contaminate the desiccant bed and be carried downstream on changeover.

Blower dryers are available with a fixed outlet dewpoint or with dewpoint suppression. Always check with the manufacturer.

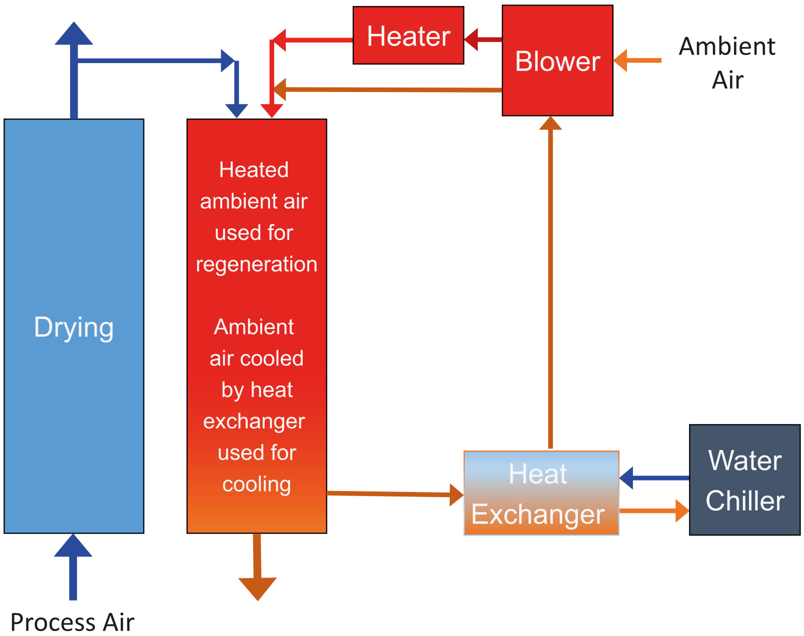
There are many variants of blower regeneration technology available on the market today. You are advised to speak to a BCAS member for further information.

6.5.8.4 Adsorption (Desiccant) Dryers – Blower Regeneration – Closed Loop

The closed loop blower dryer also uses the ambient air for regeneration of the desiccant material, but not for the cooling of the desiccant material.

For cooling, the heater is switched off and the air generated by the blower is now passed through a water-cooled heat exchanger to reach the required cooling temperature.

Once cooled, the air is passed over the desiccant material and then directed back through the water-cooled heat exchanger for cooling and moisture removal. Closed loop dryers are often used for installations with high ambient air temperatures and relative humidity.



Unlike heatless and heated purge dryers that use clean, dry process air, blower dryers use contaminated ambient air, which can, in some instances, contaminate the desiccant bed and be carried downstream on changeover.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Blower Regeneration	✓	✕	✓	✓	✓	✕	✕

6.5.8.5 Adsorption (Desiccant) Dryers – Blower Regeneration – Ambient Air Cooled

Blower dryers are also available that do not consume process air for cooling or require a closed loop cooling system. Outlet dewpoint performance of these derivatives is subject to ambient conditions and may deliver dewpoint suppression.

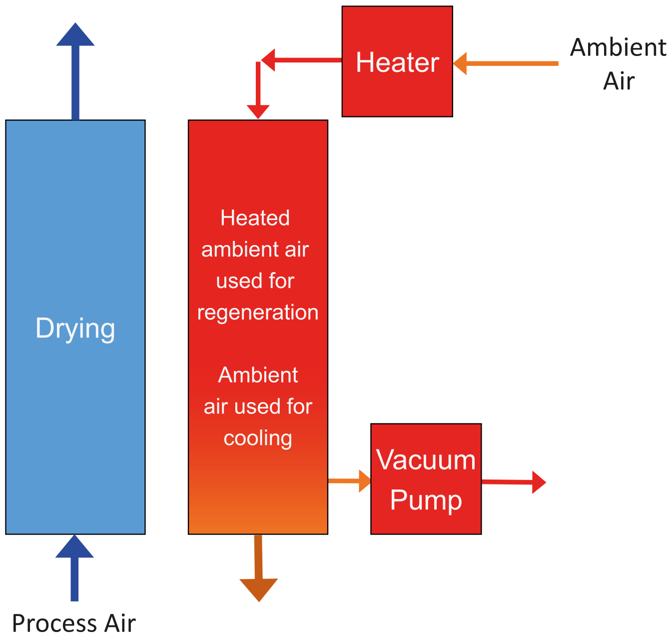
Unlike heatless and heated purge dryers that use clean, dry process air, blower dryers use contaminated ambient air, which can, in some instances, contaminate the desiccant bed and be carried downstream on changeover.

These dryers are available with a fixed outlet dewpoint or with dewpoint suppression. Always check with the manufacturer. Also, reference the ISO class to ascertain how long it will take for this to be achieved.

6.5.8.6 Adsorption (Desiccant) Dryers – Vacuum Regeneration

Vacuum regeneration dryers operate on a similar principle to the blower dryer. However, instead of using a blower that pushes ambient air through a heater and over the desiccant bed, it uses a vacuum pump to pull the ambient air over the heater and then over the desiccant bed.

This is particularly beneficial when the bed requires cool down, as any heat generated by the vacuum pump is vacated via the vacuum pump exhaust, meaning it is not added to the ambient air being used for regeneration. Typically, switching off the heater is enough to cool the desiccant bed.



Important Note:

Except in tropical conditions or for extremely low, specialist dewpoints, vacuum regeneration dryers typically do not require any process air for cooling and could be classified as 'zero purge' dryers.

Should an installation have steam, hot water, gas or hot oil on site, the electrical heat exchanger can be replaced with an alternative heat exchanger to further reduce energy consumption.

Ambient air temperature is important and adequate ventilation is required at the point of installation.

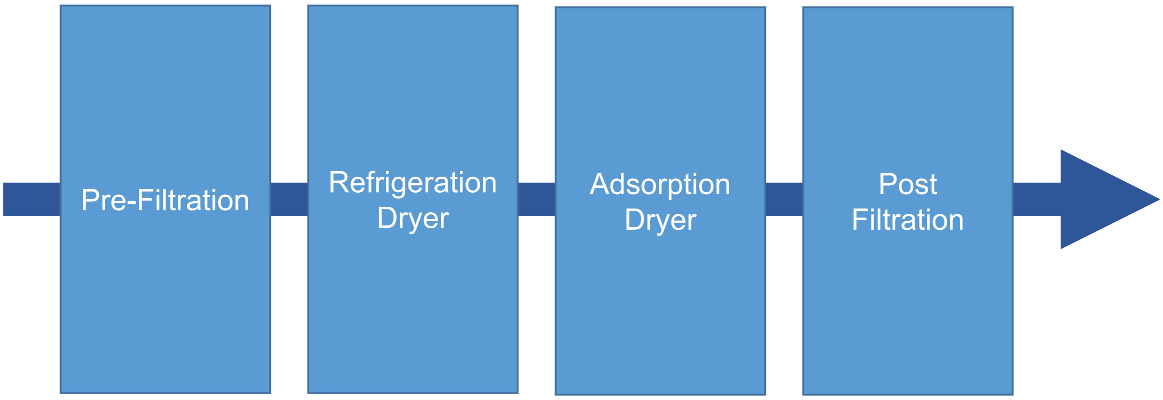
Unlike heatless and heated purge dryers that use clean, dry process air, vacuum regeneration dryers use contaminated ambient air which can in some instances contaminate the desiccant bed and be carried downstream on changeover.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Vacuum Regeneration	✓	✕	✕	✓	✕	✓	✕

