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Introduction

This white paper focuses on the Refrigerated compressed air dryer and its instrumental role in treating compressed air by eliminating the undesirable moisture from it. The paper also provides an in-depth understanding of the selection and maintenance process that must be followed while opting for a refrigerated dryer.

Compressed Air

Before talking about Refrigeration dryer, we need to assess the composition of air and the reasons for compressed air treatment. Compressed air is an integral part of every manufacturing industry from small machine shops to large scale plants. It is widely regarded as the fourth utility.

Compressed air is the ambient air that has been pressurized to perform a particular task. It is preferred over utilities like electricity and steam because of its flexibility, safety and adaptability along with its ease of storage and transmission. Compressed air system consists of supply and demand side. The supply includes the compressor, treatment equipment and air receiver while demand is the point of use application.

Compressed air moisture treatment

Atmospheric air is a mixture of gases and other constituents in varying proportion. Ambient air composition includes water and other constituent. Water is found in ambient air in the form of vapour. The amount of water vapour present in the atmosphere depends on the ambient temperature. At a given temperature and pressure, the air can hold a maximum amount of water per cubic meter of air, in which case the air has a relative humidity of 100%. In words we call that air is saturated. Any amount of water beyond this form liquid would condensate. As the temperature decreases, the water holding capacity of air also decreases. When we decrease the temperature of air, we increase its relative humidity till it reaches 100% and finally water get condensed.

During the compression process, the volume of air decreases. But the amount of water vapour remains the same since it is incompressible. Thus, the concentration of water remains the same until the air reaches 100% saturation and water condenses.

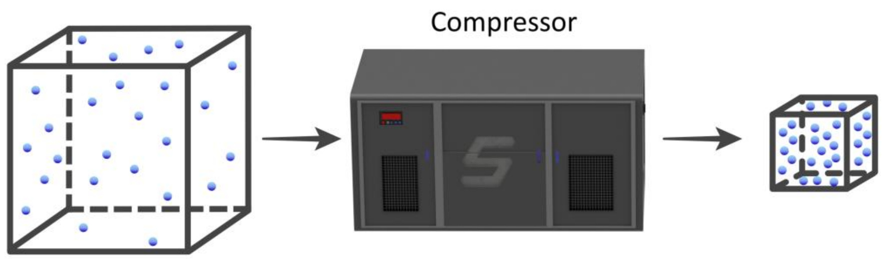


Fig.1: Increase in relative humidity of ambient air by compression

Dew point denotes the temperature to which air must be cooled to become saturated with water vapor. Further cooling will condense the airborne water vapour into liquid water. Pressure Dew Point (PDP) is used to denote water content in compressed air. It is the temperature at which water vapour condenses into water at the given pressure. Lower the PDP value, lower is the water vapour content in the compressed air.

Pressure dew point must not be mistaken with Atmospheric Dew point (ADP). This means the saturation of water vapour in the given volume of air occurs at $+3^0$C PDP for 7 bar and it achieves a lowering in concentration of water vapour (Dryness) equivalent to a dew point of (-) 23^0C at atmospheric pressure. This helps in selecting the method we want to use for drying compressed air. From financial standpoint, lower the dew point we try to accomplish, higher is the investment required.

The moisture carrying capacity of air increases as temperature increases. An oil- lubricated compressor increases the temperature of air to $75\text{-}90^0$C.There are multiple methods of drying air. Some are:

- Air is over-compressed to increase the concentration of water and is cooled. Finally it is expanded to working pressure to attain lower PDP. It is not recommended due to high energy consumption.
- After-cooler connected next to compressor uses heat exchanger to reduce the temperature of air and condense more than 70% of the moisture in compressed air. It also cools down

the temperature of air to approximately 10^{0}C above the coolant (water or air) temperature.

- Refrigerant Dryer works on the principle of refrigeration cycle to cool the air and attain its PDP. We will look further into this in this whitepaper.
- Adsorption dryer uses hygroscopic desiccant material to remove moisture from air and become saturated. They can achieve a very low level of PDP.
- Deliquescent chemicals are used for absorption drying.
- Membrane dryers filter water molecules from air, based on difference in membrane pore size.

Reasons for drying

Water from compressed air causes machinery down-time, production loss, product rejection and high maintenance cost. This is true for pneumatics as well as applications with direct air-product contact.

