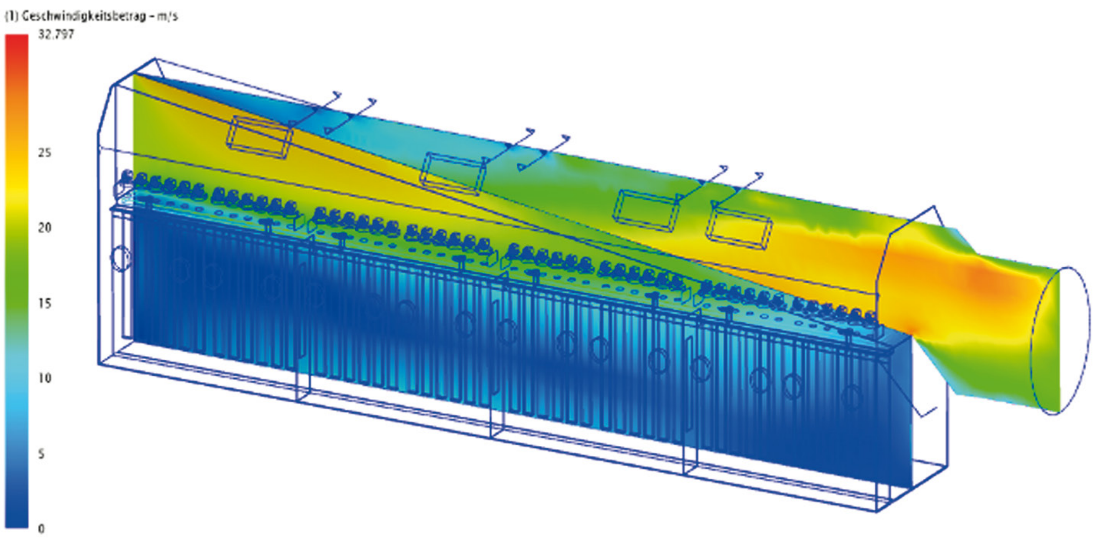
GEORESOURCES
Journal

Journal for Resources, Mining, Tunnelling, Geotechnics and Equipment

SPECIAL ISSUE



Auxiliary Ventilation for dust-intensive Working Environments

GeoResources Verlag ISSN | Online 2364-8430 • Print 2364-8422 www.georesources.net

Source of the Article

Kegenhoff, J. (2022): Auxiliary Ventilation for dust-intensive Working Environments. GeoResources Journal (2-2022), pp. 25–31.
Online: https://www.georesources.net/download/GeoResources-Journal-2-2022.pdf

Auxiliary Ventilation for dust-intensive Working Environments

Dipl.-Ing. (FH) Jens Kegenhoff, Korfmann Lufttechnik GmbH, Witten, Germany

All kinds of technical correlations and parameters have to be taken into account when designing professional cleaning systems for dust-laden air. In order to filter the dust load from the air the latter has to be set in motion by means of fans so that it can pass through the filter system. For mechanised and conventional tunnelling operations the air circulation and dedusting regimes have to be properly coordinated with each other. Auxiliary ventilation systems have to take many different parameters and relationships into account if they are to achieve effective dust removal and air cleaning results.

Tunnelling • Mining • Dedusting • Ventilation • Workplace safety • Construction operation

Introduction

For most people involved in dust extraction work the nature of the process itself will usually dictate the kind of dust reduction and suppression equipment that is required. For tunnelling and mining engineers, however, this is often just the first step in the planning process. They now have access to a tool that has to be properly adjusted and deployed. The technical process of dust control is a very complex one and involves much more than just the dust removal capacity of the filter. The dedusting equipment must be operated within its working parameters and this requires a complete and fully functional system. The mining and tunnelling personnel present on site are essentially the only ones capable of determining that the dust control measures in place are properly and constantly adapted to the operating conditions, thereby ensuring that the system is functioning correctly. Taking a cutter-head tunnel excavation project as an example this paper will look at how dust control is achieved under the given boundary conditions and constraints in order to investigate how the various relevant factors are brought into the overall system context. There are two distinct parts to this analysis:

- **Part A:** Dry dedusting unit operating behind the heading face
- **Part B:** Fresh-air ventilation to the tunnel face

Case Study – Tunnelling with a cutter-head Excavator

The ventilation concept used for excavating a tunnel with a cutter-head system (**Fig. 1**) with dedusting at the heading face essentially involves two basic processes (**Figs. 2 and 3**). In the first of these a fresh air duct is used to blow air to the tunnel face, while in the second process two extraction conduits are set up at the heading face to collect the dust and transfer the dust-laden air back to a dedusting system behind the fresh air duct,

Fig. 1: Tunnelling with a cutter-head excavator

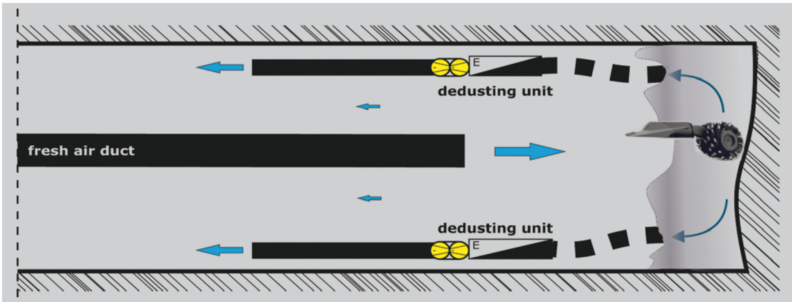


Fig. 2: Plan view illustrating the basic principles of tunnel ventilation

Fig. 3: Looking back from the tunnel face towards the fresh air duct and dedusting equipment

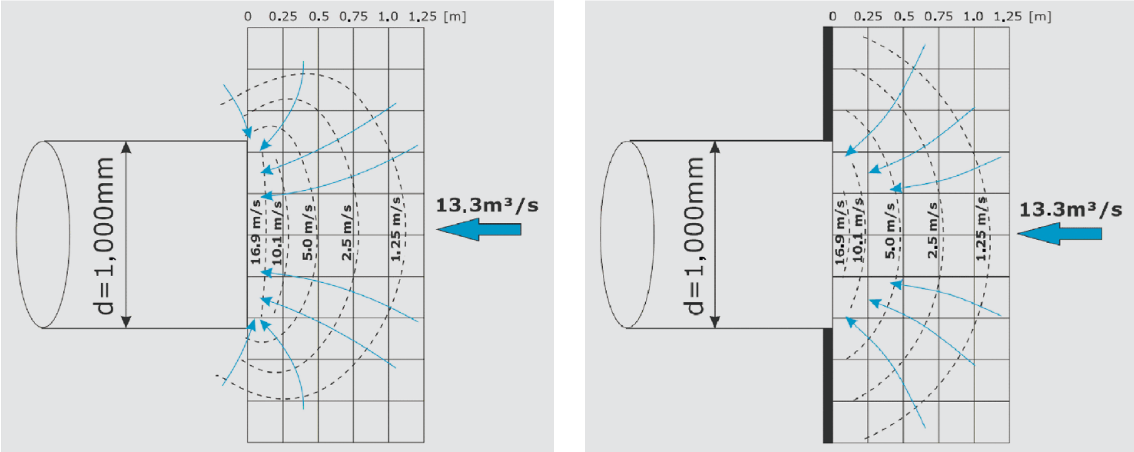


Fig. 4: Suction bellmouth – with free pipe end (left) and with plate fitted to pipe end (right)

where it is cleaned. This ensures that the used air is always directed backwards away from the face.

Various implementation rules are required here in order to ensure that the system functions correctly and the filtration performance is kept within the permissible parameters. The airflow relationships that affect the different parts of the ventilation system have a major impact on the effectiveness of the entire system.

