White Paper
“Oil Vapour” in Ambient Air

Where does it come from and how does it affect the quality of your compressed air?

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“Oil Vapour” in Ambient Air

In this white paper, Mark White - Compressed Air Treatment Applications Manager at Parker Hannifin Manufacturing Ltd, discusses the effect that ambient oil vapour levels can have on downstream compressed air quality and what to consider when looking for ‘Technically Oil-Free’ compressed air to ISO8573-1 Class 0 or Class 1 for total oil.

If you asked someone to describe oil and where it comes from, most people will describe a thick, black liquid, drilled from deep in the earth, pumped out and shipped around the world in large tankers. And if you asked the same question relating to oil in a compressed air system, you will most likely be given a description of a thick black liquid coming from a lubricated air compressor.

Unbeknown to many, the ambient air around us, the air we breathe (and which the air compressor also “breathes”) also contains oil, but not in the thick, black, liquid form we normally think of, but in a vapour (gaseous) phase which we are unable to see.

To understand how oil vapour ends up in our ambient air (and ultimately in our compressed air systems), we must understand what “oil” is, where it comes from, how it is processed and what happens to it when it is used.

What is “Oil”?

In general conversation, we use the term oil to describe a myriad of different things, for example petrol (gasoline), diesel, kerosene, compressor oil, engine oil.

An organic chemist however, would not refer to these things as oil, they would refer to them as hydrocarbons. Hydrocarbons are organic compounds containing only elements of carbon and hydrogen. They belong to chemical groups called functional groups. These functional groups (of which there are many) include alkanes, alkenes, alkynes, alcohols, aromatics, aldehydes, ketones, carboxylic acids, amides, esters.

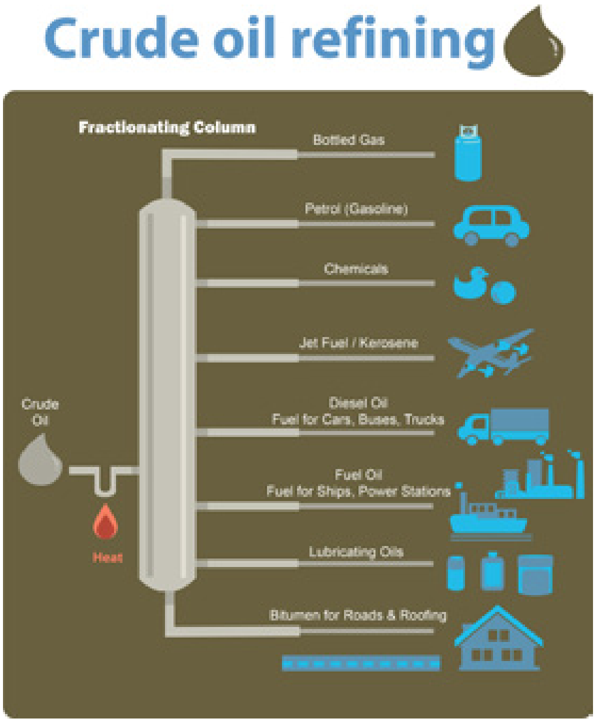
Volatile Organic Compounds (VOC)
Today the term VOC or Volatile Organic Compound is frequently used in media, often in relation to ambient air quality. VOC are those compounds which change easily from liquid form to vapour. They are released into the atmosphere from burning fuels, such as petrol, diesel, kerosene, wood, coal, or natural gas. They are also emitted from oil and gas fields and other things such as paints and solvents.

Making "Oil" (as we perceive oil)
Approximately 95 percent of the lubricants and liquid fuels currently used today are derived from crude (mineral-based) oil which is the thick, organic liquid pumped from the ground. Without proper processing, crude oil has limited uses for us and certainly won't lubricate our machinery, power our vehicles or allow us to generate electricity in power stations.
To produce fuels or lubricating oils from crude oil, it must first be processed in a refinery. The refining process separates molecules of various sizes and structures, so they can be used for different things. For example, petrol (gasoline), diesel and kerosene are all derived from crude oil.

In simplistic terms, the refining process removes impurities, heats the crude oil and separates different compounds for different uses.

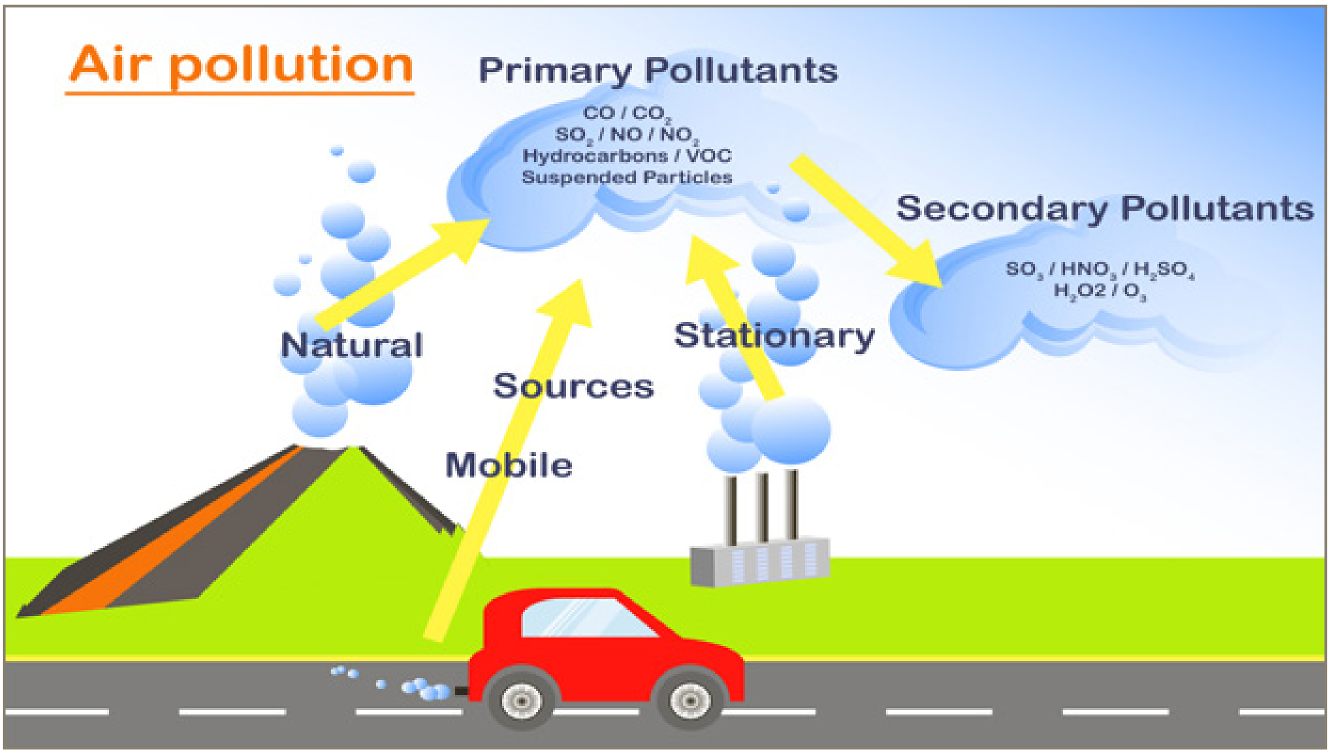
Separation occurs in a fractionating column, where the crude oil is heated further to vaporise it. As the vapours rise, they are drawn off at different heights in the column and allowed to cool and condense. This process allows the crude oil to be separated based on boiling point.