Some of the common problems caused by moisture in the industry are:

- Corrosion and scale formation in pipelines and vessels.
- Sluggish movement of the piston in the pneumatic cylinder.
- Washing away of the lubricants and degrading oil quality.
- Malfunctioning of control and air logic equipment.
- Contamination of products such as food and medicines.
- Microbial growth causing challenges in healthcare and food industry.
- Freezing of moisture in pipelines and creating obstruction to air flow.

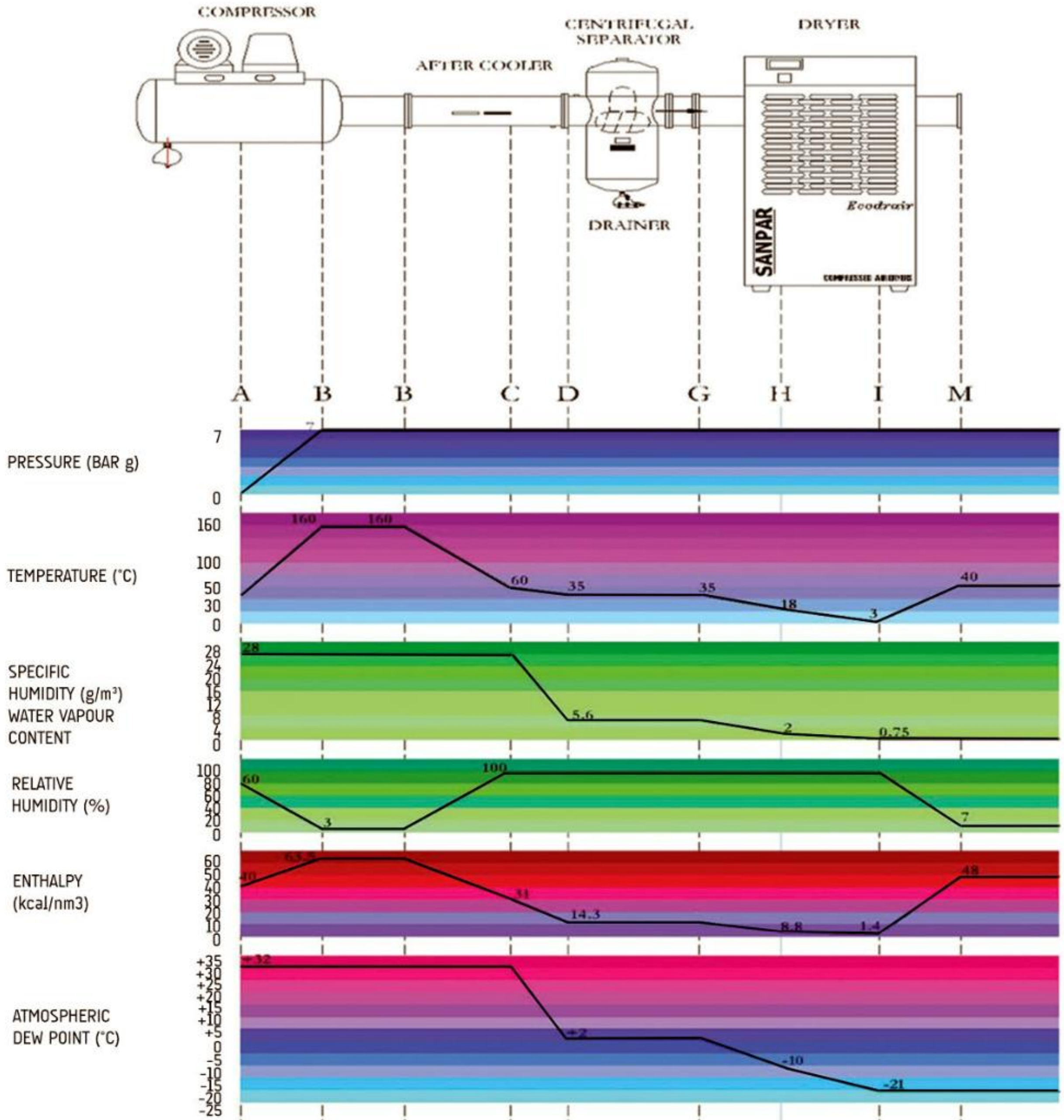


Fig.2: Varying air properties at different points in the compressed air layout

ISO 8573.1

International Organization for Standardization (ISO) has defined a quality standard for the production and testing of compressed air, termed ISO 8573 Series. ISO 8573.1 is used to classify the purity while ISO 8573.2-9 specify the test to check for one or more contaminants in the compressed air. ISO 8573.1 was published in 2010 and last reviewed in 2017.