The moving cutter-head (**Fig. 1**) ranges over the entire profile of the tunnel face and in doing so produces varying quantities of dust in different concentrations. The dedusting units operating in parallel with the machine draw the dust-laden air away from the tunnel face via the extractor conduits. It is vital that the latter are positioned close to the actual source of the dust, with ideally one conduit placed on each side of the cutter-head and about one third of the way up between the tunnel floor and roof in order to achieve a uniform dedusting result.

In order to collect the dust effectively over the entire tunnel cross section, and not to leave any residual dust in the zone behind the heading face, the ventilation system has to create a 'stable' dust screen at the tunnel face. This boundary between the clean air and the dust dispersal zone around the dedusting area is maintained by ensuring that the quantity of dust-laden air being extracted and the incoming fresh air flow are perfectly coordinated. The transition from positive to negative pressure, as defined by the physical conditions, forms the borderline between the dust-free and the dust-laden zones.

Using a purely exhaust-based ventilation system to draw air from the heading face cannot achieve the same symmetry of flow as a locally-installed extraction unit operating in combination with a fresh-air supply via a secondary ventilation set-up. This can clearly be seen by analysing the flow speeds of the respective intake ducts.

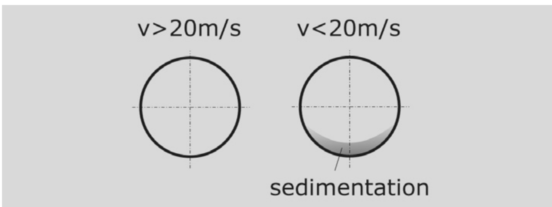


Fig. 5: Sedimentation at low flow speeds

Suction Extraction

It is obvious from a physical viewpoint that the dust is drawn in by the vacuum or negative pressure. Positioning the extraction unit as consistently and as close as possible to the dust generating point results in greater efficiency. At the same time it is evident that partly enclosing the extractor unit, i.e. when a plate is fitted as shown in **Fig. 4** (right), brings significant benefits for the system. While the pressure equalisation and flow speeds are somewhat delayed, this modification really improves the impact and effectiveness of the system.

As the tunnel is continuously advancing the dedusting plant has to be designed to allow some degree of mobility. Given that any type of equipment will interfere with operations when sited close up to the tunnel face a connecting duct has to be set up between the heading face and the filter unit. This suction duct has to be designed in such a way that the effective negative pressure does not compromise the stability of the system. At the same time it is important to ensure that the air velocity inside the duct is sufficient to carry the dust particles to the filter. This means achieving air velocity rates of around 20 m/s inside the suction passage. Any change in the cross section of the conduit will inevitably affect the air velocity inside the suction duct.

Failure to achieve the minimum velocity needed for particle transport will result in sedimentation inside the passageways and the larger-sized particles will be deposited (**Fig. 5**). This sedimentation process will eventually create a situation inside the duct where balancing will take place between the deposition and the air velocity. As a result, less air will be entrained for the ventilation process and energy consumption levels will increase. The volume of air at the tunnel face may potentially no longer be sufficient to maintain a stable system. If the speed of flow inside the suction duct is too high the result will be increased wear and greater abrasion. Furthermore, the spiral air ducts that are often used in such cases have a physical limit at which the internal pressure tends to fold up the spirals. This process greatly reduces the cross section and the air volume and performance will be affected as a result.

Filter Unit

Changes in air volume and speed also have an effect on the dedusting system. While dry dedusters with their compact filter elements (**Fig. 6**) do benefit from being able to cope with deviations in nominal airflow, nevertheless even here there are limitations and if these are exceeded there will be aerodynamic consequences.

