TECHNICAL ARTICLE PROGRAM (TAP)
Compressed Air: The Best Choice

1300 SUMNER AVENUE, CLEVELAND, OHIO 44115 • 216-241-7333

TAP #106

Written by Donald White and Clemens Heinrici,
Donaldson Company, Inc.

What is Clean, Dry Air?

Atmospheric air is composed of countless contaminants consisting of unwanted gases, liquid droplets, and particles. Air is the universal diffuser, as water is the universal solvent. Essentially all gases, vapors, and aerosols small enough to be suspended enter the atmosphere eventually. The atmosphere transports the entrained components, quite often over long distances, until they return to the earth's ecosystem.

Air is composed of a multitude of gases, vapors, and aerosols that all vary in concentration, depending on time, location of nearby sources, etc. In addition, the definition of a contaminant depends on the application. Airborne pollen, for example, is a boon to vegetation (and is certainly not a contaminant) as it is transported from one location to another. But it can also be a plague to animals or humans with respiratory ailments. Similarly, water vapor in the air we breathe is essential to keep the mucous glands moist, but it also breeds harmful microbes and contributes to metal corrosion.

Contaminants in compressed air systems are also defined by how the air is used. Because of this, compressed air requirements in various industries and laboratories vary considerably – and are quite different from the requirements for the air people breathe. So the purification method needed for any particular application will depend on the specific requirements for that application.

The first concern in the treatment of air is the reduction or elimination of aerosols (any suspension of fine solid or liquid particles in gas). Relatively large dust particles (over 100 microns in size) are easily removed in screen strainers and coarse panel filters. Particles below 100 microns require finer filtration. These particles are smaller than the width of a human hair, and are too small to be seen individually by the human eye. Particles of this size, often generated from road dust or volcanic eruptions, have been known to remain in suspension in the atmosphere for more than a year. Most of these particles can be removed by dust filters with a rating of 5 microns and larger. Finer aerosols and mists require even better filtration, often as low as 0.01 micron. Microbes require absolute filtration for their removal, where the largest pore size in the filtration media is less than the smallest microbe present.

Liquid aerosols are removed by coalescing filters, which are composed of several media layers. The first layer consists of a fine pore media to retain the particulate contaminant and remove the fine liquid aerosols. The liquid collected on the first layer coalesces into droplets as it migrates through the media. A second layer of coarser grade media with larger pores causes the liquid to agglomerate into larger droplets. In the outer layer, the drainage media, droplets collect and flow by gravity in narrow rivulets into a collection sump below the filter. Some type of drainage device is required to continually remove the liquid collected in the drainage sump.

This article was accepted as part of the CAGI Technical Article Program (TAP), Compressed Air: The Best Choice. CAGI is the leading organization representing manufacturers of compressed air system equipment, including air compressors, blowers, pneumatic tools, and air and drying and filtration equipment. TAP articles are information tools and should not be used as substitutes for instructions from individual manufacturers. Always consult with individual manufacturers for specific instructions regarding their equipment.

CAGI, its members and participants in its activities, assume no responsibility, obligation or liability to anyone for any loss or damages in connection with the use, completeness, interpretation of, or reliance upon this article.

Gaseous and vaporous contaminants are reduced or eliminated by thermal or adsorptive devices. The choice of treatment again depends on the application, as this defines what components are harmful and the degree of purification required.

In compressed air applications, the compression process also tends to increase contaminant concentrations. Because of the increase in concentration, the system can become more susceptible to contaminant fouling and corrosion. The paragraphs that follow describe a number of compressed air applications, possible contamination issues, and some of their very specific compressed air requirements.

Energy Converters

Energy converters require clean, dry air for cooling and, in some cases, for the supply of oxygen. Water vapor, hydrocarbons, carbon dioxide, hydrogen sulfide, nitrogen oxides and sulfur oxides reduce the efficiency of the energy converter and can lead to premature equipment failures due to surface fouling and overheating.