The smallest (shortest carbon chain length) of the hydrocarbons (those made up of 5 to 10 carbon atoms) will rise to the very top of the column and will be processed into products like petrol. Vapours condensed just below the top of the column will have compounds containing 11 to 13 carbon atoms, used for kerosene and jet fuel. Condensing further down the column, those compounds containing 14 to 25 carbon atoms will be used for diesel and further down again, compounds in the range of 26 to 40 carbon atoms will become lubricating oils.



What do we mean by "Oil Vapour"?

When we (the compressed air industry) talk about oil vapour in ambient air, we are actually refering to a combination of hydrocarbons and VOC mentioned previously.



Ambient air typically contains between 0.05mg/m3 and 0.5mg/m³ of oil vapour, however this can be higher in dense, urban or industrial environments or next to car parks and busy roadways.

How do we know how much "Oil Vapour" is in the ambient air?
As we have previously stated, the oil as we know it is a mixture of many different compounds and as there is no single "oil" in air test, therefore we must test the ambient air for the different compounds and combine the test results.

Global and European targets to improve air quality has led to many air quality sample stations being set up to test for the compounds which are more harmful to human health (typically, NOx, SOx, CO, CO2 & Ozone). However, a number of these facilities also test for additional compounds, especially the VOC and we can use this data to verify the presence of "Oil Vapour" in the ambient air.

In the United Kingdom, DEFRA (Department for Environment, Food and Rural Affairs) freely publishes data obtained from their UK sampling facilities. Most of these sites (30+) use manual sampling and test methods, looking for specific hazards, whilst 4 sites (2 rural & 2 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.

Example of a Perkin Elmer Automatic Ozone Precursor Analyser as used at the automated test sites.

At the time of publishing this paper (2018), the last 4 UK Hydrocarbon reports available from DEFRA were used (these cover the years 2012, 2013, 2014 & 2015).

The tables below incorporate the 12 months hourly mean concentration from the 4 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	438.68	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 (hydrocarbons) in ambient air of between 0.05 mg/m³ - 0.5 mg/m³.

Important Notes Regarding DEFRA results:

- The recorded values for each of the 29 compounds measured at each site can be found in the tables in Appendix 1.
- Global and EU reports only target substances of concern or those which are hazardous to human health.
- They do not necessarily measure compounds hazardous to process health e.g. the taste of a product that is in direct contact with compressed air during manufacture).
- Many species (compounds) which are less (or not) harmful to human health, slip through the detection net, as the chemist / analyst isn't looking for them and has no interest in them.
- These chemicals still exist in the ambient air and their contribution to the "true" total VOC level is lost (but must always be considered).
- The reported VOC level is therefore much lower than reality.
- From the summary tables, we can see that some sites are within the typical values of between 0.05mg/m^3 and 0.5mg/m^3, whilst one exceeds these typical values.
- As the test sites used by DEFRA and highlighted in their reports are not testing for every VOC, only those of interest, the values in the summary tables should therefore be viewed as "best case".

Compressing Air – The Problem Increases

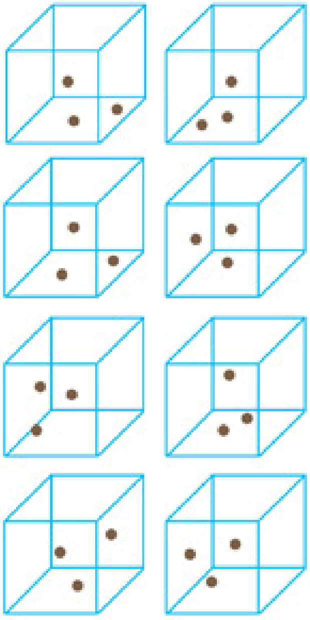
To many, the ambient levels of 'oil vapour' may be considered "negligible", however when we talk about compressed air contamination, we must also consider the effect that compressing the air has on the ambient contamination, the amount of air flowing into the compressed air system and the time the compressor is operating.

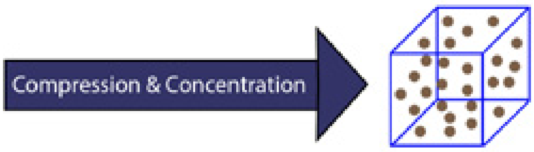
Compression = Concentration

When the ambient air is compressed, it is "squeezed" down into a smaller volume. Unfortunately, this does not apply to the contaminants in the ambient air which instead are concentrated. The higher the pressure the air is compressed to, the higher the concentration of contamination.

Typical values quoted by the compressed air industry for oil vapour in ambient air are between 0.05 mg/m^3 & 0.5 mg/m^3

Recorded values are shown to confirm these values or are in fact higher.





IMPORTANT NOTE:
This is not oil free compressed air

Basic Principles of Compressing Air

To generate 1 cubic metre of compressed air, the compressor must draw in and compress multiple cubic metres of ambient air. The higher the pressure the air is compressed to, the higher the concentration of contamination.

Concentration Examples

To highlight the effect of concentration, the table below contains the maximum hourly 'oil vapour' concentration values from page 5 (averaged from the values recorded over the 4 years).

Recorded Contamination Levels in 1 Cubic Meter of Ambient Air Before Compression

Pressure	Industry Values		Recorded Ambient Values (Averages over 4 years)			
	Min	Max	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
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).

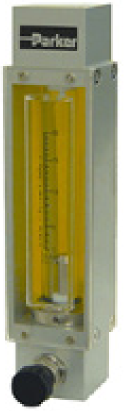
Oil Vapour Contamination Levels 1 Cubic Meter of Compressed Air

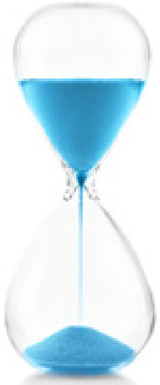
Pressure	Industry Values		Effect of Compression on Recorded Ambient Values			
	Min	Max	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
7 bar g	0.40	4.00	2.32	1.12	3.84	5.36
10 bar g	0.55	5.50	3.19	1.54	5.28	7.37
13 bar g	0.70	7.00	4.06	1.96	6.72	9.38
40 bar g	2.00	20.0	11.6	5.6	19.2	26.8
All Concentration 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.

Volumetric Flow & Time





Another consideration is the volumetric flow rate of the air compressor. Most people look at the figures per cubic metre of ambient air and forget to work out how many cubic metres per hour their air compressor is delivering into their distribution piping system. Air compressors are constantly operating, constantly drawing in the contaminated air and constantly adding to the concentration of contamination.