ISO 8573.1-2010 Class	Solid Particles				Water		Oil
	Max. number of particles per m^3			Mass concentration	Vapour pressure dew point	Liquid	Total oil content (liquid, aerosol and vapour)
	0.1 – 0.5 µm	0.5 – 1 µm	1 – 5 µm	mg/m3	°C	g/m3	mg/m3
0	As specified by the equipment user or supplier and more stringent than Class 1						
1	≤ 20,000	≤ 400	≤ 10	–	≤– 70	–	0.01
2	≤ 400,000	≤ 6,000	≤ 100	–	≤ –40	–	0.1
3	–	≤ 90,000	≤ 1,000	–	≤ –20	–	1
4	–	–	≤ 10,000	–	≤ +3	–	5
5	–	–	≤ 100,000	–	≤ +7	–	–
6	–	–	–	5	≤ +10	–	–
7	–	–	–	5 – 10	–	≤ 0.5	–
8	–	–	–	–	–	0.5 – 5	–
9	–	–	–	–	–	5 – 10	–
X	–	–	–	> 10	–	> 10	> 10

Table 1: Overview of purity classes in compressed air for particles, water and oil as per ISO 8573-1:2010 at 20°C and 1 bar abs pressure.

ISO 8573-1:2010 specifies purity classes of compressed air with respect to particles, water and oil independent of the location in the compressed air system at which the air is specified or measured.

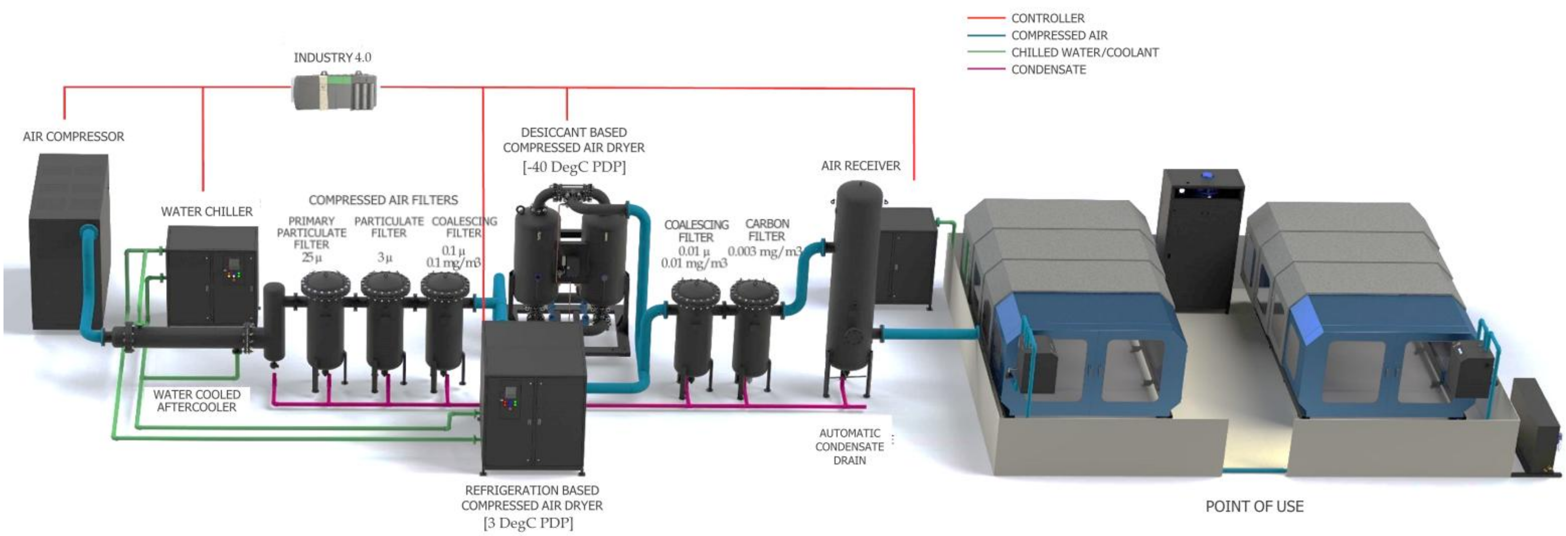
ISO 8573-1:2010 provides general information about contaminants in compressed-air systems as well as links to the other parts of ISO 8573, either for the measurement of compressed air purity or the specification of compressed-air purity requirements. In addition to the above-mentioned contaminants of particles, water and oil, it also identifies gaseous and microbiological contaminants. The standard is further divided into Classes. The standard defines the maximum level of contaminants in compressed air for each of these classes. Higher the class, lower is the required degree of purity.