6.5.9 Tandem (Hybrid) Technology Dryers

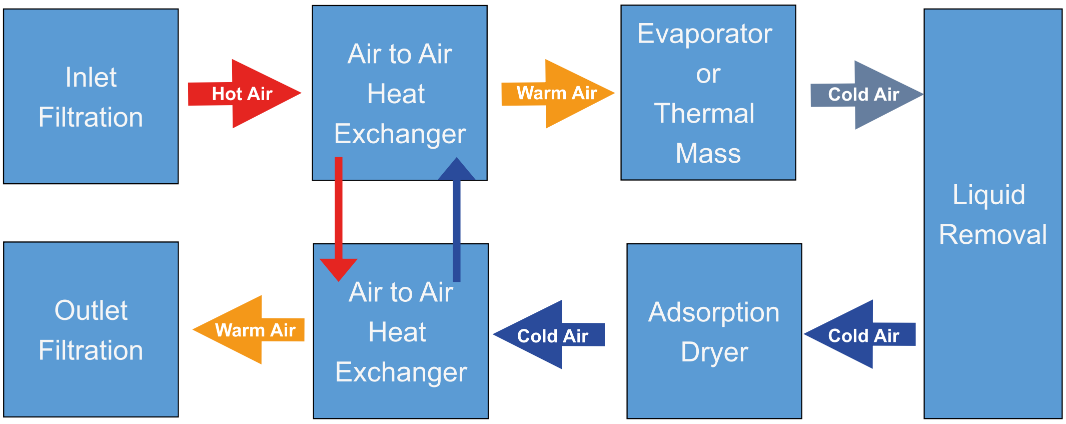
Basic Principle of the Tandem (Hybrid) Dryer



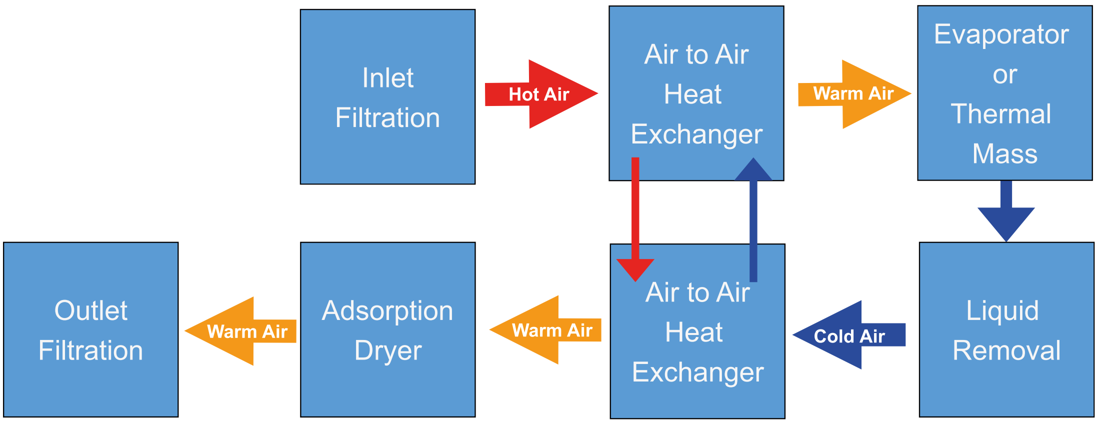
Tandem (hybrid) dryers are available in many variations depending on the manufacturer.

Below are two block diagrams showing the function of the typical tandem (hybrid) dryers available:

Block Diagram of a Typical Tandem (Hybrid) Dryer #1



Block Diagram of a Typical Tandem (Hybrid) Dryer #2



Tandem or hybrid-type dryers use a combination of technologies to reduce energy consumption.

The compressed air is first pre-dried to a pressure dewpoint of around 5°C by a refrigeration dryer.

However, unlike a traditional refrigeration dryer that cools the air, removes the liquid water and then re-heats the outgoing air, the compressed air is filtered with a high efficiency coalescing filter to remove aerosols. The still 100 per cent saturated compressed air is then passed through a reduced size adsorption dryer where the final dewpoint is achieved.

The adsorption dryer size is also smaller as the incoming water vapour level has already been reduced by the refrigeration dryer. As the adsorption dryer bed size is reduced, so is the volume of desiccant requiring regeneration. Purge percentage is around five percent of the dryer's specified conditions however, regeneration times are reduced, saving energy.

The adsorption dryer is typically an externally-heated purge type and, as with a standard external heated purge dryer, has heaters both on-phase for regeneration and off-phase for cooling.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Process Air (Purge)	Process Air (Cooling)	Electrical Energy for Heater	Electrical Energy for Blower	Electrical Energy for Vacuum Pump	Electrical Energy for Refrigeration Circuit
Hybrid (Tandem)	✓	✓	✗	✓	✗	✗	✓

Important Note:
A benefit of this type of dryer is that the adsorption dryer may be bypassed in summer conditions to reduce energy further, as the dewpoint will only be around 5°C. However, bypassing the adsorption dryer is not recommended in food, beverage or pharmaceutical applications as the positive dewpoint will no longer inhibit the growth of micro-organisms.