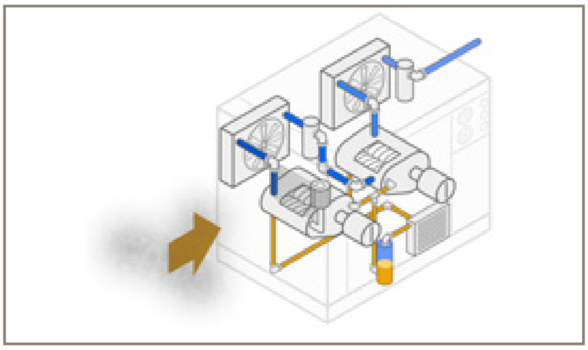
Compressor Intake Location

We have discussed the levels of oil vapour in the ambient air, however there is also another factor to consider and this is the proximity of the compressor intake to car parks and roads. It is extremely common to find air compressors installed next to a car park, site transportation hubs (goods in / out) or major roads & motorways. The effect of vehicular movement next to the compressor intake raises the risk associated with harmful VOC considerably, especially if a vehicle can park or wait with its engine running right next to the compressor intakes.

So, why should we be concerned about ambient oil vapour levels?

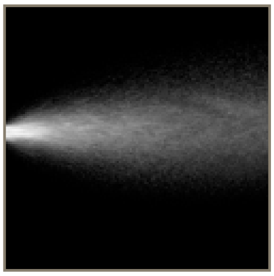
Many companies, especially those in the food, beverage, pharmaceutical, cosmetics & electronics industries use compressed air as part of their manufacturing process. Often this compressed air will directly or in-directly contact production equipment, instrumentation, products & packaging materials. If this compressed air contains "oil", the consequences can be high both financially and in terms of brand damage. For this reason, many companies specify the use of an oil-free compressor, in the mistaken belief that this will deliver "oil-free" compressed air to the critical applications.

We have already shown in this paper that the ambient air contains oil in the form of hydrocarbon compounds & VOC and once drawn into the compressor intake, these are concentrated.



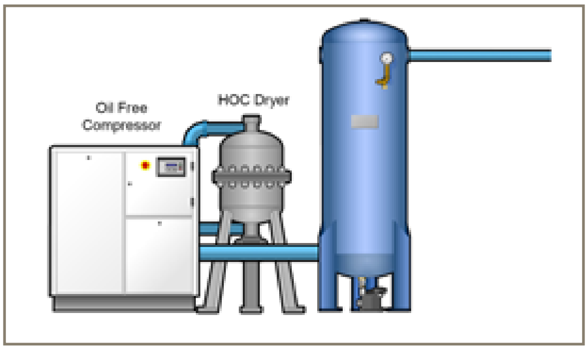
As the compressed air exits the compressor and enters the piping system, some of these compounds will cool, condense and form what we know as liquid oil and aerosols of oil, whilst others remain as oil vapour.

Oil Vapour



Oil Aerosol

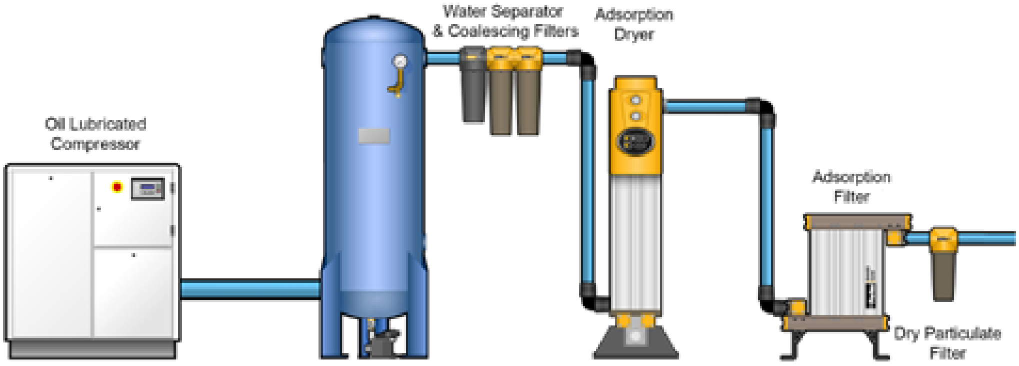
As typical oil-free compressor installations do not include purification equipment downstream for the reduction of oil, (be it in a liquid, aerosol or vapour phase) as the belief is, no oil is present, therefore this 'oil' contamination will pass directly to the products and processes mentioned previously.



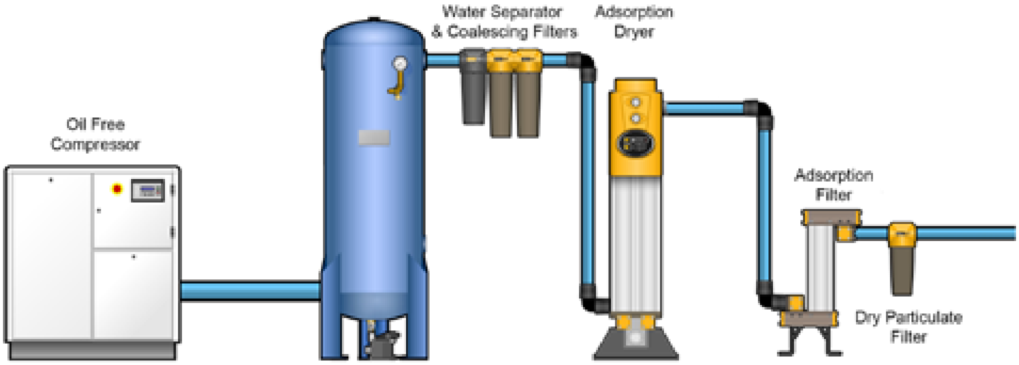
‘Technically Oil Free’ Compressed Air

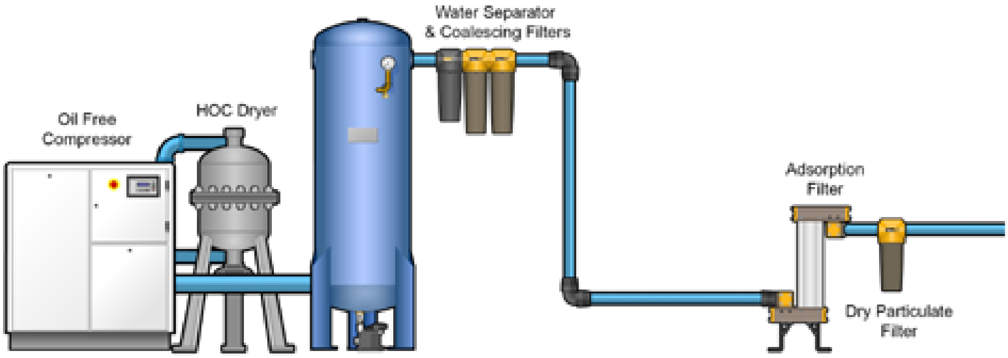
In accordance with ISO8573-1 Class 0 or Class 1 for Total Oil

Approximately, 75% of the industrial screw compressors sold globally are oil lubricated (oil injected / contact cooled). These are typically installed with downstream purification equipment (water separators and coalescing filters) to treat the compressed air, reducing oil in a liquid and aerosol phase. For critical applications an adsorption filter will also be included for the treatment of oil vapour. Compressed air treated in this way is said to be ‘Technically Oil Free’ and with the installation of the correct purification equipment will be in accordance with ISO8573-1 (international standard for compressed air purity) Class 0 or Class 1 for Total Oil.