The required class of air is usually defined by the manufacturer of the point of use machines and the application. Here Class 0 air is the highest purity of compressed air achievable. The essential air quality will be defined by the supplier or the consumer and will be adhering to stricter quality than Class 1. Class 0 air is mainly used in industries like pharmaceuticals, food, textile and electronics etc. where the air comes in direct contact with the product and contaminants can hamper the quality of the product. It is achieved through a combination of oil-free compressor and compressed air treatment equipments

Compressed air system layout

A typical compressed air layout is shown. The compressor is connected to a series of treatment equipments to remove the contaminants and moisture from the compressed air. The supply side equipments also have the function of reducing the temperature of the air as high temperature can damage the end-use machine parts like rubber seals and diaphragm. The selection of the equipments depends on the application and the quality standards.

Fig.3: Compressed air system layout



Refrigerated Compressed Air Dryer

Refrigerated air dyer is suitable for drying compressed air in most industrial air applications. It works on the principle of refrigeration cycle. It is designed to maintain a PDP of (+) 2 to (+) 5^0C. Advantages of refrigerated air dryer include low initial and operating cost, low maintenance requirements and fairly constant dew point control.

Refrigerated air dryers are divided as cycling and non-cycling refrigerated dryer. Cycling type makes use of a thermal mass to cool the compressed air. This allows for accommodating varying load and shutting down refrigerant compressor when not in use. This is bulky and expensive equipment compared to its non-cyclic counterpart. Non-cyclic dryer does not vary its compressor operation with load. They are much simpler and widely used. We will be talking about them in detail for further parts.

Working Principle

Refrigerated air dryer works by the principle of refrigeration cycle. It utilizes the thermal properties of the refrigerant to cool the air to its PDP. Modern dryers use chlorine free refrigerants such as R134a, R407c or other environmentally friendly gases that have a low Global Warming Potential (GWP).