6.5.9.1 Heat of Compression Dryers (HOC)

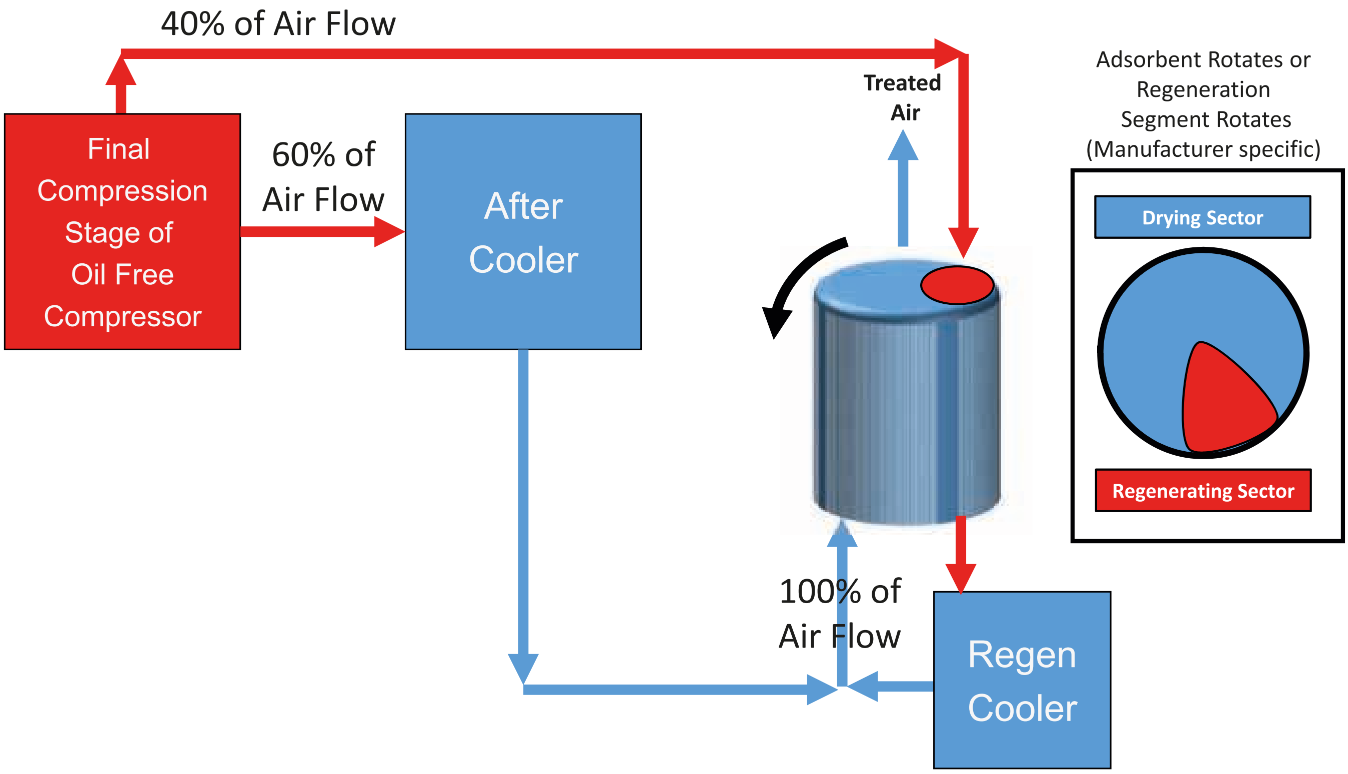
Oil-free compressors operate at higher internal temperatures typically to oil-lubricated machines and some models can be supplied fitted with heat-of-compression dryers. Unique to oil-free compressors, they use the hot compressed air (before after-cooling) to regenerate the off-line desiccant material. The construction of HOC dryers is either the 'drum' type or of the more traditional 'twin tower' type typically, with variations of each being available.

6.5.9.2 Drum Type Heat of Compression Dryers

With this type of dryer, the adsorption material is held in a 'drum'. Unlike typical beaded desiccants, the adsorbent used by a drum is typically paper or another substrate which is impregnated with the adsorbent material. On certain designs, the drum is rotated to allow 'sectors' of the adsorbent to either dry the compressed air or be regenerated. Alternative designs do not rotate the drum, instead, rotating sealed housings top and bottom, again allowing 'sectors' of the adsorbent material to be used for drying or to be regenerated.

6.5.9.3 Standard Drum Dryer (Split Air Flow before Compressor After-Cooler)

On the standard drum dryer, a single regeneration cooler (air-cooled or water-cooled) is used along with the compressor's own aftercooler and these can be air-cooled or water-cooled. After the final compression stage, the flow of hot, wet, compressed air is split. A proportion of the hot air is used in the regeneration sector to regenerate the adsorbent material, while the remaining flow is passed through the compressor aftercooler. The partial flow of hot air is passed through the regeneration 'sector' where it picks up moisture from the adsorbent material. The air is then directed through a regeneration cooler where the air is cooled, allowing condensation and liquid removal to take place. The air from the regeneration cooler is now re-combined with the air that was passed through the aftercooler prior to being passed into the drying sector. The dried compressed air then exits the dryer.

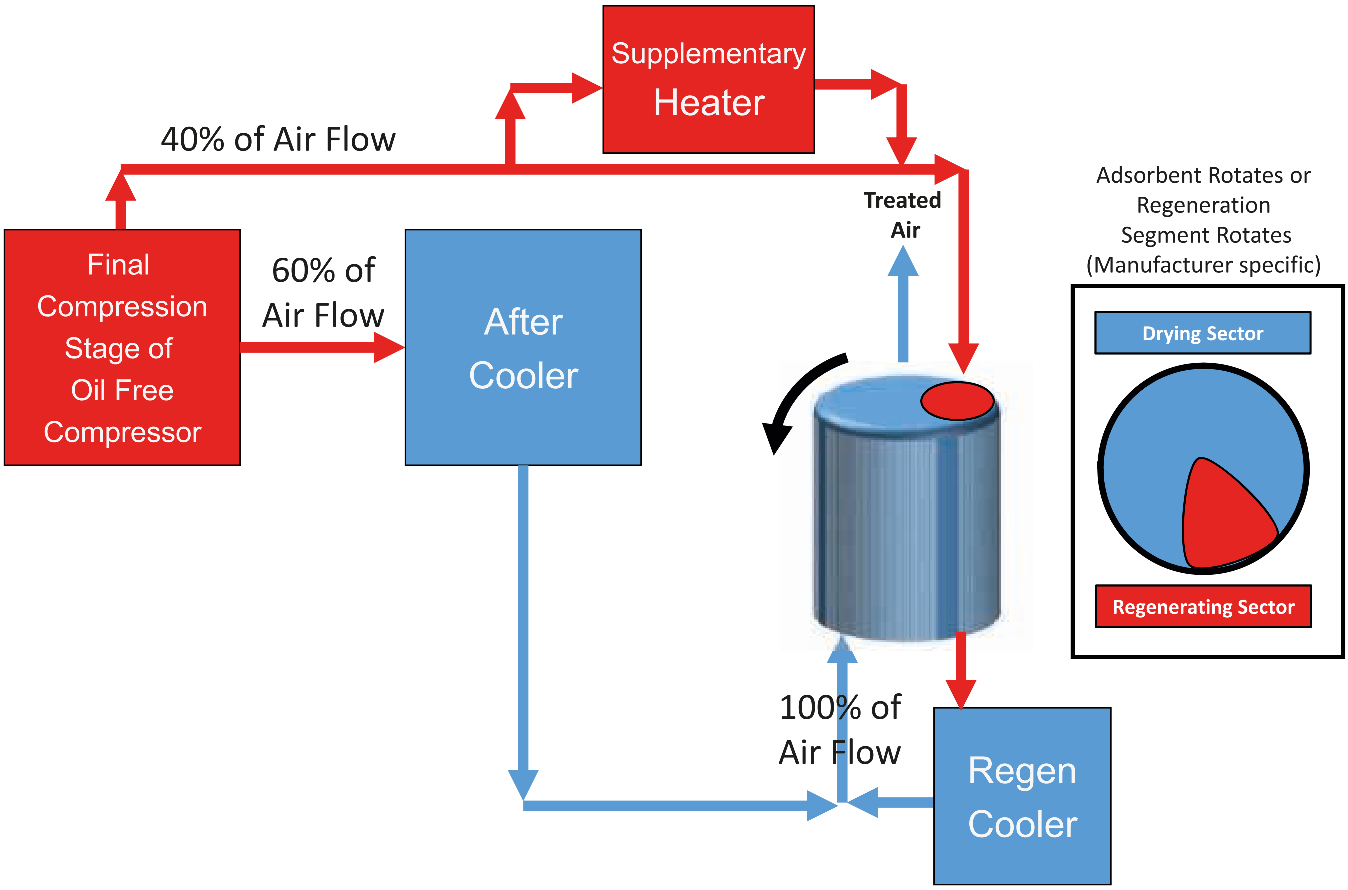


6.5.9.4 Drum Dryer + Supplementary Heaters (Split Air Flow before Compressor After-Cooler)

On this type of drum dryer, a regeneration cooler (air-cooled or water-cooled) is used along with the compressor's own aftercooler and these can be air-cooled or water-cooled. After the final compression stage, the flow of hot, wet, compressed air is split. A proportion of the hot air is used in the regeneration sector to regenerate the adsorbent material, while the remaining flow is passed through the compressor aftercooler.

