ZF | AFTERMARKET



CLEARING THE AIR:

THE IMPORTANCE OF ADVANCED AIR DRYER TECHNOLOGY FOR TODAY'S MODERN TRUCKS

By Fraz Andani, Category Manager
ZF Group

September 2026

wabco-customercentre.com

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BACKGROUND

Air systems have evolved to support functions beyond braking, including automated transmissions (ATs), environmental control systems, and suspension systems. As additional functions are integrated into the air system, performance requirements become increasingly stringent, encompassing not only safety but also environmental impact and fuel economy.

Contaminants in the charging system contribute to system failures where the increasing need for clean uncontaminated air in the braking, automated transmission, and other systems are necessary to operate. Failure to do so can lead to system breakdowns outside of manufacturer warranty leaving owners and operates with inoperative equipment and substantial repair bills.

Air dryer cartridges are the first line of defense that capture these contaminants before being released into the various systems that rely on the air for operation. Therefore, air dryer cartridges are critical to ensure longevity and prevent disruptions to vehicle operations. A robust cartridge with multiple stages of defense will save owners and operators in the long-term regarding cost, downtime, and reliability.

With technological improvements, proper maintenance of the air system becomes more critical. As more vehicles begin to rely on air systems for operations, the quality of air dryer cartridges become crucial. This paper will explore 3-stage and 4-stage cartridges in the market, which may not be the best option for modern air systems that are heavily reliant on ultra clean air versus a 5-stage cartridge with multiple layers of protection from start to finish that has been tested to eliminate contamination to 99.999% clean air.

PROBLEM

Modern air systems require ultra clean air. As technology advances to increase operating efficiency, fuel economy, and reduce environmental impact, these systems become complex with strict requirements and tighter tolerances.

Most cartridges today only offer 3-stage or 4-stage cartridges. These cartridges are not fully suitable to clean the air removing oils, moisture, or aerosols to ultra clean levels before entering the air system. Ultimately, this can lead to expensive repairs and part failures leaving owners and operators to foot the bill. Manufacturers have strict maintenance schedules and cartridge requirements that combat this risk therefore leading to expenses outside of warranty. For example, an automated transmission costs over $10,000 in parts alone without including labor and lost business opportunity.

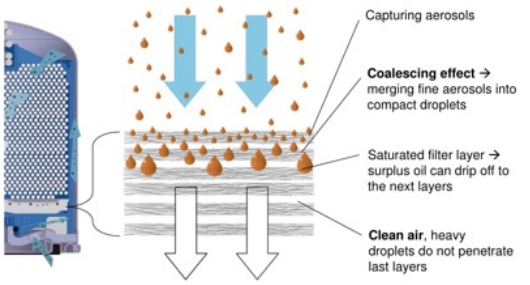
3-STAGE & 4-STAGE CARTRIDGES

Air dryer cartridges consist of several key components, including the base plate, outer shell, desiccant, and filter. These elements are standard across most spin-on cartridge designs, with the coalescing filter included only in specific applications. Depending on the cartridge configuration, desiccants and coalescing filters may be positioned at various stages of the filtration cycle and can vary in material composition, size, and structure.

3-STAGE CARTRIDGE

A 3-stage cartridge features only desiccant as its one line of defense against contaminants going into the air system. Some may include a fleece material to capture particles before traveling through the outer shell but this is typically only able to capture large or solid particles.

THE COALESCING EFFECT



Oil separation by coalescing filters

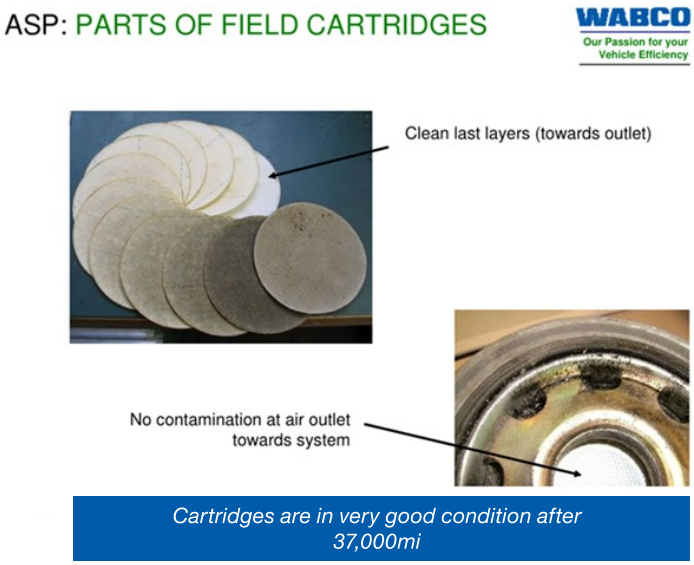
The first stage of a 3-stage cartridge begins as the air enters the cartridge through the fleece ring (#1), if applicable, providing initial separation of liquid water and oil contaminants. Next, the air travels through the outer shell (#2), where the hot compressed air cools and water vapor begins to condense. Lastly, the air passes through the dessicant bed (#3) to capture water, oil, and aerosols before exiting through the base plate and entering the air system.