Lasers, an acronym for light amplification by stimulated emission of radiation, are used in many printing, metal cutting, and welding devices. High intensity light generated in the resonator is sharply focused by optical lenses into a very narrow beam. Compressed air is normally used to cool the resonator. The length of the resonator (the distance between the stenotic lenses), affects the required purification level. The contaminate gases and vapors are primarily triatomic and exhibit strong polarization effects. Water vapor is highly polar, and carbon dioxide is a strong dipolar gas. Electromagnetic energy of light is easily absorbed by the contaminant gases, similar to water in a microwave oven, resulting in an elevation in temperature between the lenses and a significant loss of energy from the laser system. In high concentrations, a rise in temperature can be sufficient to fracture the glass lenses. Also, aerosol contamination from dust and oil mist can agglomerate on the lens, distorting and reflecting the beams of light. This can also result in overheating and lens breakage. Fine filtration is required to keep the lenses free of contamination reduce moisture content. For short length resonators, such as those used in printing devices, filtered +40°F dry air is sufficient. For long resonators typically used in welding and cutting devices, Zero-Air is required. This has less than 0.003 ppmw hydrocarbon vapor, -100°F dew point air, and less than 1 ppmw carbon dioxide. (Note: The dew point is the temperature at which water vapor will begin to condense.) In sum, the quality of the air used in a laser cooling system has a significant effect on its efficiency and durability.

Fuel cells, another form of energy conversion, are affected by the quality of the natural gas used to provide hydrogen, the purity of the hydrogen gas fed to the fuel cell, and the contamination level of the air providing oxygen that combines with hydrogen to produce electricity in the fuel cell. Fuel cell membranes are fouled by very small quantities of contaminant gases including the odorant in natural gas, water vapor, carbon dioxide, carbon monoxide, nitrogen oxides, and sulfur compounds. As a result, fuel cells require very pure hydrogen and oxygen, plus Absolute Air (having a moisture dew point below –100°F, a carbon dioxide level below 100 ppbw, and NOX and SOX levels below 10 ppbw). With proper purification of the system gases, high efficiency and long life of the fuel cell converter is assured.

Ozone, microwave, and plasma generators, as well as high voltage electrical transformers require –40°F dew point dry air to prevent corrosion and insulation break-down. Electrical transformers in Canada normally use high-pressure air to accomplish this, as opposed to insulating oil typically used in the USA.

Electrical Generators in power plants use hydrogen gas at slightly elevated pressure to reduce windage losses between the rotor and stator of the generator. Hydrogen, being a very low density gas, provides an almost frictionless gap between the two generator components. This hydrogen must be dry and aerosol free. Moisture in the hydrogen gas has been found to be problematic, as it can cause significant corrosion of the high voltage terminal strip. Drying hydrogen to -40° F dew point has eliminated these types of corrosion problems.

Pneumatic Power

Air motors use compressed air to power tools ranging from dental drills to roadside jackhammers. Air motors also serve as starting engines for large compressors and shipboard power plants. They provide very light, versatile drives for countless services. Energy is extracted thermally from compressed air and a large temperature reduction occurs adiabatically from the expansion of the air through the motor. To prevent condensate and to obtain maximum energy from an air motor, the compressed air is dried to -40°F or less. Condensation fouls the air motor and in certain instances can block the exhaust port with ice.

Military weapons often rely on pneumatic power. One example is the Phalanx gun, which is used on ships to protect against airborne missile attacks. The Phalanx propels hundreds of rounds per minute, and the reliability of its shell loading racks depends on highly pressurized, clean, dry air. Condensate in the air motor, or ice formation in cold climates, could be disastrous. To assure reliable service, the compressed air in this type of application is cleaned with coalescing filters and the air is dried to -100°F dew point.

Air brakes used in trucks and high-speed trains also require dry, clean air. The air must be dried to less than –40°F dew point to assure the reliability of the brakes in these critical service applications.

Air actuated control valves need clean, dry pilot air in order to perform reliably. Pneumatic control valve actuators include: 1) piston actuators (often with rack and pinion drives to rotate the valve stem); 2) diaphragm actuators (of either the rubber diaphragm or metal bellows type); and 3) vane actuators (which pivot through an arc of approximately 90°). Valve positioners and pneumatic controllers, such as pressure or temperature controllers, are used to regulate the pilot air and modulate the valve position. Solenoid-actuated air valves are commonly used for on-off service. These actuators and control devices are subject to fouling by dust and oil in wet compressed air. Dust particles often cause erosion in critical orifices, and when combined with oil or water, they often form a sticky grime that hinders or prevents movement of critical components. To prevent fouling and corrosion, fine filtration is required, and the pilot air is dried to –40°F dew point.