When using an oil free compressor, if the user wishes to achieve the same ‘Technically Oil Free’ air quality in accordance with ISO8573-1 Class 0 or Class 1 for total oil, the purification equipment required downstream of the compressor is identical. Installing purification equipment will ensure treatment of the ‘oil’ vapour drawn into the compressor intake (including the vapour which condenses to form liquid oil and oil aerosols).

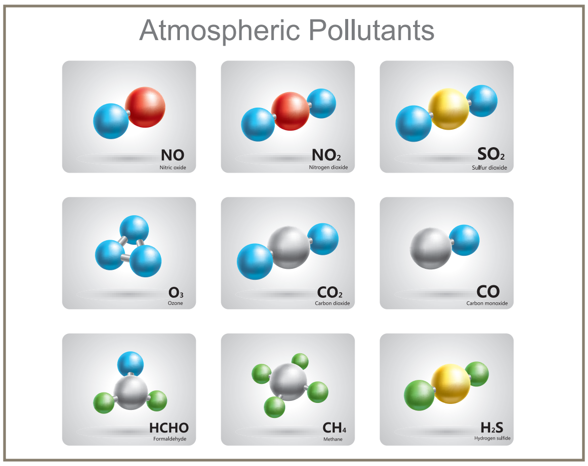




Other Gaseous Contaminants of Concern

Sulphur Dioxide (SO2)

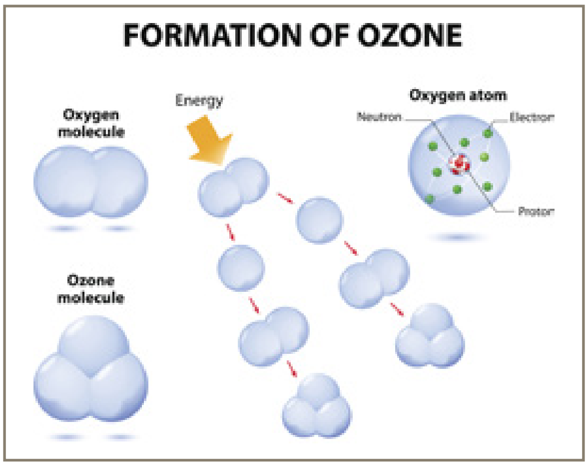
Sulphur Dioxide is produced as a by-product of the burning of fossil fuels and is also present in the ambient air drawn into the compressor intake. The oil in an oil lubricated compressor also provides additional benefits as it can also neutralise sulphur dioxide (SO2) drawn in through the compressor intake.



In an oil free compressor there is no oil to neutralise harmful vapours such as SO2. As the intercooler and aftercooler in an oil-free compressor condenses water vapour into liquid water, the SO2 from the air reacts with condensed water vapour to form sulphurous acid (like acid rain). Measurements from compressed air systems show that the resulting condensate has a pH value between 3 and 6 attacking the downstream air receivers, piping and purification equipment more aggressively than condensate from a lubricated compressor.

Ozone

Another factor to consider is ozone. Oil-free screw compressors, whilst using oil to lubricate bearings and gearboxes, do not inject oil into the compression stage for cooling. This means the temperature during compression becomes extremely high (above the safe operating temperature of many materials), therefore they typically compress in two stages, unlike an oil lubricated machine which does it in a single stage. An intercooler is placed between the first and second stages to help reduce the temperature, however the compressed air temperature can be in the range of 180°C – 200°C (on oil lubricated screw machines, the compressed air temperature is typically around 80°C).



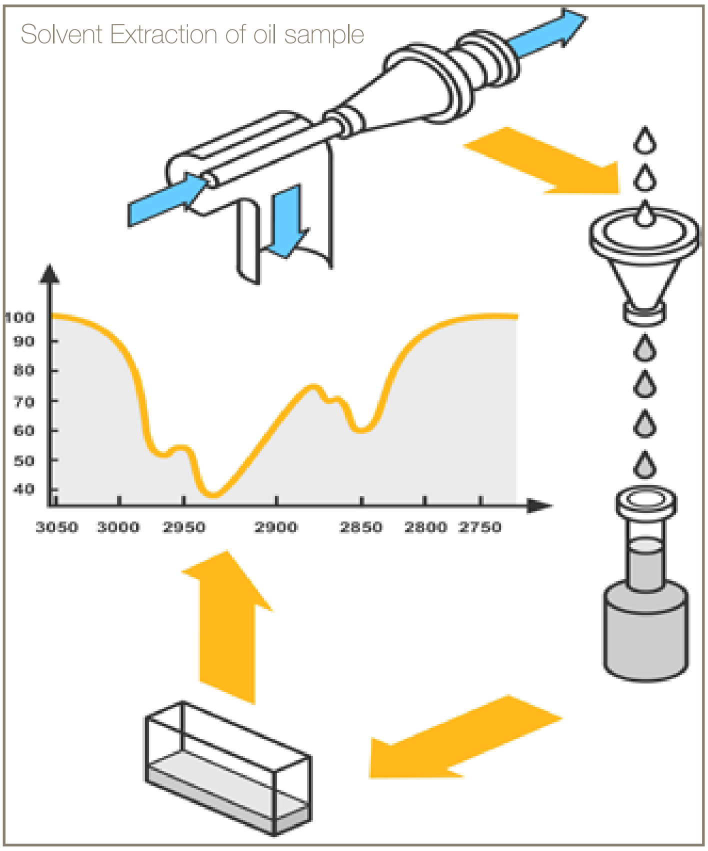
The compression process, its associated high temperature, oxygen and the presence of VOC can create ozone which preferentially and sacrificially attacks certain organic functional groups. Without oil being present in the gas stream, such as in the oil-free machine, it is difficult for the ozone to react and its concentration to reduce and therefore ozone levels in the compressed air discharged by an oil free compressor are likely remain significantly higher than those in an oil lubricated system. The ozone therefor enters the distribution piping downstream of the compressor, often damaging seals, gaskets, valves and purification equipment.

Large bed, activated carbon adsorption filters used for the reduction of oil vapour have the advantage of not only reducing the levels of oil vapour in the compressed air, they will also reduce ozone levels present.