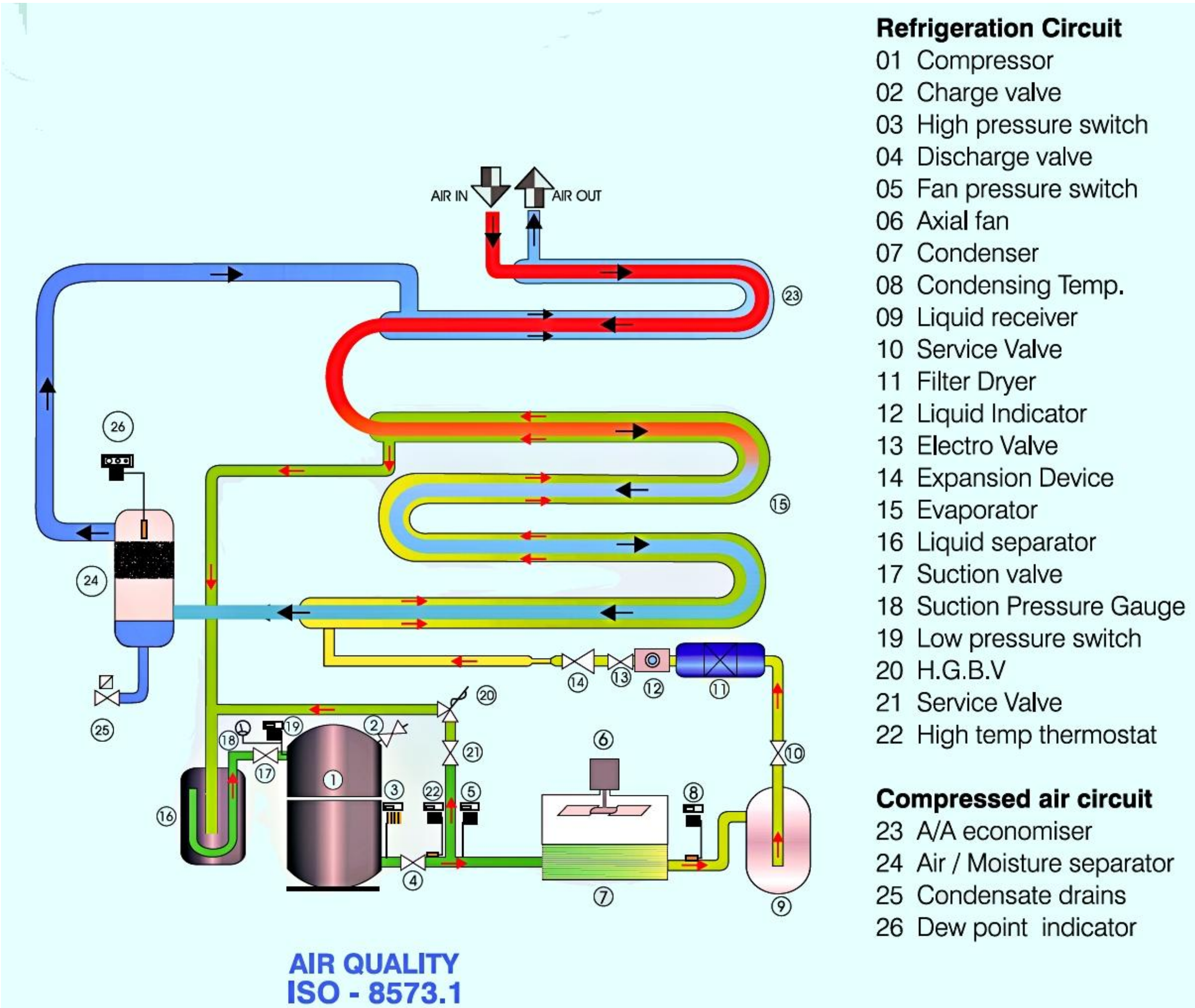


Fig.4: Working of refrigerated air dryer

Working Principle (Simplified in Three Stages)

1. **Air/Air Heat Exchanger (Economizer):**

The compressed air enters the dryer through an air-to-air heat exchanger (economizer). The incoming hot compressed air is pre-cooled by the outgoing cold dry air. In this process, the outlet air (approximately +3 °C) gets heated by the hot incoming air.