Any increase in the air volume above the nominal filter capacity will cause a disproportionate rise in the pressure resistance and in the air velocities in the passages. The higher velocities will result in increased material wear as a function of the dust grain properties. Particles directly striking the filter material at an excessive velocity will gradually cause the latter to become damaged. While it is convenient to note that a high pressure difference can do practically no harm to the actual filter material, nevertheless the high resistance offered by the filter and filter cake will tend to diminish the cleaning function. Intermittently flushing through with compressed air will not overcome the surface pressure and will only serve to reduce the cleaning performance. This is often not obvious to the user, as the compressed air is delivered at an operating pressure of about 4.5 bar (**Fig. 7**).

As the pressure is released and expands across the entire surface of the filter the pressure level will be reduced as a function of the surface area, with the result that thorough cleaning will not be possible at a total resistance of 5 to 6 kPa. This results in a reduction in air volume and in a disruption to the entire ventilation system.

Any kind of water infiltration is also to be avoided when dry filter elements are being used as moisture will cause the material to lose its filter and support structure. At the same time the filter cake can no longer be flushed clean, the cake thickens and the filter system exhibits less permeability.

Fan System

A fan unit that is the correct specification can run trouble-free as long as the system is operated carefully and the filter unit is regularly cleaned in line with the threshold values. When selecting the fan system it is essential to factor into the overall resistance rating not only the flow resistance of the individual filters but also the intake and exhaust air conduits. The overall system must therefore be properly coordinated with the operational processes right at the design stage. An extension of the intake line or a reduction in the pipe diameter at a later date will create different workplace conditions and will result in changes to the airflow rates, with all the consequences referred-to above. It is particularly important to avoid any crossing of the specified thresholds, which can result in a failure of the ventilation system and other individual problems, including velocity reductions in the overlap area. The diagram in **Fig. 8** summarises the various relationships that come into play.

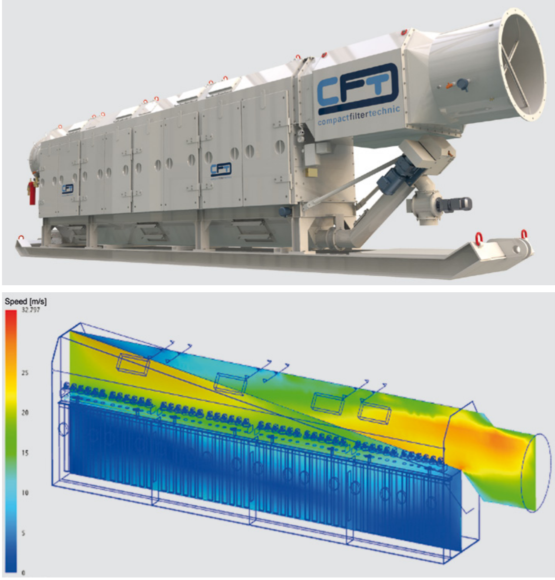


Fig. 6: Dry deduster system with compact filter elements – newly patented system from CFT