Testing for Oil Contaminants in Compressed Air

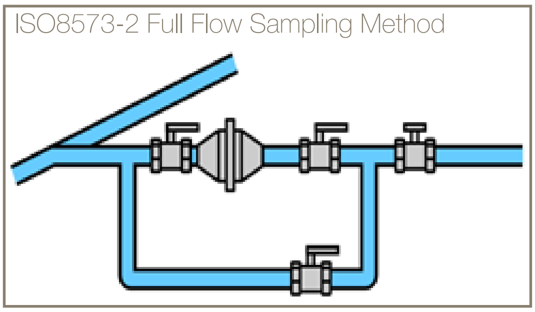
ISO8573 Parts 2 to 7
Unlike ambient air testing where a test for each different compound is carried out, testing for oil based contamination in a compressed air system is split into testing for oil aerosol and testing for oil vapours (with the results combined for total oil). ISO8573-2 & ISO8573-5 are the international standards relating to testing of oil aerosol and oil vapour in compressed air.

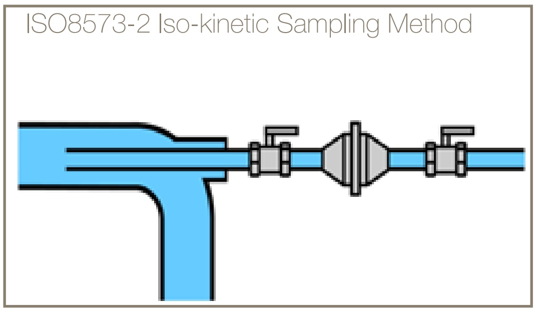
Both use a capture method specific for the phase of the contaminant and a solvent extraction process to remove a sample from the test media. The solvent sample is then analysed using an FTIR (Fourier-transform infrared spectroscopy) or GC (gas-chromatography) analyser. The combination of the two methods will provide an accurate reading down to 0.003mg/m³ and will cover all the compounds previously listed.


Solvent Extraction of oil sample

Using Test Equipment & Methodologies other than those shown in ISO8573 Parts 2 to 9
Other test methods or test equipment are sometimes used and many of these are photometer based instruments. Unfortunately, due to the limitations their Photo Ionisation Detector (PID), the sensor will “miss” (be unable to detect) certain chemicals present in the compressed air stream.

Because many species are missed, and the total VOC concentration will be under reported compared to the “true” total VOC concentration if all species could be detected. Therefore, this type of instrumentation should be used for ***indication*** purposes only.


ISO8573-2 Full Flow Sampling Method


ISO8573-2 Iso-kinetic Sampling Method

Examples of test methodology & equipment used for accurate measurement of oil aerosols in compressed air (ISO8573-2).

Summary

- **Ambient air may look clean but is not**
- **Ambient air is not ‘oil free’**
- **In addition to water vapour, ambient air contains Hydrocarbons, Volatile Organic Compounds and other gaseous contaminants such as NOx, SOx, CO, CO2. (see Appendix 3 for further information on contaminants and sources)**
- **Ambient air contains oil vapour, with typical levels between 0.05 mg/m³ & 0.5 mg/m³ (this can be higher in places)**
- **Air quality reports from DEFRA and other global testing corroborates this**
- **These compounds are drawn into the compressor intake**
- **As the ambient air is compressed, the Hydrocarbons, VOC and other contaminants are concentrated**
- **As the ambient air is not “oil free”, oil-free compressors are unable deliver “oil-free” air without the addition of downstream filtration for the reduction of liquid oil, oil aerosols and oil vapour**
- **Many Oil-free compressors still use oil for lubrication of bearings & gearboxes**
- **This oil can also pass into the flow of compressed air from damaged seals and from vapours released by the crank case breather as the compressor operates**
- **The practice of omitting filtration on the belief that an oil-free compressor is delivering oil free air is incorrect**
- **The purification equipment required downstream of an oil-free compressor is identical to that of an oil lubricated compressor**
- **To accurately test for oil in a compressed air system the methodology and equipment shown in ISO8573 Parts 2 (oil aerosol) and Part 5 (oil vapour) should be used**
- **Ozone can be generated when oil-free compressors are used**
- **The oil in an oil lubricated compressor can reduce certain gaseous contaminants and prevent the formation of ozone**
- **The condensate from an oil-free compressor can be more aggressive, for example Sulphur Dioxide from the ambient air mixing with condensed water vapour can produce sulphurous acid**

References, Data & Support:

- Dr Kristopher J. Elliott MChem. Hons., PhD, CChem., CSci., MRSC, MACS. - Senior Aerospace R&D Chemist
- Scott Kelly - R&D Manager
- Ben Birch BSc (Hons), DipCAM - Research Scientist
- Jeremy Wright, Noria Corporation - Article: The Fundamentals of Mineral Base Oil Refining
- DEFRA (Department for Environment, Food and Rural Affairs) – UK Hydrocarbon Network Annual Reports for 2012 / 2013 / 2014 / 2015

DEFRA Reports available at: ***https://uk-air.defra.gov.uk/library/reports?section_id=13***

Appendix 1
Appendix 1 contains data taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.

Data specific to the 4 automated monitoring stations.

Automatic monitoring stations test for 29 compounds of interest.
Tables in Appendix 1 show totals for all 29 compounds.

Appendix 2
Appendix 2 contains the same data as in Appendix 1, taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.

Data specific to the 4 automated monitoring stations.

Data in Appendix 2 has been split to show those compounds (17 in total) that can condense and combine into a liquid at temperatures within a compressed air system (or lower) and are C5 and above and those compounds (12 in total) that will remain in a gaseous phase.

The 17 compounds that can cool & condense are:
1,2,3-trimethylbenzene / 1,2,4-trimethylbenzene / 1,3,5-trimethylbenzene / 1-pentene / 2-methylpentane / benzene / ethylbenzene / toluene / iso-octane / iso-pentane / m+p-xylene / n-heptane / n-hexane / n-octane / n-pentane / o-xylene / trans-2-pentene.

The 12 compounds that will remain in a vapour phase are:
1,3-butadiene / 1-butene / ethane / ethene / ethyne / isoprene / propane / propene / cis-2-butene / iso-butane / n-butane / trans-2-butene

Appendix 3
Other contaminants found in compressed and their sources.