Varying compressor loads may lead to insufficient heat for full regeneration and on this type of drum dryer, supplementary heaters are used to ensure enough heat for regeneration to take place.

The partial flow of hot air is passed through the regeneration 'sector' where it picks up moisture from the adsorbent material. The air is then directed through a regeneration cooler where the air is cooled, allowing condensation and liquid removal to take place. The air from the regeneration cooler is now re-combined with the air that was passed through the aftercooler prior to being passed into the drying sector. The dried compressed air then exits the dryer.

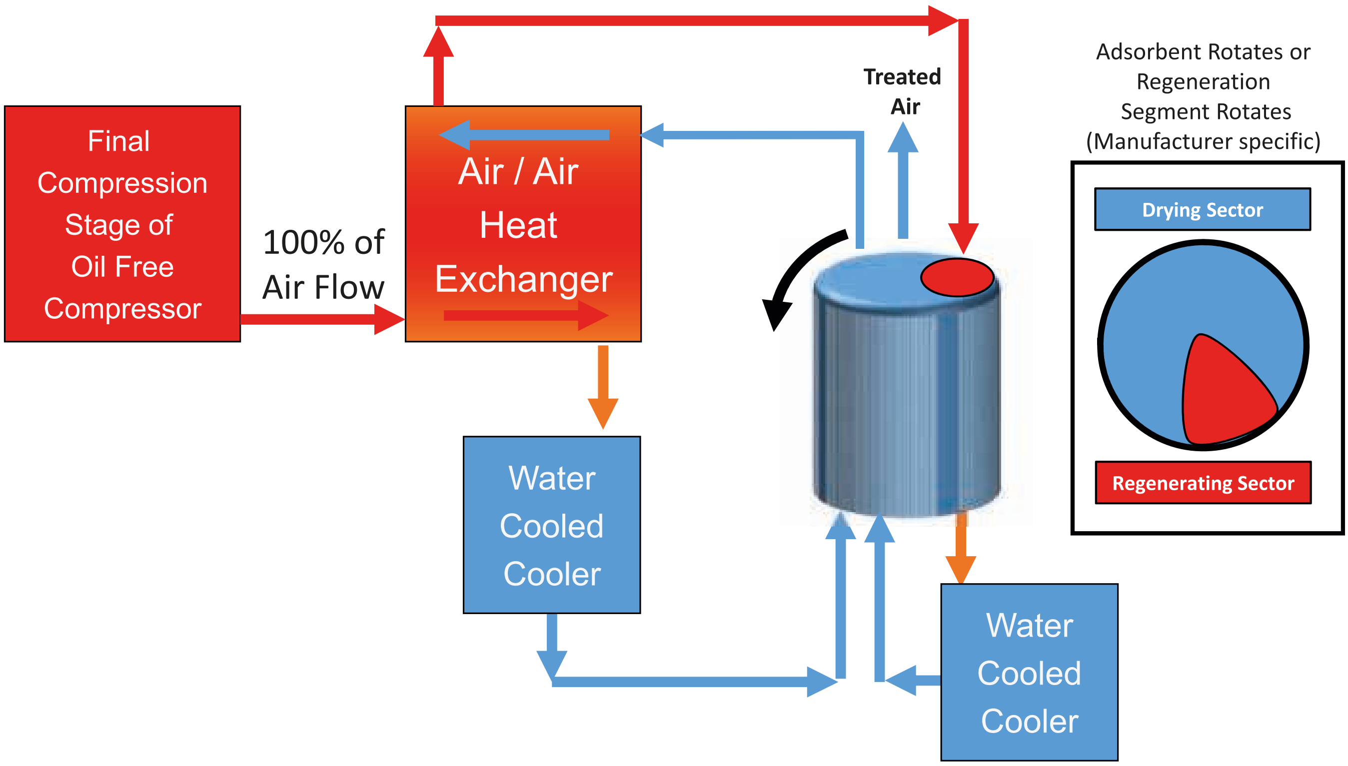


6.5.9.5 Drum Dryer (Split Air Flow – No Aftercooler)

This type of drum dryer uses three separate coolers. The traditional aftercooler is replaced with an alternative style cooler and two water-cooled coolers are also used. The full flow of hot, wet compressed air after the final compression stage is first passed through an air/air-heat exchanger (like a refrigeration dryer) where it is used to heat a proportion of dry air to be used for regeneration.

It is then passed through a water-cooled heat exchanger prior to entering the drying sector of the drum. The flow of dried air leaving the drum is then split, with most exiting the dryer while a proportion is passed through the air/air-heat exchanger where it is heated by the hot, incoming air.

This heated air is then passed through the regeneration sector where it is used to regenerate the adsorbent material. The hot regeneration air is then passed through the second water-cooled cooler before being re-combined with the incoming air about to enter the drying sector.