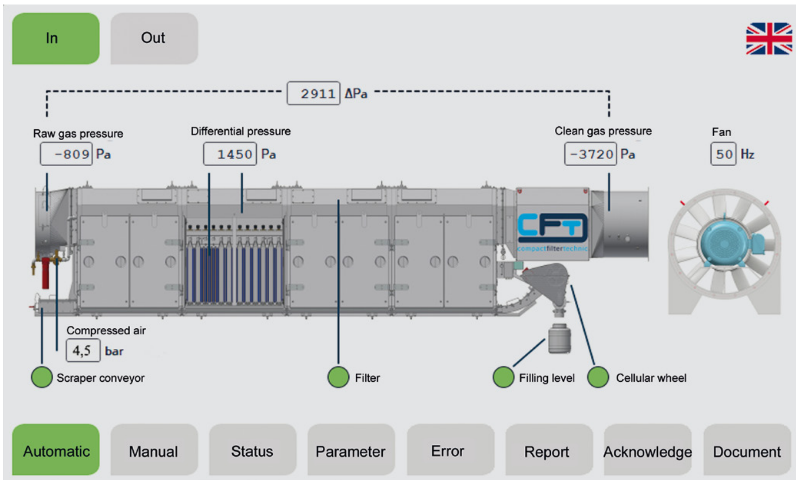


Fig. 7: Operating data for filter unit

Serious fan problems can occur if a fan is installed before the filter unit or is loaded with dust as a result of incorrect filtration. Dust particles can cause abrasive wear and this will especially affect those components that develop high rotational speeds, such as the tips of the fan blades (**Figs. 9 and 10**). A change in the shape of the blade profile can lead to laminar separation and cause uneven flow patterns that affect fan performance. The service life of the blades is very much reduced as a result. Such an operating regime entails high maintenance and spares costs.

Moist and/or adhesive dust presents the additional risk of caking. This initially develops uniformly because

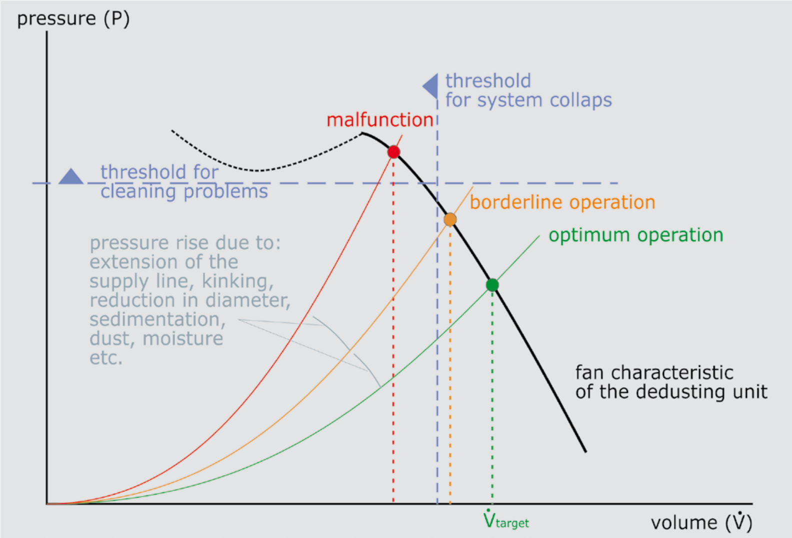


Fig. 8: Fan characteristics

Fig. 9: Impeller conveying dust

Fig. 10: Wear due to dust

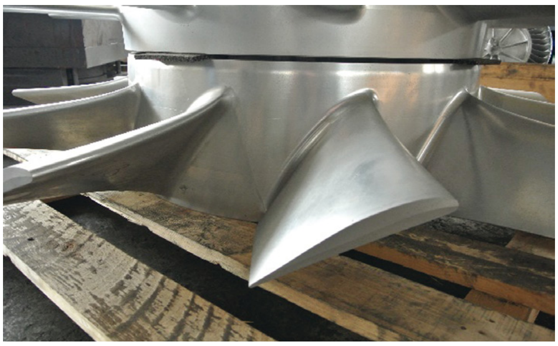


Fig. 11: Impeller with special surface designed to prevent dust deposits

of the rotational movement of the impeller. However, as the cake thickness increases there is a real possibility of material flaking off, and this can lead to imbalance at the impeller wheel. This in turn can result in bearing damage in the medium term. If the fan is not designed specifically for use below ground (**Fig. 11**) it is possible that other forms of damage can occur much sooner than anticipated as a result of dust entering the electrical system, inadequate material thicknesses and the frequent and irregular deposition of dust on the rotating surfaces. In some cases a fan blade may even suffer a complete fracture.

Air Intake System

From an analysis of the dedusting components it is clear that the dedusting process is completely interdependent on the fresh air supply system. Given the case in point of the moving cutter-head it is systematically relevant to have a stable dust screen in place. Experiences acquired from tunnel construction projects and mining industry investigations carried out under explosive gas conditions have led to positioning rules for components that have helped ensure optimum functionality (**Fig. 12**).