Appendix 1

Compound	Maximum Hourly Concentration (µg/m³) - 2012			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
1,2,3-trimethylbenzene	<LOD	0.70	3.30	3.30
1,2,4-trimethylbenzene	<LOD	2.80	3.30	9.00
1,3,5-trimethylbenzene	<LOD	0.60	1.80	9.40
1-pentene	<LOD	1.30	2.10	1.50
2-methylpentane	4.60	6.10	18.00	20.00
benzene	2.80	3.10	12.00	7.70
ethylbenzene	9.20	1.60	5.70	7.10
toluene	58.00	16.00	43.00	64.00
iso-octane	9.60	2.40	7.90	9.50
iso-pentane	9.80	6.40	47.00	48.00
m+p-xylene	29.00	6.40	18.00	24.00
n-heptane	4.40	2.60	4.50	11.00
n-hexane	8.20	2.10	16.30	8.20
n-octane	1.70	0.57	1.60	5.80
n-pentane	11.00	3.40	17.00	18.00
o-xylene	8.80	2.40	5.90	7.90
trans-2-pentene	<LOD	<LOD	5.00	1.90
1,3-butadiene	0.70	1.30	1.40	2.00
1-butene	<LOD	1.30	1.40	2.60
ethane	16.00	19.00	94.00	70.00
ethene	1.90	7.30	17.00	16.00
ethyne	2.40	3.00	4.30	11.00
isoprene	1.80	0.59	7.00	2.20
propane	130.00	25.00	33.00	365.00
propene	1.90	3.00	4.50	6.10
cis-2-butene	<LOD	0.16	0.79	0.93
iso-butane	23.00	15.00	24.00	75.00
n-butane	36.00	27.00	36.00	47.00
trans-2-butene	<LOD	0.40	1.00	1.40
Totals (µg/m³)	**370.80**	**161.52**	**436.79**	**855.53**
Totals (mg/m³)	**0.37**	**0.16**	**0.44**	**0.86**

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

Compound	**Maximum Hourly Concentration (µg/m³) - 2013**			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,2,3-trimethylbenzene	0.02	0.90	3.74	4.24
1,2,4-trimethylbenzene	0.02	2.34	3.39	8.78
1,3,5-trimethylbenzene	0.02	0.60	1.60	8.13
1-pentene	0.10	0.01	0.99	2.85
2-methylpentane	9.37	1.39	13.27	12.76
benzene	4.99	3.08	6.29	8.37
ethylbenzene	20.02	14.96	71.01	83.58
toluene	51.55	4.64	56.34	76.03
iso-octane	53.37	8.08	57.35	51.15
iso-pentane	8.94	2.58	4.03	8.56
m+p-xylene	5.36	2.75	14.02	7.12
n-heptane	19.34	2.48	23.47	18.89
n-hexane	7.18	1.45	3.31	6.74
n-octane	66.39	10.12	41.00	93.74
n-pentane	4.54	3.35	6.01	15.68
o-xylene	8.64	5.85	21.11	38.63
trans-2-pentene	0.01	0.01	3.06	3.84
1,3-butadiene	0.56	0.31	1.53	1.66
1-butene	2.21	0.51	1.65	2.31
ethane	5.73	0.14	0.88	1.56
ethene	2.41	20.55	28.30	43.88
ethyne	7.05	0.97	3.48	5.91
isoprene	0.96	17.10	3.31	8.68
propane	21.85	5.28	41.07	28.09
propene	7.35	0.81	5.92	4.60
cis-2-butene	12.89	0.62	7.55	0.01
iso-butane	14.10	2.73	12.56	18.51
n-butane	7.49	2.80	1.28	3.37
trans-2-butene	1.79	0.21	1.16	1.75
Totals (µg/m³)	**344.25**	**116.62**	**438.68**	**569.42**
Totals (mg/m³)	**0.34**	**0.12**	**0.44**	**0.57**

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

Appendix 1

Compound	Maximum Hourly Concentration (µg/m^3) - 2014			
	Auchencorth Moss	Harwell	Eltham	Marylebone Rd
1,2,3-trimethylbenzene	0.03	1.00	65.00	3.50
1,2,4-trimethylbenzene	0.03	1.60	4.90	6.80
1,3,5-trimethylbenzene	0.03	1.00	1.60	4.90
1-pentene	0.02	0.02	1.10	4.50
2-methylpentane	3.80	33.00	5.00	49.00
Benzene	1.60	2.40	31.00	6.10
ethylbenzene	1.10	1.20	4.80	5.40
Toluene	3.90	5.90	13.00	30.00
iso-octane	0.04	1.30	1.50	4.50
iso-pentane	13.00	5.00	26.00	60.00
m+p-xylene	3.40	4.10	17.00	19.00
n-heptane	0.46	1.30	2.10	4.30
n-hexane	2.90	3.80	7.70	9.70
n-octane	0.04	0.38	0.90	3.10
n-pentane	6.80	2.60	14.00	17.00
o-xylene	1.50	1.80	5.70	7.80
trans-2-pentene	1.40	0.17	1.40	3.30
1,3-butadiene	0.52	0.29	3.00	3.10
1-butene	1.70	0.61	5.10	6.00
ethane	120.00	24.00	68.00	74.00
ethene	7.00	6.30	110.00	15.00
ethyne	0.67	2.20	11.00	8.00
isoprene	2.10	0.37	6.70	6.10
propane	60.00	29.00	110.00	230.00
propene	4.20	7.50	33.00	38.00
cis-2-butene	1.00	0.21	1.20	2.50
iso-butane	8.40	18.00	32.00	59.00
n-butane	14.00	41.00	55.00	52.00
trans-2-butene	1.40	0.26	1.90	3.20
Totals (µg/m^3)	**261.01**	**196.31**	**639.60**	**735.80**
Totals (mg/m^3)	**0.26**	**0.20**	**0.64**	**0.74**

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

Compound	Maximum Hourly Concentration ($\mu g/m^3$) - 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
1,3,5-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 ($\mu g/m^3$)	**164.59**	**77.15**	**401.86**	**505.28**
Totals (mg/m^3)	**0.16**	**0.08**	**0.40**	**0.51**

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

Appendix 2

Compound	Maximum Hourly Concentration (µg/m^{3}) - 2012			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,2,3-trimethylbenzene	<LOD	0.70	3.30	3.30
1,2,4-trimethylbenzene	<LOD	2.80	3.30	9.00
1,3,5-trimethylbenzene	<LOD	0.60	1.80	9.40
1-pentene	<LOD	1.30	2.10	1.50
2-methylpentane	4.60	6.10	18.00	20.00
benzene	2.80	3.10	12.00	7.70
ethylbenzene	9.20	1.60	5.70	7.10
toluene	58.00	16.00	43.00	64.00
iso-octane	9.60	2.40	7.90	9.50
iso-pentane	9.80	6.40	47.00	48.00
m+p-xylene	29.00	6.40	18.00	24.00
n-heptane	4.40	2.60	4.50	11.00
n-hexane	8.20	2.10	16.30	8.20
n-octane	1.70	0.57	1.60	5.80
n-pentane	11.00	3.40	17.00	18.00
o-xylene	8.80	2.40	5.90	7.90
trans-2-pentene	<LOD	<LOD	5.00	1.90
Totals (µg/m^{3})	**157.10**	**58.47**	**212.40**	**256.30**
Totals (mg/m^{3})	**0.16**	**0.06**	**0.21**	**0.26**

Compound	Maximum Hourly Concentration (µg/m^{3}) - 2012			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,3-butadiene	0.70	1.30	1.40	2.00
1-butene	<LOD	1.30	1.40	2.60
ethane	16.00	19.00	94.00	70.00
ethene	1.90	7.30	17.00	16.00
ethyne	2.40	3.00	4.30	11.00
isoprene	1.80	0.59	7.00	2.20
propane	130.00	25.00	33.00	365.00
propene	1.90	3.00	4.50	6.10
cis-2-butene	<LOD	0.16	0.79	0.93
iso-butane	23.00	15.00	24.00	75.00
n-butane	36.00	27.00	36.00	47.00
trans-2-butene	<LOD	0.40	1.00	1.40
Totals (µg/m^{3})	**213.70**	**103.05**	**224.39**	**599.23**
Totals (mg/m^{3})	**0.21**	**0.10**	**0.22**	**0.60**

Data as in Appendix 1, taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.
Data specific to the 4 automated monitoring stations.
Data in Appendix 2 has been split to show those compounds (17 in total) that can condense and combine into a liquid at temperatures within a compressed air system (or lower) and are C5 and above and those compounds (12 in total) that will remain in a gaseous phase.