6.5.9.6 Twin Tower Heat of Compression Dryers

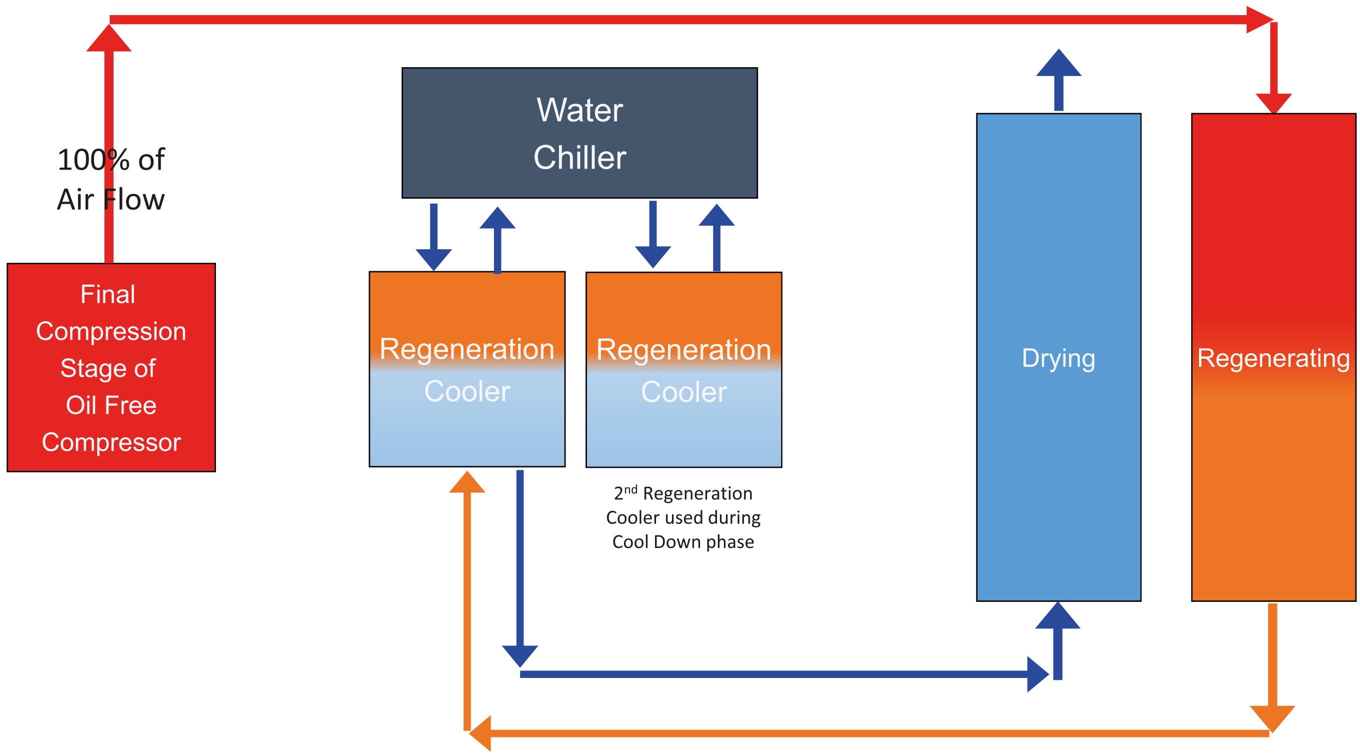
Two variants of the twin tower heat of compression dryer are typically available. These are the full flow and the partial flow variants. Differences are explained below:

6.5.9.7 Heat of Compression Twin Tower Dryer (Full Flow)

On the full flow heat of compression dryer, two regeneration coolers are used, eliminating the need for the compressor to have an aftercooler of its own. After the final compression stage, the hot, wet, compressed air is first directed into the adsorption column requiring regeneration where it picks up more moisture from the adsorption material.

The air is then directed through a regeneration cooler where the air is cooled, allowing condensation to take place. Liquid is removed prior to the air being passed into the on-line column for drying to take place prior to the air leaving the dryer.

Prior to changeover, the off-line bed undergoing regeneration must be cooled. During the cooling phase, the hot air from the final compression stage is first cooled by a regeneration cooler and liquid removed from the air. The air is then passed over the off-line bed to cool the adsorption material. The air is then passed through another regeneration cooler prior to being passed through the online column to be dried.



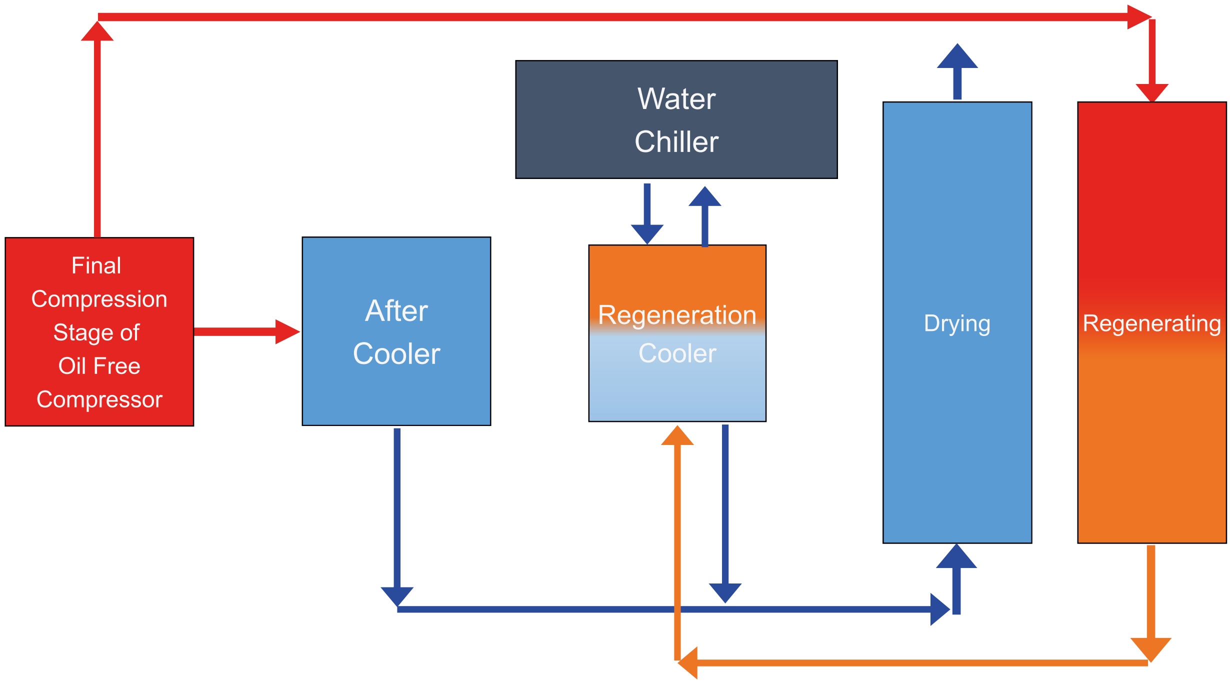
6.5.9.8 Heat of Compression Twin Tower Dryer – (Partial or Split-Flow)

On the partial flow heat of compression dryer, only one regeneration cooler is used along with the compressor's own aftercooler. After the final compression stage, the flow of hot, wet, compressed air is split. A proportion of the hot air is used for regeneration of the off-line column, while the remaining flow is passed through the compressor aftercooler.

The partial flow of hot air is passed over the adsorbent material undergoing regeneration where it picks up more moisture from the adsorption material. The air is then directed through a regeneration cooler where the air is cooled, allowing condensation and liquid removal to take place.

The air from the regeneration cooler is now re-combined with the air that was passed through the aftercooler prior to being passed into the on-line column for drying to take place and leaving the dryer.

Prior to changeover, the off-line bed undergoing regeneration must be cooled. During the cooling phase, 100 per cent of the hot air from the final compression stage is first cooled by a regeneration cooler and liquid removed from the air. The air is then passed over the off-line bed to cool the adsorption material. The air is then passed through the regeneration cooler prior to being passed through the online column to be dried.



Important Note:

Heat of compression (HOC) dryers typically offer dewpoint suppression not constant outlet dewpoints (refer to section 6.5.3 on the differences between constant and dewpoint suppression).

HOC dryers are purchased typically with the oil-free compressor as they are integrated into the compressor operation and controls.

Retrofit to existing compressors can often invalidate the compressor warranty as modification of an existing compressor is required.

Regeneration coolers used by HOC dryers are typically water-cooled and will require a chiller and cooled water supply.

Supplementary heaters may be required for some installations.