Air Purging and Conveying

Microelectronics manufacturers demanding high production yields depend on clean, dry air to remove microscopic debris from the surfaces of computer chips and computer boards. Small amounts of particulate contamination and oil aerosols can cause bridging and shorts in the microcircuits, and moisture can promote oxidation of the micro terminal strips, resulting in product failure. Cleaning operations in the electronic industry require fine filtration, less than 0.003 ppmw hydrocarbon vapor, and less than –40°F moisture dew point. In fact, some manufacturers have found the need to reduce moisture content to less than -100° dew point.

Food and beverage manufacturers use compressed air for product conveyance and mixing. Unpurified air can result in product contamination and spoilage. Air containing less than 0.003 ppmw oil vapor and -40°F moisture dew point is generally specified for these types of applications.

Pharmaceutical and chemical manufacturing plants typically require cleaner air than the food industry. Small quantities of impurities can ruin a batch of product, or alter it to the point that the product is of lower quality than required. Compressed air used in this industry for conveyance and mixing typically contains less than 0.003 ppmw hydrocarbons and has a dew point as low as -100°F.

Painting systems use compressed air to atomize and spray paint onto surfaces. Trace amounts of oil and water can create fish-eye craters in the finished surface, and moisture can affect the paint's surface tension and texture. Small industrial paint booths normally use air dried to 40°F dew point, while large-scale automotive paint operations call for at least -40°F dew point air.

Atmospheric air filters (such as pulse cleaned dust collectors) filter large flow rates of air. Cleaning of the media prolongs the service life of the filters. In order to remove debris from the filtration media, these filters often rely on short bursts of clean, compressed air from jetting nozzles. Particulate matter and liquid aerosols are filtered from the pulse air to prevent contamination of the filter media during the cleaning process. The air is dried to a dew point of -5°F (or lower) to prevent moisture from being adsorbed by the hygroscopic dust particles. Wetted dust particles will agglomerate and resist removal by the pulsed air jet. In this application, an air receiver is typically required to dampen the pressure pulses so effective filtration and drying methods can be applied to the compressed air.

In power plant boilers, *soot blowers* often use dry, compressed air to periodically clean the boiler tubes. However, moisture in the compressed air can form corrosive sulfuric acid when it's combined with sulfur compounds found in the ash deposits. Compressed air used for these types of operations is dried to -40°F moisture dew point to prevent sulfuric acid formation. Air motors rotate the soot blower tubes, and the air required for this function is also dried to -40°F dew point to prevent condensation and fouling of the motor vanes, which can cause motor failure. Motor failure could allow excessive soot accumulation on the tubes and overheating, which can then result in boiler failure.

Instrumentation Air

Instruments used to measure air quality and analyze air constituents often require purified air. For example, automotive exhaust emissions control analyzers, electrolytic cell hygrometers, infrared detectors, and gas chromatography analyzers require pure air, both as a carrier gas and for proper calibration. Zero hydrocarbon air is often used in these situations, as it has a moisture content below -100°F, less than 1 ppmw carbon dioxide, and less than 0.003 ppmw hydrocarbon vapors.

Radar systems require dry air in the wave-guide tubes to prevent frost or freeze-up in cold climates. The drying of wave guides is critical in aircraft and shipboard applications, where sub-zero temperatures are often encountered. During the Falklands War in 1982, wet air in the radar wave guides prevented the detection of incoming missiles, and as a consequence, several ships and many lives were lost.