Compound	Maximum Hourly Concentration (µg/m³) - 2013			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,2,3-trimethylbenzene	0.02	0.90	3.74	4.24
1,2,4-trimethylbenzene	0.02	2.34	3.39	8.78
1,3,5-trimethylbenzene	0.02	0.60	1.60	8.13
1-pentene	0.10	0.01	0.99	2.85
2-methylpentane	9.37	1.39	13.27	12.76
benzene	4.99	3.08	6.29	8.37
ethylbenzene	20.02	14.96	71.01	83.58
toluene	51.55	4.64	56.34	76.03
iso-octane	53.37	8.08	57.35	51.15
iso-pentane	8.94	2.58	4.03	8.56
m+p-xylene	5.36	2.75	14.02	7.12
n-heptane	19.34	2.48	23.47	18.89
n-hexane	7.18	1.45	3.31	6.74
n-octane	66.39	10.12	41.00	93.74
n-pentane	4.54	3.35	6.01	15.68
o-xylene	8.64	5.85	21.11	38.63
trans-2-pentene	0.01	0.01	3.06	3.84
Totals (µg/m³)	**259.86**	**64.59**	**329.99**	**449.09**
Totals (mg/m³)	**0.26**	**0.06**	**0.33**	**0.45**

Compound	Maximum Hourly Concentration (µg/m³) - 2013			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,3-butadiene	0.56	0.31	1.53	1.66
1-butene	2.21	0.51	1.65	2.31
ethane	5.73	0.14	0.88	1.56
ethene	2.41	20.55	28.30	43.88
ethyne	7.05	0.97	3.48	5.91
isoprene	0.96	17.10	3.31	8.68
propane	21.85	5.28	41.07	28.09
propene	7.35	0.81	5.92	4.60
cis-2-butene	12.89	0.62	7.55	0.01
iso-butane	14.10	2.73	12.56	18.51
n-butane	7.49	2.80	1.28	3.37
trans-2-butene	1.79	0.21	1.16	1.75
Totals (µg/m³)	**84.39**	**52.03**	**108.69**	**120.33**
Totals (mg/m³)	**0.08**	**0.05**	**0.11**	**0.12**

Data as in Appendix 1, taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.
Data specific to the 4 automated monitoring stations.
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Appendix 2

Compound	**Maximum Hourly Concentration (µg/m³) - 2014**			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,2,3-trimethylbenzene	0.03	1.00	65.00	3.50
1,2,4-trimethylbenzene	0.03	1.60	4.90	6.80
1,3,5-trimethylbenzene	0.03	1.00	1.60	4.90
1-pentene	0.02	0.02	1.10	4.50
2-methylpentane	3.80	33.00	5.00	49.00
benzene	1.60	2.40	31.00	6.10
ethylbenzene	1.10	1.20	4.80	5.40
toluene	3.90	5.90	13.00	30.00
iso-octane	0.04	1.30	1.50	4.50
iso-pentane	13.00	5.00	26.00	60.00
m+p-xylene	3.40	4.10	17.00	19.00
n-heptane	0.46	1.30	2.10	4.30
n-hexane	2.90	3.80	7.70	9.70
n-octane	0.04	0.38	0.90	3.10
n-pentane	6.80	2.60	14.00	17.00
o-xylene	1.50	1.80	5.70	7.80
trans-2-pentene	1.40	0.17	1.40	3.30
Totals (µg/m³)	**40.02**	**66.57**	**202.70**	**238.90**
Totals (mg/m³)	**0.04**	**0.07**	**0.20**	**0.24**

Compound	**Maximum Hourly Concentration (µg/m³) - 2014**			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
1,3-butadiene	0.52	0.29	3.00	3.10
1-butene	1.70	0.61	5.10	6.00
ethane	120.00	24.00	68.00	74.00
ethene	7.00	6.30	110.00	15.00
ethyne	0.67	2.20	11.00	8.00
isoprene	2.10	0.37	6.70	6.10
propane	60.00	29.00	110.00	230.00
propene	4.20	7.50	33.00	38.00
cis-2-butene	1.00	0.21	1.20	2.50
iso-butane	8.40	18.00	32.00	59.00
n-butane	14.00	41.00	55.00	52.00
trans-2-butene	1.40	0.26	1.90	3.20
Totals (µg/m³)	**220.99**	**129.74**	**436.90**	**496.90**
Totals (mg/m³)	**0.22**	**0.13**	**0.44**	**0.50**

Data as in Appendix 1, taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.
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Compound	**Maximum Hourly Concentration (µg/m³) - 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
1,3,5-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
Totals (µg/m³)	**63.58**	**26.09**	**165.02**	**236.40**
Totals (mg/m³)	**0.06**	**0.03**	**0.17**	**0.24**

Compound	**Maximum Hourly Concentration (µg/m³) - 2015**			
	Auchencorth Moss	**Harwell**	**Eltham**	**Marylebone Rd**
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)	**101.01**	**51.06**	**236.84**	**268.88**
Totals (mg/m³)	**0.10**	**0.05**	**0.24**	**0.27**

