Current Situation

Innovative vehicle designs and increased environmental awareness call for new engineering solutions for on-road and off-road vehicle components. Diesel engine air intake suppliers are facing increasing challenges as vehicle manufacturers demand higher performance in a smaller volume while minimizing life-cycle costs. This paper will discuss the market drivers behind these changes, air filtration solutions that have worked in the past, and a new filter technology that promises to better meet these increasing challenges.

Many factors are affecting the changing demands on diesel engine air intake systems. One of the most prominent changes in the market is the various emissions standards being adopted around the world (Fig. 1).

These new requirements not only increase the space consumed by advanced emission components, but also impact other vehicle parameters. For example, current and future diesel engine designs are placing more emphasis on lower restrictions in the air intake system, as higher restrictions can increase the emission levels being measured in the engine exhaust. These air intake system pressure losses have long been considered during vehicle and component design to minimize the performance and fuel efficiency penalty that these restrictions incur. Although fuel efficiency changes due to diesel engine intake restriction changes appear small on a percentage basis (<1%), the annual additional fuel usage with a sub-optimal air filter can easily exceed the original purchase price of the filter. With continued increases in fuel costs, efforts to squeeze additional fuel economy out of vehicles have resulted in additional time and expenses being allotted to lowering these intake losses. These fuel savings also translate into reduced CO₂ emissions. In addition to benefiting our environment, CO₂ reductions will result in additional financial benefits in regions where taxation is based on vehicles emissions.

Many manufacturers are placing more emphasis on safety, and improved visibility for the vehicle operator is one part of those efforts. This has resulted, in some cases, in the lowering of engine compartment hoods in order to improve the operators’ sightlines. The effect of lowering the vehicles’ engine compartment hoods has been an additional reduction in space for components such as the air intake systems.
In the search to improve the value provided by vehicle components, air intake system life cycle costs continue to be examined. This can often take the form of either increasing the air filter’s life at equal cost, or reducing the air filter cost at equivalent life. In some cases, customers are looking for ways to reconfigure the air intake system layout to reduce cost. In on-highway trucks for example, behind the cab air intake systems have been typical for some regions because of the under hood space constraints. Size reductions in the system can allow for alternate configuration such as a frontal intake system. This can shorten the ductwork thereby reducing costs and also utilize the engine compartment to mitigate noise transmission through the inlet.

These market drivers are challenging air intake system providers to deliver products that simultaneously improve multiple system properties that have historically been engineering trade-offs.

**Engineering Approach**

Design of diesel engine air intake systems requires the integration of many technologies and the balancing of many factors. Figure 2 is a simple graphic illustrating how the primary value measurements of a system can be affected by design changes in other system properties.

At a given technology level, each property can be improved through compromises in another property. For example, size can be reduced by reducing filter efficiency, reducing filter life, or increasing filter pressure loss. Advancements in technology are required to achieve simultaneous improvement in multiple parameters. These technology advancements can take several forms, from simply improving via design and materials expertise, to the utilization of advanced tools such as computation fluid dynamics (CFD), to the development of breakthrough configurations (Fig. 3).

Other system requirements need to be addressed during the design process as well, and can include items such as noise attenuation, elevated temperature operation, chemical resistance, durability under vibration and shock, and many others.

The ability of a supplier to satisfy these diverse air intake system requirements is perhaps most determined by the design and performance of the air filter. The air filter removes contaminant from the air in order to protect the engine from damaging wear. Engine wear rates have been calculated to decrease by a factor of 10 when high efficiency air filters are used in place of standard efficiency filters.

High efficiency levels have been achieved through the optimization of the fibrous structure of the filter media. The use of nanofibers on the media surface (Fig. 4) has allowed the thickness and density of the media to be reduced thereby decreasing the pressure losses through the media and the amount of material used. These nanofibers also show very high initial efficiency compared to standard cellulose media which only achieves its targeted efficiency level after it has built up a sufficient dust cake on its surface.
Methods for Diesel Engine Air Intake & Filtration System Size Reductions

Figure 4. Scanning Electron Microscope photograph of Donaldson’s Ultra-Web® nanofiber filter technology

The build-up of contaminant on the filter media causes pressure losses to increase over time, until it reaches a magnitude which is determined to be the maximum allowable by the engine. This filter life is desired to be as long as possible to minimize the cost of filter replacement. The ability of an air filter to load slowly, that is have low pressure loss for an extended period of time, is also important because the longer an engine operates at low restriction, the lower the average fuel consumption that can be achieved.