Pure Gas Generators

Air fractionators are used to produce a single component from air. All other constituents are considered to be contaminants. Oxygen and nitrogen are produced in fractionators, either by adsorption processes at ambient temperature or by thermal processes at cryogenic temperatures. The fractionators vary in size from large cryogenic systems to small, home oxygen medical generators that use adsorptive separation. For fish farm or welding applications, for example, 90% purity oxygen is normally sufficient, while for fighter aircraft breathing applications, 95% purity oxygen is required. And for industrial applications such as for inert gas welding or combustible tank blanketing, nitrogen with 99.5+% purity is normally required. In the cryogenic sequestration of oxygen, nitrogen, argon, helium and other gases, the air must be dried initially to -100°F dew point, and the carbon dioxide level reduced to less than 1 ppmw to prevent frost formation and riming on the heat exchanger tubes. Adsorption systems are often used for the initial purification of air in cryogenic plants. Some contaminant components are present in the product of the separation system. Cryogenically produced liquid oxygen, or nitrogen, typically contains 10 to 50 ppbw hydrocarbon residue. An all-Teflon® cryogenic filter containing a molecular sieve adsorbent can reduce the hydrocarbon contamination level to less than 1 ppbw.

Medical Breathing Air

Respiratory air in hospitals is the purest form of breathable air, and is typically used to treat patients in critical care units and in operating rooms. It has an oxygen content of 19.5% to 23.5%, with 14% being the minimum required to support human life. Respiratory air has a reduced dew point of -65°F or 10°F lower than the coldest ambient temperature, less than 500 ppmv carbon dioxide, less than 10 ppmv carbon monoxide, less than 5 ppmv sulfur dioxide, and less than 2.5 ppmv nitric oxide or nitrogen dioxide. It should also have less than 0.003 ppm oil vapor.

Operating room air is typically a blend of pure respiratory air and recirculated exhalent containing an anesthetic gas. The recirculation of anesthetic gas is essential because it is vital to establish and maintain a critical concentration of the anesthetic, particularly because the anesthetic is extraordinarily expensive (a small vial often costs several hundred dollars). For over a century, soda lime has been used to reduce the carbon dioxide and water vapor in the exhalent so that it can be recirculated. Other impurities, (some noxious) cannot be removed by soda lime and they increase in concentration with the minutes and hours required for various operations. Increased concentrations of these contaminants can limit the duration of the operation and cause injurious side effects. In addition, liquid drains from the soda lime trap can release small quantities of the anesthetic gas, and as a consequence, many anesthesiologists and technicians have become so sensitized to the gas that they can no longer practice their profession. This problem can be remedied by applying modern adsorption technology. Improved methods of separation using regenerative adsorption can replace soda lime treatments and offer improved exhalent air purification without anesthetic leakage, benefiting both patient and operating room staff.

General breathing air quality in hospitals is less stringent. This air typically needs to have a maximum moisture dew point of 35°F, less than 25 ppmv hydrocarbon vapors, and a maximum of 5 mg/m^3 particulate aerosols. Reliability is critical in hospital air applications. To assure continued supply of treated air, purification systems are required to have two air dryers arranged in parallel - with switchover controls in the event of system failure or fault detection.

Industrial breathing air systems should be as pure as general hospital air, but system redundancy is not required. The air in industrial breathing air systems is used for supplying pure air to breathing hoods, face masks within hazardous areas (e.g., paint booths and chemical or petroleum storage tank inspection or cleaning), and pressurized suits such as used in nuclear power stations. Here, fumes may be toxic and the oxygen content insufficient to support human life. In these types of situations, however, purified air must be rehumidified at the point-of-use so as not to dry out the mucous membranes of personnel in the area.

Ventilation air in commercial buildings and aircraft require purification treatment to prevent the intrusion of microbial contamination and limit the concentration of contaminant vapors and gases. Contaminant concentration will increase in enclosed ventilation systems without proper treatment. At a minimum, ventilation air must meet Grade D requirements to prevent illness and the spread of disease (such as the 1976 Legionnaire's Disease). Grade D air must contain less than 1000 ppmv carbon dioxide and less than 10 ppmv carbon monoxide. The carbon dioxide limit is used as a surrogate to provide assurance that any toxic contaminants have not increased to harmful levels. Carbon dioxide is not toxic; naval testing has shown that submariners are not affected even with 35,000 ppm carbon dioxide in their breathing air provided the oxygen concentration is maintained between 20% and 23%. However, a level of 1000 ppm is more than double the normal CO_2 concentration and the assumption is made that any toxic contaminants will also be more than double in concentration.

In military service, breathing air must be treated for chemical and biological warfare agents, and for radioactive fall-out debris. Gas mask canisters provide individual protection, and collective protection is required in closed environments such as in battle stations, helicopters, aircraft, tanks, and personnel carriers. Regenerative adsorption systems are required for collective protection to assure continuous protection during a prolonged attack.