It is worth noting that 3-stage cartridges are adept at removing water but are weak at removing oil and aerosols. The later particles are able to pass through and reenter the air system meaning that sensitive systems of complex and modern vehicles will notice an increase in pass through particles in the air system. This in turn will lead to weakening and eventual failure of the air system. These filters are better suited for much older applications that are designed to work with these particles, not modern air systems that include several subsystems or vehicles that have high demand for air such as buses, in-city vehicles that constantly use air for braking, and so on.

4-STAGE CARTRIDGE

A 4-stage cartridge builds upon the 3-stage design by incorporating a coalescing filter as an additional filtration stage. During operation, compressed air first passes through the initial filter (#1), when applicable, before entering the outer shell (#2) and moving toward the top of the cartridge. As the air flows along the outer shell, it cools and condenses, causing moisture to form into liquid droplets. The air then passes through the desiccant bed (#3), where water and aerosol contaminants are removed. In the final stage, the coalescing filter (#4) captures remaining fine droplets and moisture, preventing contaminant bypass and helping ensure clean, dry air enters the system.





1. Fleece ring for pre-separation

2. Outer shell
   - Temperature reduction of air
   - Condensation of water vapor
   - Condensation of oil

3. Desiccant
   - Air drying
   - Adsorption of some oil products
   - Condensation of oil products

4. Coalescing filter
   - Separation of finest aerosols

Regeneration of:
- Desiccant
- Coalescing filter

5-STAGE CARTRIDGES

To better serve the market and deliver the ultimate performance and removal of contaminants from commercial vehicle air systems. This 5-stage cartridge differs significantly from a traditional 4-stage coalescing cartridge, which is why it is considered as a third category of cartridges – an “oil-separator cartridge.”

Why an oil-separator cartridge? Simply put, performance. The WABCO *Air System Protector* ^{PLUS} Gold Cartridge is an oil-separator cartridge that delivers 99.999% oil separation efficiency down to contaminants less than 1 micron.

5-STAGE GOLD CARTRIDGE CONSTRUCTION

There are 5 distinct stages in the WABCO *Air System Protector* ^{PLUS} Gold Cartridge. First, the air from the compressor enters the cartridge into the first coalescing filter (#1) providing initial separation of oil and water. Next, the air travels through the outer shell (#2) cooling the hot compressor air resulting in condensation of water vapor. Once the air has reached the top of the cartridge, the air will flow into the first batch of Silica Gel Desiccant (#3) optimized for high humidity removal. Going further is the second batch of Molecular Sieve Desiccant (#4) optimized to remove water. Lastly (#5), the air will travel through a final layer of protection, a coalescing filter to remove fine aerosols down to less than 1 micron.