On this type of dryer, energy is consumed through:

Dryer Type	Pressure Drop	Drive Motor	Supplementary Heater
Drum HOC	✔	✔	✔

Important Note:

For drum dryer (dewpoint suppression) efficient regeneration, the compressor should always operate at full-load conditions to produce enough heat for regeneration to take place.

Ambient air temperature along with adequate ventilation and cooling are critical for efficient operation.

Outlet dewpoint will vary if full-load and ambient conditions are not constant.

6.5.10 Total Cost of Ownership

Compressed air dryers should always be selected for the highest water vapour loading they will handle, at maximum flow rate, in summer conditions and at minimum operating pressure. This ensures that the dryer will always be able to deliver the required dewpoint. The adsorption dryer regeneration types above assume operation of the dryer on a fixed cycle.

Many manufacturers now have options, or even include as standard, systems that monitor the dewpoint of the compressed air leaving the dryer and adjust the drying/regeneration cycle to match the incoming water vapour loading closely.

Often, when selecting compressed air dryers, energy consumption alone was the overriding decision-making factor, with many dryer types not even being considered. The explanations above show that to reduce energy consumption, dryer complexity increases. With advances in measurement techniques and the inclusion of energy-management systems, dryer types that were once thought as inefficient may now become a viable solution.

Best practice is to use total cost of ownership (TCO) rather than calculating on running costs alone when selecting any purification equipment. To calculate TCO, factor in purchase price, operational costs and maintenance costs over the lifetime of the dryer. Speak to your supplier who will be pleased to advise.

7. Condensate Management

Compressor condensate is an aggressive, acidic mixture of oil, water, particulates and micro-organisms. Condensate management refers to the efficient drainage or discharge of compressor condensate from various points around the compressed air system and its disposal in a manner that is safe, legal and friendly to the environment.

Additional information is given in the BCAS factsheet 302. Please refer to the BCAS web site for the most up-to-date fact sheet - **www.bcas.org.uk**

Once removed from the compressed air flow and collected by the various purification technologies, compressor condensate must then be drained from the system. Due to the high volume of condensate produced, this needs to occur on a very regular basis. Condensate drainage points are typically: the air compressor intercoolers/aftercoolers, air receivers, water separators and coalescing, filters and refrigeration dryers. Some of the greatest wastages of compressed air (and therefore energy), often up to 10 per cent of the average air demand, are found due to inefficient condensate drainage.

Additional information is provided in the BCAS Condensate Guide. Please visit the BCAS web site for further information - **www.bcas.org.uk**

7.1 Condensate Drain Types

There are many condensate drainage technologies available and they can be segmented into two distinct types – those that discharge compressed air along with the condensate and, those that do not.

	Zero Air Loss	Energy Efficient	Fully Pneumatic Operation	Electricity Supply Required
Filter Float Drain	✔	✔	✔	✕
External Float Drain	✔	✔	✔	✕
Electronic Level Sensing Drain	✔	✔	✕	✔
Timed Solenoid Drain	✕	✕	✕	✔
Thermodynamic Disc Trap	✕	✕	✔	✕

Compressed air is costly to generate and losing compressed air to drain condensate is wasteful, therefore to efficiently and cost effectively drain condensate is to do so without the loss of compressed air. To do this, a zero-air loss drain is employed.

7.1.1 Zero Air Loss Drains

Zero air loss drains are any condensate drain (also known as a drain trap) that discharge condensate from a compressed air system without discharging (wasting) compressed air. These can be internal float drains as found in water separators and coalescing filters or, external float drains or electronic level sensing drains. Properly maintained, any of these types of drains will reduce air loss and improve energy efficiency significantly.

7.1.2 Timed Solenoid Drains

Timed solenoid drains use an electronic timer to open and close a solenoid valve and discharge condensate. They will lose compressed air during discharge typically and hence waste energy. Correctly set up (with a short duration between discharges and short opening times), the air loss can be minimised, however they will need re-setting to match seasonal conditions.

7.1.3 Thermodynamic Disc Traps

Thermodynamic disc traps are modified steam traps and were once very common due to their low cost. By design, they discharge compressed air constantly as well as emulsifying condensate as it is discharged to a point where standard gravity oil/water separator will not work, requiring costlier disposal methods. It is recommended to replace thermodynamic disc traps with more energy-efficient solutions.

Important Note:

Failure of a condensate drain will result in carryover of liquid resulting in overload of filtration and drying equipment and or contamination of downstream distribution piping and applications.

Daily checks of condensate drain function are recommended.

Almost all condensate drains are susceptible to particulate contamination and where necessary, should be protected by strainers.

Except for timed solenoid drains, condensate discharged from float drains and level sensing drains will be under gravity, not system pressure – do not try to 'lift' condensate above the point of drainage or 'push' condensate over long distances.

For condensate discharge piping, use large internal diameter piping and keep pipe lengths short to prevent back pressure.

Never combine or tee condensate drain lines. Always run individual drain lines to a common, open-ended or vented condensate manifold prior to feeding into storage vessels or on-site treatment devices.

Condensate drains require regular maintenance (or replacement in the case of internal float drains). Always follow manufacturer's recommended maintenance instructions.

Additional information is provided in the BCAS factsheet 302. Please refer to the BCAS web site for the most up-to-date fact sheet - **www.bcas.org.uk**

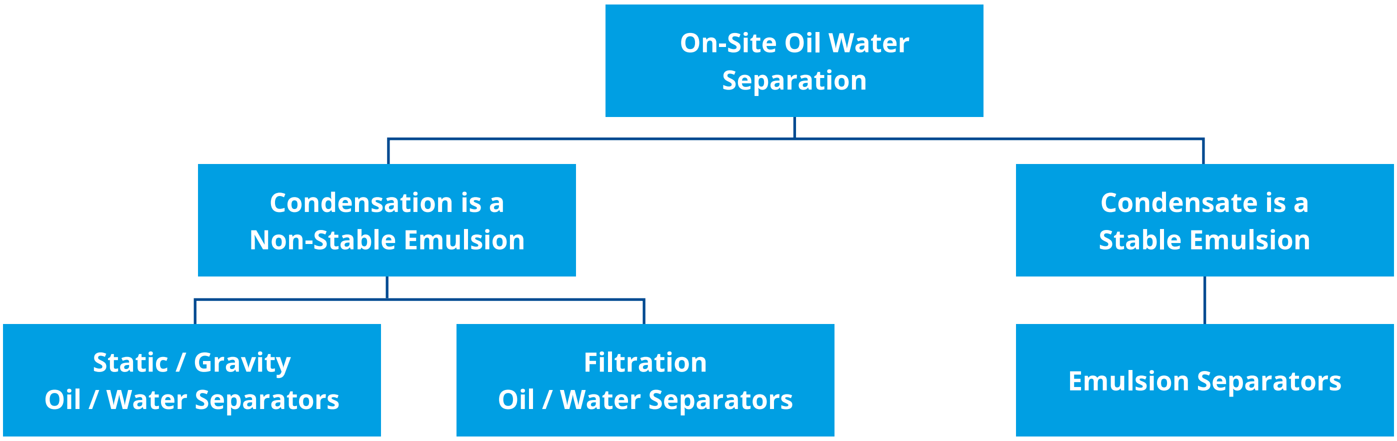
7.2 Oil/Water Separators

Rigid legislation exists to protect the environment against contamination. Compressed air users are required to comply with this legislation and show use of environmental protective systems and procedures. Most compressed air users are unaware of exactly how much condensate is produced by their system each year, and of the devastating effect it can have on the environment.