2. **Air/Refrigerant Heat Exchanger & Refrigeration Cycle:**

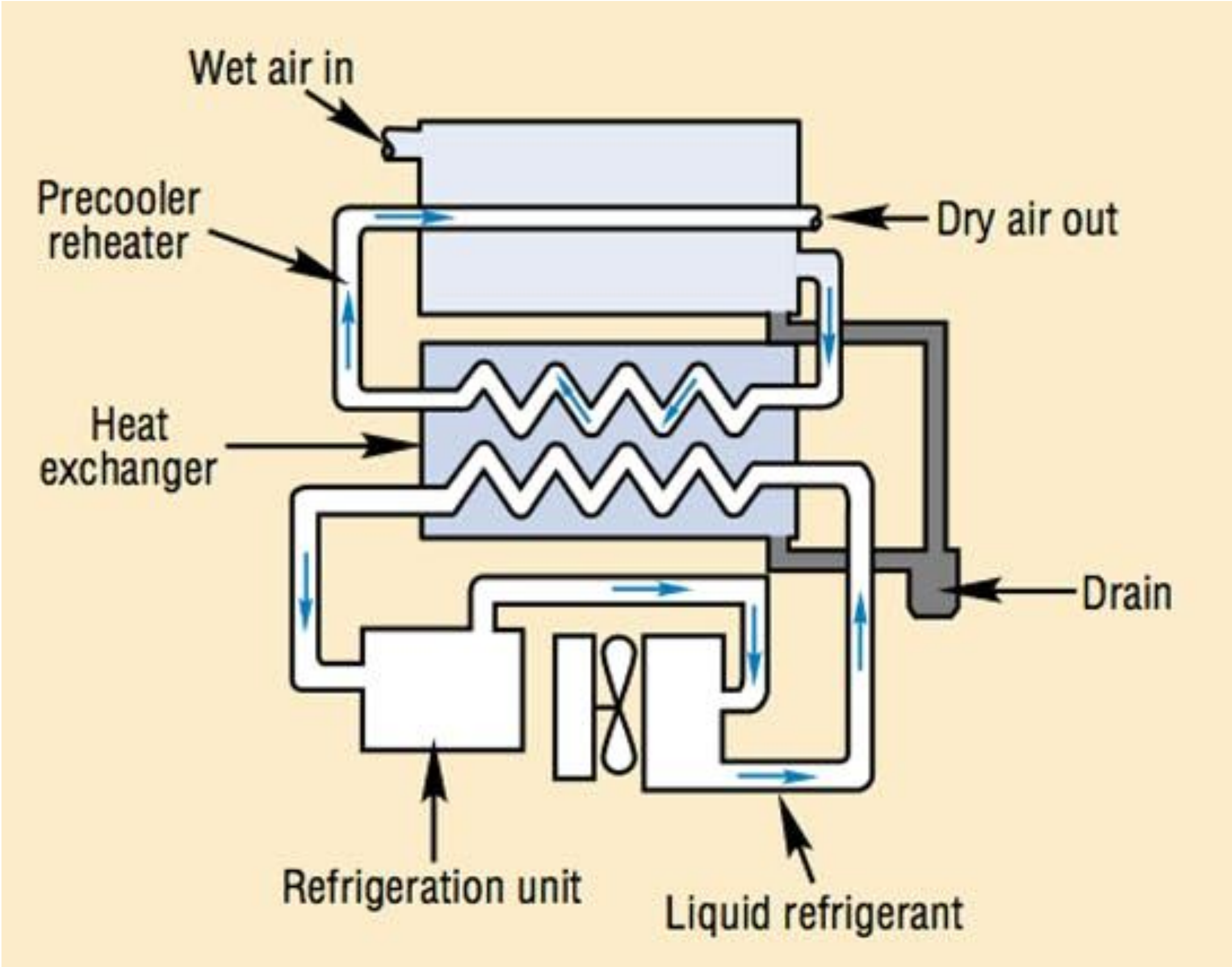
The pre-cooled compressed air then passes into an air-to-refrigerant heat exchanger. Here, the air is cooled further to around +3 °C, reaching its saturation temperature. The condensate formed is removed by an automatic drain.

3. **Reheating of Outgoing Air:**

Finally, the outgoing compressed air is reheated to near inlet temperature by exchanging heat with the incoming warm air. This reheating ensures the relative humidity of the outgoing compressed air is significantly reduced, preventing condensation in downstream applications.

4. **The refrigerant flows through its own closed refrigeration circuit:**

- The refrigerant absorbs heat from the compressed air and evaporates.
- The resulting low-pressure vapor is drawn into the refrigerant compressor, where it is compressed to a high-pressure, high-temperature state.
- This high-pressure refrigerant is then cooled in the condenser by a cooling medium (air or water).
- Next, it passes through the expansion valve, which reduces its pressure and temperature.
- The refrigerant, now around 0 °C, enters the evaporator for further cooling of compressed air.
- A Hot Gas Bypass Valve (HGBV) is used to regulate refrigerant flow and maintain stable operating conditions within the refrigeration system.



Selection and Sizing

Compressed air treatment equipment selection depends on the needs of the manufacturing plant. Every company has different values, applications and production strategies that dictate their choice. But a mutual theme that unifies every industry is the requirement for energy conservation and cost effective growth.

Compressed air is a key utility in modern production and the equipments associated with its generation and treatment are capital equipments. It needs a significant investment of all forms to maintain the performance of the process and product.

Accurate sizing and selection of the dryer goes a long way and the factors it depends on are:

- **Application**: The primary selection process is between desiccant and refrigerated dryer. Desiccant dryer can achieve (-) 70^0C PDP while refrigerated can only attain (+) 3^0C PDP. The consumer must verify the ISO 8573.1 compressed air quality class rating they must adhere to. So industries like automobile uses refrigerated air dryer while pharma, food and other critical application industries use desiccant dryer.