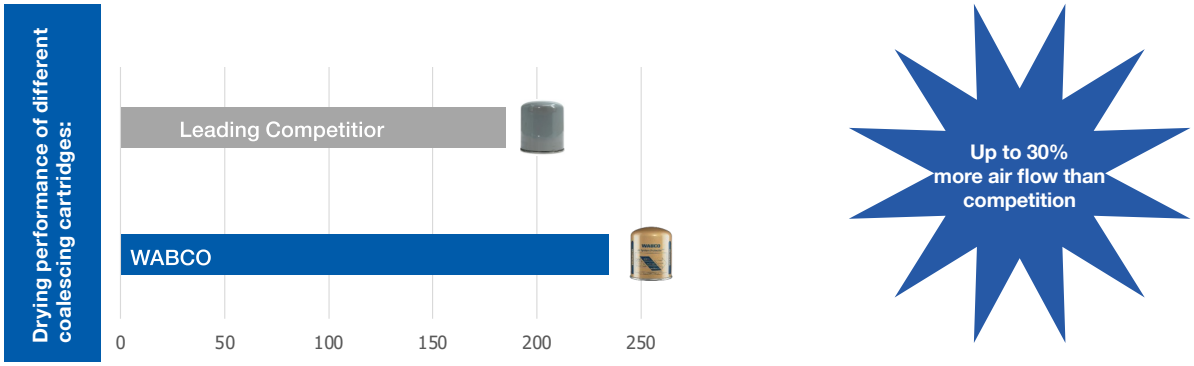


For a size comparison, consider the following table for reference:

Item	Size
Strand of Hair	70 Microns
Pollen	30 Microns
White Blood Cell	25 Microns
Dust	(up to) 10 Microns
Red Blood Cell	8 Microns
Bacteria	(up to) 3 Microns
Wildfire Smoke	(up to) 2.5 Microns
Bread Mold Spore	2 Microns

TESTING RESULTS AND PERFORMANCE

All cartridges do well with larger particles but small particles over time are what will create the largest issues. Above 2.5 microns, most cartridges will achieve 100% removal but as particles get smaller we can see how the 5-stage approach delivers much more performance. The WABCO *Air System Protector* PLUS surpasses oil separation test requirements with 99.999% aerosol seperation efficiency.



TEST CONDITIONS: Drying performance test rig acc. SAE J2384 at dew point depression to 17°C, mechanical air dryer with regeneration tank operating range of 7.0-8.4 bar and 3.3 liter regeneration volume.

BEST DEFENSE AGAINST OIL AEROSOL CONTAMINATION:ADVANCED 5 STAGE COALESCING CARTRIDGE





PROTECT DOWNSTREAM CRITICAL SYSTEMS

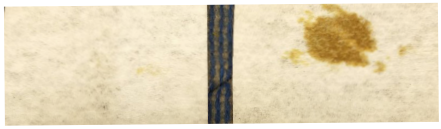
AIR SYSTEM PROTECTOR[PLUS]

- Up to 30% more useable dry air available – volumetric flow in liters / cycle.
- Higher drying performance when new, with limited degradation over service life.
- Reduced contamination and moisture to critical downstream pneumatic systems.
- Ensures longer cartridge service life, up to 2X the leading competitor.

AUTOMATED TRANSMISSION CASE STUDY

SITUATION

- Transmission service lamp on with one or more solenoid valve fault codes.
- During inspection, contamination in the transmission control housing air inlet, passages, and internal components is found. Source of contamination is from the vehicle air system in the form of an amber color substance.
- Internal components affected by contaminated air results in sticking solenoid valves that caused incomplete shifts and active fault codes.
- Transmission air actuation system may need to be replaced.
- Failure to ensure supply of clean air may be considered secondary damage resulting in a **non warrantable repair.**



A paper test was performed at the 24th hour of oil carry over testing at the primary tank inlet port. The leading competitor's cartridge passed oil which can damage downstream components. The gold cartridge did not pass oil.

IMPACT ON TCO

Towing Costs	**$300 - $1,500**
Parts & Labor	**up to $15,000**
Downtime/Day	**$1,000-$2,000**
Driver Retention (1 Driver)	**$12,799***
Load Delivery Delays	**$50-$100/hr.**
Customer Dissatisfaction	**Invaluable**

*Commercial Carrier Journal - March, 2026

Air Dryer Cartridge:
Contamination indicated:



BEST PRACTICE

- Ensure air supply is between 99 PSI and 130 PSI.
- Temperature at inlet of air dryer must not exceed 175°F or 80°C for short periods, less than 1 hour of duration.
- Replace cartridge with a **5- stage** coalescing cartridge.
- Follow vehicle manufacturer's recommended cartridge replacement intervals.

CONCLUSION

The increased need for safety, performance, driver comfort, reduced emissions, and energy efficiency has caused the trucking industry to adapt increasingly complex systems. Many of these technologies use compressed air supplied and controlled by the vehicle's braking system. As technology advances and costs increase, so does the pressure to protect your investment.

Contaminated air in these critical systems reduces life, performance, and increases repair bills.

The best protection for air systems and critical downstream components is a high-quality cartridge that provides the cleanest, driest air possible and cartridge replacement following vehicle OE recommended service intervals.