Conclusion

Clean, dry air is defined by the application in which it is used. Similarly, the definition of a contaminant depends on the application as well. Because of this, compressed air requirements in various industries and laboratories will vary significantly. And the purification method needed for any particular application will depend on the specific requirements for that application. As a result, it is critical for compressed air users to be aware of potential contaminants in their systems, the effects of these contaminants, and potential remedies for successful contamination control.

Generally speaking, air used for critical industrial applications is required to have a moisture content below -100° F dew point, less than 1 ppm carbon dioxide, and less than 0.003 ppm hydrocarbon vapor. In less critical areas, -40°F dew point air is sufficient, and for even less critical applications, +40°F dew point is acceptable.

For breathing air systems, it is essential that all air contain between 18% and 23% oxygen. Furthermore, the concentration of toxic and noxious contaminant vapors must be reduced to tolerable low levels.

Modern air treatment systems based on adsorptive and thermal processes can be used to assure the highest quality air for the application.

Composition of Air
Laboratories and Breathing Air

	Atmospheric Air (ASHRAE)[1] % by Vol.	*Typical Urban Air % by Vol.*	*Zero Grade Air (Grade J)[2] % by Vol.*	*Absolute Quality Air % by Vol.*	*Breathing Air (Grade D)[3] % by Vol.*	*Respirator Air (Grade N)[2] % by Vol.*	*Hospital Breathing Air[4] % by Vol.*
Nitrogen	78.0840%	78.1%	—	—	—	—	78 – 80%
Oxygen	20.9476%	20.9%	20.5±2%	20.5±2%	20.5±2%	20.5±2%	20 – 21%
Argon	0.9340%	0.9%	—	—	—	—	—
	PPMV	*PPMV*	*PPMV*	**PPMV**	*PPMV*	*PPMV*	*PPMV*
Carbon dioxide	314	650	≤ 0.5	≤ 0.10	≤ 1000	≤ 500	≤ 500
Carbon monoxide	trace	25	≤ 1.0	≤0.10	≤ 10	≤ 10	≤ 5
Nitrogen oxides	0.5	0.5 – 5	≤ 0.2	≤ 0.02	—	≤ 5	—
Sulfur oxides	0 – 1.0	0.2 – 2	≤ 0.1	≤ 0.02	—	≤ 5	—
Hydrocarbons	—	30	≤ 0.5	≤ 0.10	—	—	≤ 10
Methane	1.5	10	—	≤ 1.0	—	—	≤ 10
Hydrogen sulfide	—	10	—	≤ 0.02	—	—	—
Hydrogen fluoride	—	3	—	≤ 0.02	—	—	—
Hydrogen	0.5	—	—	—	—	—	—
Ammonia	trace	—	—	≤ 0.01	—	—	—
Ozone	0.02 – 0.07	—	—	≤ 0.01	—	—	—
Inert Gases	24.657	—	—	—	—	—	—
Aerosols	—	—	—	0.01mg/m^3	5 mg/m^3	0 mg.m^3	1 mg/m^3
Water Vapor	36%rh	0 – 100%rh	≤ 1 ppmv	≤ 1 ppmv	—	-65° F	-60° F

[1]ASHRAE Brochure on Psychrometry
[2]CGA G-7.1-1997 Commodity Specification for Air, Compressed Gas Association
[3]OSHA Standard 29 CFR 1910.134 and Compressed Gas Association G-7.1-1007
[4]National Standard of Canada CAN/CSA-Z180.1-00 Compressed Breathing Air and Systems; NFPA 99C

Industrial Compressed Air Quality
International Standard ISO 8573

Class	*1*	*2*	*3*	*4*	*5*	*6*
Max. Particulate Size, micron	0.1 ì m	1 ì m	5 ì m	15 ì m	40 ì m	—
Max. Particle concentration, mg/m^3	0.1	1	5	8	10	—
Oil Aerosol and Vapor, mg/m^3	0.01	0.1	1	5	25	—
Water Vapor Pres. Dew point, °F	-94F°	-40 F°	-4 F°	37.4 F°	44.6 F°	50 F°