- **Operating parameters:** Properties such as flowrate (Free Air Delivery), working pressure, PDP, maximum ambient temperature and maximum inlet air temperature. The inlet air temperature must be brought down to at least 45^0C using an after cooler for the dryer to work efficiently.
- **Pressure drop:** The user must select the dryer with least pressure drop as this can elevate energy consumption. The pressure drop increases with flowrate and operating pressure, so the dryer must be appropriately sized. Pressure drop is specified by most brands
- **Capital cost and maintenance:** The selection of the brand should depend on their compliance to standards like ISO 7183- Compressed air dryer- specifications and testing. Installation of non-reputed brands often results in frequent maintenance.
- **Hidden Cost:** Cost of energy consumption, maintenance and cost of machines the dryer protects must be considered. Machine downtime due to dryer malfunction escalates production cost that is not tied down to the dryer.
- **Weather:** Water freezes in pipelines during winter due to below 0^0C ambient air, forming an obstruction. In such cases, a desiccant dryer is preferred. Summer also affects the dryer by increasing ambient and inlet air temperature above the acceptable limit.

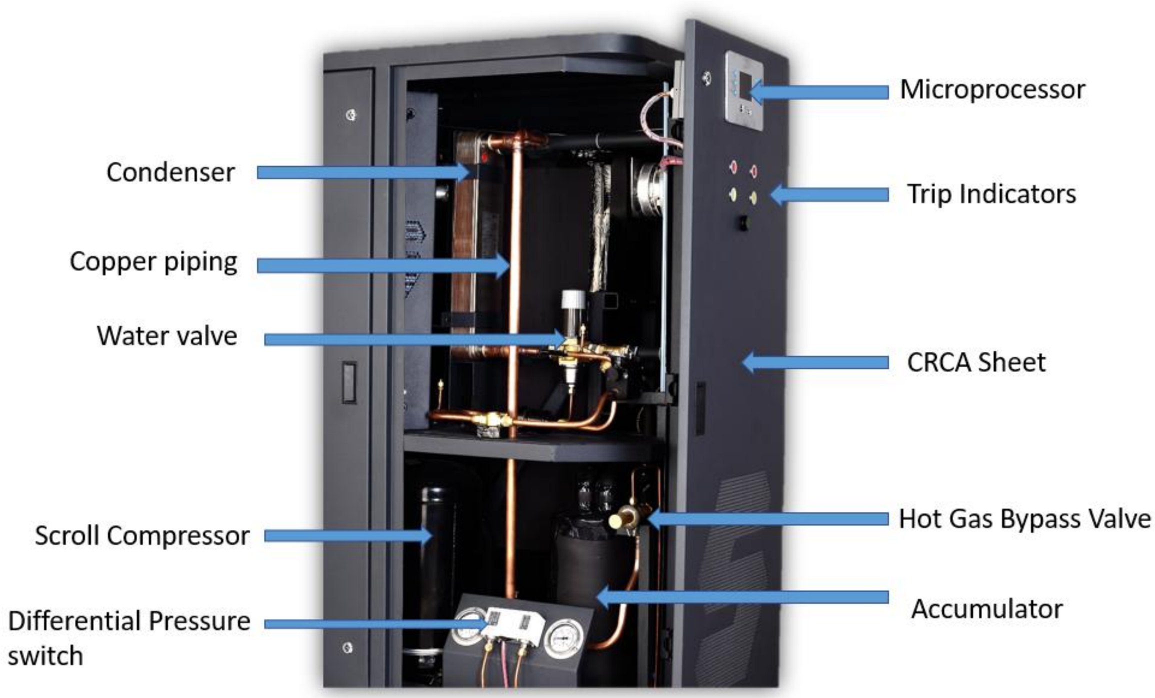


Fig.5: Parts of refrigerated air dryer

Maintenance

Refrigerated air dryer require low maintenance and has a lifespan of well over 15 years. Refrigerated dryer has limited moving parts in except refrigerant compressor and condenser fan in air cooled type. So there is low chance of wear and tear.

Common problem that arises in the dryer is refrigerant leakage. This can be due to flaws in brazing of copper pipes or their rupture due to physical damage. The refrigerant used must be eco-friendly and should have a low Global Warming Potential (GWP). Care must be taken not to inhale the refrigerant. The supplier must conduct Nitrogen-leakage test to guarantee the internal piping of the dryer is leak proof.