Compliance with environmental legislation forces the compressed air user to dispose of large volumes of oily condensate in a legal and responsible manner. The most cost-effective disposal solution is to separate the small volume of oil from the larger volume of water using an on-site oil/water separator.

7.3 On-Site Oil/Water Separator (OWS) Types

On-site oil/water separators can be segmented based upon the condensate being separated.



Typically, the oily condensate discharged from much of the compressed air systems is not a stable mixture and if left the oil and water will separate out over time. This type of condensate is typically treated by a 'static' separator (also known as a 'gravity' separator) or a 'filtration' based separator.

On a small number of compressed air systems, the type of lubricant and/or the type of drain used causes the oily condensate to form a stable emulsion which will not separate over time. This type of condensate requires the use of an 'emulsion separator'.

This type of condensate is typically treated by a 'static' or 'gravity' separator which uses a large settlement tank to separate the bulk oil and water (activated carbon then provides a final polish) or a 'filtration' based separator which passes the condensate through filtration media then adsorption media (usually activated carbon)   On a small number of systems, the type of lubricant used coupled with the type of drain used causes the oily condensate to form a stable emulsion which will not separate over time. This type of condensate requires the use of an 'emulsion separator.'

OWS separators were designed to remove oil from water before discharge and that remains their primary function. Water sampling should be carried out in accordance with EPA Method 1664. (UK OFFICIAL Water and Sewerage Company Environmental Performance Assessment (EPA) Methodology (version 3) November 2017.)

8. Breathing Air

In some work areas, the atmospheric air is too contaminated for operators to breathe without risk to health (or is oxygen deficient). In these cases, it is normal to provide a clean compressed air supply which can be used safely.

All employers have a duty of care to their employees. They must ensure that the compressed air they are supplying to masks, helmets, hoods, suits, etc. is adequate for the respiratory protective device they are using and is safe to inhale.

Compressed air for breathing normally originates from a compressor system installed or operating at the place of use and there are various factors that can affect the quality and safety of this air.

Important Note:

Safety

Only competent personnel should be involved in designing breathing-air systems and preparing risk assessments. Standard compressed air filtration is probably not enough to ensure air quality continuously meets the requirements of BS EN12021.

Certain types of membrane and adsorption dryers can also reduce the oxygen content of the compressed air in breathing-air applications therefore specialist advice must be sought.

Further guidance on the issues and the design requirements of breathing-air systems is available from BCAS and through advice from its members.

Additional information is provided in the BCAS factsheet 304. Please check the BCAS web site for the most up-to-date fact sheet - **www.bcas.org.uk**

9. Performance Validation of Compressed Air Purification Equipment

Many manufacturers now provide third-party performance validation of compressed air purification equipment. There are several ISO standards that can be used to test a filter or dryer and classify the delivered air purity (quality) in accordance with ISO 8573-1 purity (quality) classifications. The most commonly used are show in Fig 18. below:

(Fig 18.)

Standard(s)	Product Type	Test for
ISO 12500-1 (ISO 8573-2)	Coalescing Filters	Oil Aerosol Reduction
ISO 12500-4 (ISO 8573-9)	Water Separators	Liquid Separation Efficiency
ISO 8573-4	Coalescing and Dry Particulate Filters	Particle Count
ISO 8573-5	Oil Vapour Removal Filters	Oil Vapour Content
ISO 7183	Refrigeration and Adsorption Dryers	Water Vapour Reduction
ISO12500-2	Adsorption Filters	Time to Detect Oil Breakthrough
ISO12500-3	Coalescing and Dry Particulate Filters	Identify MPPS and Filter Element Efficiency at MPPS
ASTM D2986-95	Coalescing and Dry Particulate Filters	Filter Element Efficiency

It is always recommended to seek performance validation of purification products if available.

Important Note:

ISO 12500 series was introduced to provide manufacturers with a repeatable means to validate the performance of compressed air filters and is split into four parts.

ISO 12500-1 uses the test equipment and methodology of ISO 8573-2 for accurate measurement of oil aerosol content downstream of a filter. This standard specifies a test method and an inlet challenge concentration of oil aerosol to test the filter's performance. The test results can be directly correlated to an ISO8573-1 air purity (quality) for total oil.

ISO 12500-2 is a test to show the adsorption capacity of an oil vapour removal filter, measured as time. Its main purpose is to compare two similar types of filter to see which would last longer. As the test is an accelerated test which uses a high inlet concentration of vapour, the test results cannot be used to show how long an adsorption filter will last in an installation, nor does it provide results that can be correlated back to an ISO8573-1 air purity (quality) classification for oil vapour (use ISO8573-2 and ISO8573-5 for this).

ISO 12500-3 is a test to find the MPPS (most penetrating particle size) for a filter and its removal efficiency at the identified MPPS. This test does not provide results that correlate directly to an ISO8573-1 air purity (quality) classification for particle count (use ISO8573-4 for this).

ISO 12500-4 uses the test equipment and methodology of ISO 8573-9 for accurate measurement of liquid water content downstream of a water separator. This standard specifies a test method and an inlet challenge concentration of liquid water to test the water separator's liquid reduction performance. The test results can be correlated directly to an ISO8573-1 air purity (quality) for water (to a maximum of Class 6).

A1 Appendix

A1.1 Oil Vapour in Ambient Air

Hydrocarbons and VOC in ambient air combine to form what is referred to by the compressed air industry as 'oil vapour.' To highlight the quantity of hydrocarbons and VOC present, data from the UK Hydrocarbon Network Annual reports has been used.

In the United Kingdom, DEFRA (Department for Environment, Food and Rural Affairs) publishes data obtained from its UK sampling facilities. Most of these sites (30+) use manual sampling and test methods, looking for specific hazards, while four sites (two rural and two urban) use sophisticated automated thermal desorption with in situ gas chromatography and FID detection equipment.

At these sites, automatic hourly measurements are made of 29 different 'target' compounds.

At the time of publishing this document (2018), the last four UK Hydrocarbon reports available from DEFRA were used (these cover the years 2012, 2013, 2014 and 2015). The UK Airborne Particulate Concentrations and Numbers Network (AQ21636) currently operates these four air pollution monitoring sites. The sites are arranged so as to maximise the benefit of the measurement made. (NPL Management Limited, 2016, ISSN 2059-6030)

Full data analysis is available at **www.gov.uk/government/publications/mcerts-performance-standard-for-continuous-ambient-air-quality-monitoring-systems**

The tables below incorporate the 12 months' hourly concentration from the four automatic monitoring stations. Additionally, as the units of measurement in the reports is μg/m³ and the compressed air industry typically use mg/m³, the data in each table below has been converted to mg/m³.