Product Solutions

Cylindrical filters have been the technology of choice in the past. The radial seal version of this type of filter was an advancement that occurred in the 1980’s that enabled the transition from metal air cleaner housings to polymeric housings, thereby greatly reducing product costs and improving product quality.

A breakthrough alternative to cylindrical filters for diesel engine air intake systems was introduced in the 1990’s. Donaldson’s PowerCore filter demonstrates an axial flow arrangement that allows the airflow to pass straight through the filter without the 90° change in direction that is required for cylindrical filter configurations. This simplified airflow path decreases the potential pressure losses within the air intake system.

Figure 5. Conventional filters (axial and radial seal).

Figure 6. Schematic representation of airflow through axial flow PowerCore air filter

Figure 7. Example of an axial flow PowerCore intake system.
While axial flow style air filters have proven their value to vehicle manufacturers, very recent advances in this style of filter have achieved even higher levels of performance. PowerCore G2 is an advanced, next generation axial flow filter that has optimized the internal configuration of the filter such that every geometric feature within the filter has been reconfigured to reduce pressure losses and increase filter life (Fig. 8).

![Figure 8. Normalized ISO fine dust capacity for equal sized air filters. Performance may vary with geometry and operating conditions.](image)

One challenge in air filter design and particularly in axial style filters is the effort to minimize the media area that is unutilized or underutilized due to masking. PowerCore G2 reduces media masking when compared to previous axial flow air filters. Because increases in effective media area decrease the velocity through media, it has the dual effect of decreasing the pressure loss across the media and reducing the loading per unit area. Therefore, the increase in life is higher (Fig. 9) than the increase in effective media area.

![Figure 9. Normalized effective media area as a percentage of total air filter media area. Performance may vary with geometry and operating conditions.](image)

Additionally, PowerCore G2 has been designed to allow for increased total media area to be packaged into a filter through a unique media forming process. This can lead to increased filter life when combined with the correct filter channel configurations. (Fig. 10)

![Figure 10. Normalized total media area for equal size air filters. Performance may vary with geometry and operating conditions.](image)

Channel pressure losses can be lowered through increasing the air filter’s channel size. This also decreases the amount of media, however, so the application requirements need to be factored into the choice of channel size.

Increases in channel space can also be obtained by utilizing thin filter media. Nanofiber laminates allow for thinner media because particulate efficiency increases as media fiber size decreases.

The effect of these changes and others on filtration performance has been theoretically modeled using fluid mechanics and advanced filtration theory. The use of advanced modeling tools has allowed optimal configurations to be determined by comparison of the performance of millions of unique axial flow filter configurations. Prototypes of these selected configurations have been tested and validated against the theoretical model. Figure 11 shows an example of the restriction increase versus dust loading of an advanced axial flow filter and a previously available axial flow filter.

![Figure 11. Restriction increase versus dust loading of an advanced axial flow filter and a previously available axial flow filter.](image)
While this example illustrates achieving improved life for a constant volume, it would be a straightforward matter to provide an air filter with equal life, but smaller volume utilizing these technology advancements. Another benefit that can be seen in Figure 11 is that PowerCore G2 can provide a lower pressure loss throughout the loading period. This lower weighted average pressure loss translates into potential increased fuel efficiency and a more desirable condition for emission performance. However, in applications where initial pressure loss is less of a concern, even greater air filter life than shown in Figure 11 may be obtained with PowerCore G2.

PowerCore G2 has been developed as a family of air filtration solutions. By varying the parameters described above, greater performance can be achieved and therefore greater value can be provided to diesel engine and vehicle manufacturers. This technology breakthrough has allowed for simultaneous improvement in multiple system properties such as restriction, size, and life, and provides a variety of configuration choices in order to best match performance to customer needs.

**Conclusion**

Continued demand for further reductions in air intake system size and restriction has resulted in innovative solutions such as PowerCore G2. For given filter life and efficiency targets, the PowerCore G2 configurations can result in a 30% reduction in size from previous axial flow filters and a 60% reduction in size from cylindrical filters (Figures 12 and 13). Additionally, improvements in restriction and air filter life are now possible with PowerCore G2.