Particulate, coalescing and activated carbon filters must be connected before and after the dryer in specific configuration. Particulate and coalescing filters before the dryer protects it from contaminants including dirt and oil. It reduces the maximum size of contaminants to tolerable size before it passes through the dryer. These filters' cartridges need periodic replacement as they form a restriction to air flow. This will freeze over the refrigerant pipeline apart from raising pressure drop.

Refrigerated dryers must have multiple safety features including Low Pressure Switch (LPS), High Pressure Switch (HPS), MPCB and temperature sensors, below some of the safety features of Xeros. Consumer must ensure yearly maintenance by certified service engineers of the dryer manufacturer apart from preventive maintenance and regular checks.

Safety Rules:

Please cling to the operating instructions before attempting to install or maintenance of the dryer. Manual contains necessary information which must be followed during installation, operation and maintenance. Therefore, it must be ensured that the manual is read by the fitter/engineer prior to installation and maintenance.

Overview of Safety Instructions

Before taking any measures, instruction manual must be read by the fitter/engineer. For the safe operations dryer should be installed and operates as indicated in the manual. In addition, the national and operational statutory provisions and safety regulations, as well as the accident prevention regulations required for the respective case of application, need to be observed during employment.

Safety Pictograms Used in the Manual:

OBSERVE OPERATING INSTRUCTIONS

GENERAL DANGER SYMBOL

SUPPLY VOLTAGE

DANGER: COMPONENT OR SYSTEM UNDER PRESSURE

HOT SURFACES

NON-BREATHABLE AIR

DO NOT USE WATER TO EXTINGUISH THE FIRE

DO NOT OPERATE WITH OPEN COVER (HOUSING)

MAINTENANCE WORKS OR CONTROLLING MEASURES MUST ONLY BE CARRIED OUTBY QUALIFIED PERSONNEL

DO NOT SMOKE

Note: The device was carefully designed with particular attention paid to environmental protection:

- CFC free refrigerant
- CFC free insulation materials
- Energy saving design
- Packaging comprises of reusable materials

Conclusion

Refrigerated air dryer is an integral part of a healthy compressed air system. Every manufacturing plant must secure efficiency of the process and safety of the products by actively working to defend the quality of air. A combination of central and dedicated dryers can reduce the possibility of condensate entering the machines. Persistently working towards preventive and predictive maintenance of refrigerated dryers rewards in the form of reduced pressure drop and energy conservation.

Another important criterion is the usage of genuine parts. They are a result of multiple design improvements and rigorous testing. Imitations can never attain their quality and often fail within months. This translates to a bigger problem and heavy losses in productivity. Challenges to manufacturers are many but they do not have to solve them alone. A well strategized step based on expert opinion can be effortlessly formed today. An investment of such in compressed air goes a long way to accelerate cost effective growth and overcome obstacles.

Today, manufacturers can accomplish cost effective growth and overcome hurdles by seeking the advice of experts in the field of compressed air. This will help in strategize and forecast leading manufacturing practices in the industry

Appendix

1. Saturation: When a volume of air at a given temperature holds the maximum amount of water vapour, the air is said to be saturated. Further increase in water vapour results in precipitation.

2. Relative humidity: Simply, It is the water-vapour content of the air relative to its content at saturation. It is dependent on temperature and pressure of the system.

3. Dew point: It is the temperature to which air must be cooled to become saturated with water vapor at atmospheric pressure.

4. Pressure Dew Point (PDP): It is the temperature to which air must be cooled to become saturated with water vapor at a given pressure. It is typically related to compressed air and gas.

5. 1 Atm pressure: It is a unit of pressure that is equal to pressure of sea level in the internationally accepted standard atmosphere model.
   1 Atm =101,325 Pascal =760 mm of Hg

6. Desiccant: A desiccant is a hygroscopic substance that is used to induce or sustain a state of dryness in its vicinity. For example, silica gel, molecular sieve, activated alumina.

7. Global Warming Potential (GWP): it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2).

8. Free air delivery (FAD): It is the actual quantity of compressed air delivered at the outlet of the compressor, converted back to the inlet (free air) conditions before it was compressed. Its unit in Imperial system is CFM (Cubic Feet per Minute) and in SI unit is l/min.