Totals for the 29 Compounds of Interest	Maximum Hourly Concentration - Year 2012			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
Totals (μg/m³)	370.80	161.52	436.79	855.53
Totals (mg/m³)	0.37	0.16	0.44	0.86

Totals for the 29 Compounds of Interest	Maximum Hourly Concentration - Year 2013			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
Totals (μg/m³)	344.25	116.62	4380.68	569.42
Totals (mg/m³)	0.34	0.12	0.44	0.57

Totals for the 29 Compounds of Interest	Maximum Hourly Concentration - Year 2014			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
Totals (μg/m³)	261.01	196.31	639.60	735.80
Totals (mg/m³)	0.26	0.20	0.64	0.74

Totals for the 29 Compounds of Interest	Maximum Hourly Concentration - Year 2015			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
Totals (µg/m³)	164.59	77.15	401.86	505.28
Totals (mg/m³)	0.16	0.08	0.40	0.51

As can be seen in the tables above, when the recorded data for all 29 compounds is combined, it corroborates the typical industry figures used for oil vapour (hydrocarbons) in ambient air of between 0.05 mg/m³ - 0.5 mg/m³.

Compound	Maximum Hourly Concentration - Year 2015			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
1, 2, 3 - trimethylbenzene	0.03	0.70	2.70	2.70
1, 2, 4 - trimethylbenzene	0.03	1.50	4.80	9.50
1, 2, 5 - trimethylbenzene	0.03	1.30	1.50	3.40
1 - pentene	0.02	0.09	0.81	1.10
2 - methylpentane	4.30	1.20	6.70	19.00
benzene	1.40	1.60	4.60	5.40
ethylbenzene	0.88	0.88	3.30	7.10
toluene	5.70	4.30	59.00	57.00
iso - octane	0.66	0.57	2.70	18.00
iso - pentane	31.00	4.00	27.00	43.00
m+p-xylene	2.90	2.60	9.60	27.00
n-heptane	0.54	0.62	2.20	11.00
n-hexane	2.80	1.30	12.00	4.60
n-octane	0.19	0.38	0.81	1.80
n-pentane	12.00	2.80	21.00	12.00
o-xylene	1.10	2.10	4.00	10.00
trans-2-pentene	0.02	0.15	2.30	3.80
1,3-butadiene	0.43	0.22	0.49	0.88
1-butene	1.20	1.30	2.10	2.00
ethane	8.40	16.00	81.00	71.00
ethene	3.30	4.50	13.00	10.00
ethyne	0.62	2.90	6.10	3.80
isoprene	1.80	0.23	0.01	4.10
propane	24.00	9.90	72.00	44.00
propene	3.10	1.50	4.40	3.80
cis-2-butene	0.16	0.07	0.84	1.80
iso-butane	17.00	5.10	21.00	48.00
n-butane	40.00	9.20	34.00	77.00
trans-2-butene	1.00	0.14	1.90	2.50
Totals (µg/m³)	**164.59**	**77.15**	**401.86**	**505.28**
Totals (mg/m³)	**0.16**	**0.08**	**0.40**	**0.51**

Data taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo-AED for DEFRA.
Data specific to the 4 automated monitoring stations.
Automatic monitoring stations test for 29 compounds of interest.

A1.2 Ageing of Desiccant

Commercial adsorption units use only a fraction of the capacity that is available in the new desiccant to determine the cycle length. The 'extra' capacity considers a gradual reduction in the adsorption capacity of the desiccant during the working life (ageing). The regeneration of the desiccant causes loss in effective surface area. Chemical contamination or fouling and hydrothermal deterioration are the two main causes of aging in commercial adsorption units.

A1.2.1 Ageing by Chemical Contamination or Fouling

This form of ageing, which is theoretically reversible, occurs when the active surface of the desiccant is coated or access to its active sites is blocked. This can be either by a direct deposit of oil, or by degradation, polymerisation or oxidation of unstable compounds present in the fluid or gas passing through the desiccant. In practice this phenomenon is not completely reversible and immobile carbon deposits increase at each regeneration, leading to a progressive decrease of the adsorption dynamic capacity.

A1.2.2 Hydrothermal Ageing

Hydrothermal ageing is the result of gradual irreversible changes to the structure of the desiccant, generally due to water exposure at regeneration temperatures. Ageing is mainly dependent on the number of regenerations (i.e. the number of adsorption/desorption cycles). Therefore, it pays to regenerate at longer intervals by using all the available capacity to its fullest extent. This can be achieved by adjusting the cycle length. Under normal working conditions, ageing decreases the initial properties of the desiccant by about 50 per cent in a period of two to four years.

A1.3 Hazardous Waste Regulations and Compressed Air

A1.3.1 Owners of Compressed Air Systems

Compressed air systems are subject to the Hazardous Waste Regulations, introduced in July 2005. These affect all owners of compressed air systems with respect to the proper disposal of compressed air service parts and condensate, which will normally be contaminated with oil and other potentially harmful substances.

A1.3.2 The Sources of Hazardous Waste in Compressed Air Systems Are:

- Condensate
- Oil from servicing activities
- Used oil filter elements, desiccant and air filter elements
- Air end/pump items
- Gaskets, service parts, etc.

A1.3.3 Are Used Adsorbent Considered Hazardous Waste?

Yes, unless it has been used in an oil-free system, the desiccant will contain oil. The regulations do not specify a lower limit of oil content, so any oil content deems the component to be hazardous. Some materials such as catalysts, due to their caustic nature, are hazardous at the outset even before use in a compressed air system.

A1.3.4 Are Biodegradable Oils Considered Hazardous Waste?

Yes, even though they are less polluting than standard oil. Regardless of whether an oil complies with the international standard OECD 301B for biodegradability, it is still hazardous waste requiring proper disposal.

A1.3.5 How Should Waste Oil from Servicing Compressed Air Equipment be Disposed of?

All waste oil and oil-contaminated components from servicing activities, e.g. oil from the gearbox or sump, filter elements etc., should be removed from a site by a registered 'Hazardous Waste Producer' or a licensed 'Hazardous Waste Carrier.'

A1.3.6 How Do I Check That My Supplier Complies?

Ask to see the hazardous waste carrier/hazardous waste registration document.

Ask to see an audit trail of your waste oil for proof that it has been disposed of properly.

Additional information is provided in the BCAS fact sheet 301 - Hazardous Waste Regulations Compressed Air. Please refer to the BCAS web site for the most up-to-date fact sheet - **www.bcas.org.uk**

A1.4 Safety Information

A1.4.1 Pressure Systems

All pressure systems in the UK are subject to the regulations of the Approved Code of Practice (ACOP) in support of the Pressure Systems' Safety Regulations 2000 (S.I. 2000/128) (PSSR).

This ACOP and guidance is aimed at duty holders under the regulations, which includes users, owners, competent persons, designers, manufacturers, importers, suppliers and installers.

The aim of PSSR is to prevent serious injury from the hazard of stored energy, because of the failure of a pressure system or one of its component parts.

A1.4.2 Maintenance

The Health and Safety at Work Act 1974 and regulation 5 of PUWER require that work equipment is maintained so that it does not give rise to risks to health and safety and states:

'The user of an installed system and the owner of a mobile system shall ensure that the system is properly maintained and in good repair, so as to prevent danger.'

For more information and or training in relation to PSSR 2000, please contact **technical@bcas.org.uk**