Data as in Appendix 1, taken from the UK Hydrocarbon Network Annual Reports produced by Ricardo AEA for DEFRA.
Data specific to the 4 automated monitoring stations.
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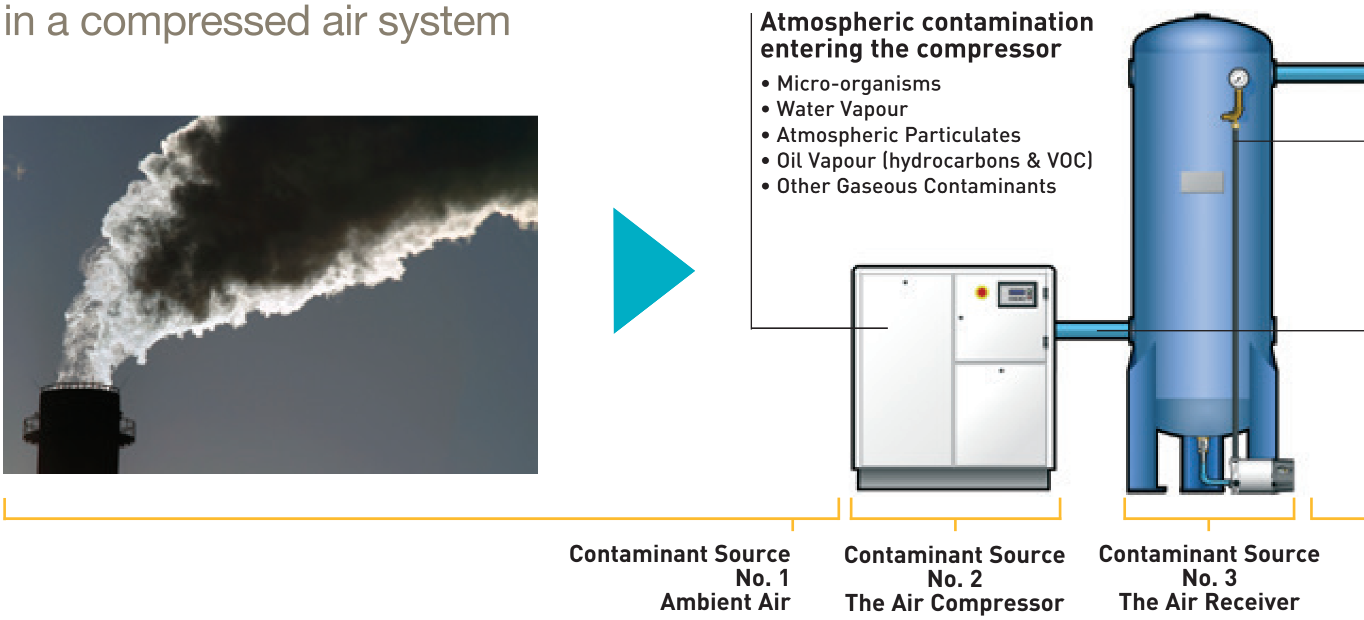
Appendix 3 - Other Contaminants & Sources

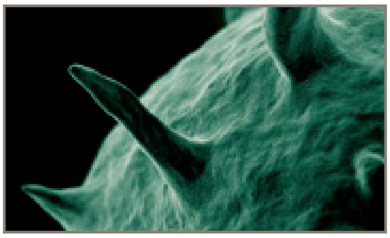
Ambient air is laden with many other unseen contaminants, not just hydrocarbons & VOC which are also drawn into the compressor intake. The ambient air is not the only source of compressed air contamination, the air compressor, air reciever and distribution piping also add contamination.

Contaminants and sources in a compressed air system



Atmospheric contamination entering the compressor

- Micro-organisms
- Water Vapour
- Atmospheric Particulates
- Oil Vapour (hydrocarbons & VOC)
- Other Gaseous Contaminants

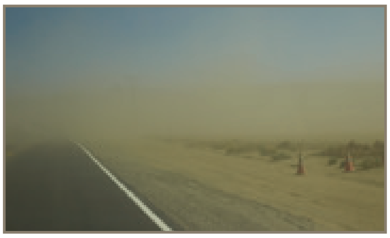


Micro-organisms

Ambient air can contain up to 100 million micro-organisms per cubic metre. Due to their small size, bacteria, viruses, fungi, yeast and spores will all pass through the intake filter and into the compressed air system. Tests carried out by the Danish Technological Institute proved that micro-organisms can survive in compressed air systems up to 400 bar, where the warm moist environment inside the air receiver and distribution piping provides an ideal environment for their rapid growth. Microbial growth is significant in compressor condensate and care must be taken when discharging condensate.

Water vapour

Water enters the compressed air system as a vapour (gas). The ability of air to hold water vapour is dependent upon its pressure and its temperature. The higher the temperature, the more water vapour can be held by the air, the higher the pressure, a greater amount of water vapour is squeezed out. As ambient air is compressed, the temperature of the air increases significantly allowing the heated air to easily retain all of the water vapour entering the compressor.



Atmospheric particulate

Ambient air in industrial and urban environments will typically contain between 140 & 150 million dirt particles in every cubic metre. As 80% of these particles are less than 2 microns in size, they are therefore too small to be captured by the compressor air intake filter and will travel unrestricted into the compressed air system.

Once in the compressed air system, many of the hazards found in ambient air change phase, leading to the creation of additional contaminants. The air compressor, air receiver and distribution also add to the problem.

Compressor Room

Contamination introduced by the air receiver and distribution piping

- Rust
- Pipescale

Contamination introduced by the compressor

- Water Aerosols
- Condensed Liquid Water
- Liquid Oil & Oil Aerosols
- Oil Vapour

Total contamination entering the compressed air distribution system

- Micro-organisms
- Water Vapour
- Atmospheric Particulates
- Oil Vapour (hydrocarbons & VOC)
- Water Aerosols
- Condensed Liquid Water
- Liquid Oil
- Oil Aerosols
- Rust
- Pipescale

Contaminant Source
No. 4
The Distribution Piping

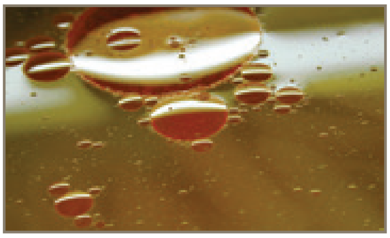
Liquid water and water aerosols

After compression, compressed air is cooled to a usable temperature by an after-cooler. This cooling reduces the air's ability to retain water vapour, resulting in condensation of water vapour into liquid water. The presence of liquid also causes aerosols to be formed.

After-coolers typically incorporate a water separator to reduce the amount of liquid entering the compressed air system (these do not remove 100% of the condensed liquid and have no effect on aerosols).

The air leaving the after-cooler and entering the compressed air system is now 100% saturated with water vapour. Any further cooling of the compressed air will result in more water vapour condensing into liquid water and the generation of more aerosols.

Condensation occurs at various stages throughout the system as the air is cooled further by the air receiver, the distribution piping and the expansion of air in valves, cylinders, production equipment.



Liquid oil and oil aerosols

As with water, oil vapour drawn in with the ambient air is cooled and condensed within the after-cooler leading to the formation of liquid oil and oil aerosols (even with oil-free compressors) which carry downstream.

The majority of air compressors in use today use oil in their compression stage for sealing, lubrication and cooling.

Even though the oil is in direct contact with the air as it is compressed, due to the efficiency of modern air / oil separators built into the compressor, only a small proportion of this lubricating oil is carried over into the compressed air system as a liquid or aerosol (typically no more than 5mg/m^3 for a well maintained screw compressor) or as oil vapour.

Rust and pipescale

Rust and pipescale can be directly attributed to the presence of water in the compressed air system and is usually found in air receivers and distribution piping. Over time, the rust and pipescale breaks away to cause damage or blockage in production equipment which can also contaminate final product and processes. Rust and pipescale problems often increase for a period of time after the installation of dryers into older piping systems which were previously operated with inadequate or no purification equipment.

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