As flow-related pressure losses are very dependent on the tunnel profile the clearances can be calculated accordingly using the root of the cross section. The dust screen is developed from the tunnel face with the volume of air extracted (as a function of the cut face and excavation method) being optimally quantified at less than about $\frac{1}{4} \cdot \sqrt{A}$. The subsequent distance to the fresh air supply duct is set at a minimum of $10 \cdot \sqrt{A}$ so that the outflowing stream of air is able to expand and a more uniform airstream is diffused over the entire tunnel cross section. By positioning the duct close to the face or tunnel roof the speed at which the core jet of air leaves the duct can affect the outreach of the airstream. Siting close to the side-walls generally extends the reach of the airflow. However, an unfavourable surface composition can very quickly deflect the flow. It also has to be borne in mind that a high flow speed at ground level can swirl up any lying dust. The core jet speed itself must recede before reaching the dust screen to the extent that the speed vectors are relatively uniform over the entire tunnel cross section. Any irregular distribution in this respect will partially disrupt and destabilise the dust screen and this would make it impossible to achieve total dust capture. This problem can be resolved by fitting an axial shutter to the end of the duct and by providing radial vents in the last few duct end sections, e. g. using perforated ducting. In practice this often involves the use of a hybrid system comprising a shutoff damper and a series of perforated or spiral-wound ducts. This system offers considerable flexibility for any application. When the damper is opened axially the core jet can reach the heading face and the entire volume of air can be directed into the tunnel (**Fig. 13**). This is especially useful at workplaces where no dust is being generated in that the heading can be ventilated without the need for deploying a dedusting system. For dust-intensive operations the entire system can be activated, the damper on the air supply duct is closed and the airstream is able to pass through the radial vents and flow uniformly along the tunnel to reach the heading face. The dust screen is not compromised and remains stable.

It is practically impossible to achieve a uniformly profiled throughflow of air in the tunnel cross section between the discharge end of the ducting and the heading face. Operating conditions may create individual areas where an exchange of air cannot effectively take place. This includes the overlap zone between the discharge end of the ducting and the exhaust end of the dedusting unit. This overlap area should be kept as small as possible, though must also be big enough to ensure that the ventilation regime can still be set up as required. The overlap zone should be short in length as air speed in this part of the tunnel profile is only based on the difference between the incoming fresh air and the air being extracted. Economic reasons and physical limits usually mean that no additional volumes of air are provided for this area. This minimal air quantity must only ever be allowed to fall below the specified minimum air speeds when it can be ensured that the tunnel cross section is fully flushed with air. Often this cannot be achieved using the conventional measures described here and breaches of the MAC (maximum allowable concentration) levels can occur. This becomes a particular problem when the tunnel heading is subject to gas emissions. Explosive pockets of gas are to be avoided at all costs.

The German coal industry developed a solution to this problem by replacing the discharge end of the perforated or radially vented fresh air ducting with a spiral-wound section of duct or a Coanda duct (**Figs. 14 to 16**). This system exploits the physical Coanda effect whereby a radial rotational flow is produced at the outer wall of the ducting. Providing the duct with a perfectly tailored longitudinal slit that acts in combination with an axial shutter means that the air can flow out in a tangential direction. The resulting vortex flow flushes the entire tunnel cross section better than a perforated ducting can and prevents the local formation of emission pockets and gas accumulations. Air exchange is effectively ensured and at the same time the fresh air is delivered in a relatively uniform manner to the heading face and extraction system. The dust screen is not disrupted by high dynamic airstreams and so remains stable over long periods.

Conclusions

If it is to be efficient a dedusting system must be based around compatible components that are to be deployed according to specification and in line with the operating procedure so that full functionality is assured. The user not only has to make provisions for the various problems referred-to above but must also keep a check on many other technical issues. These responsibilities may include the following:

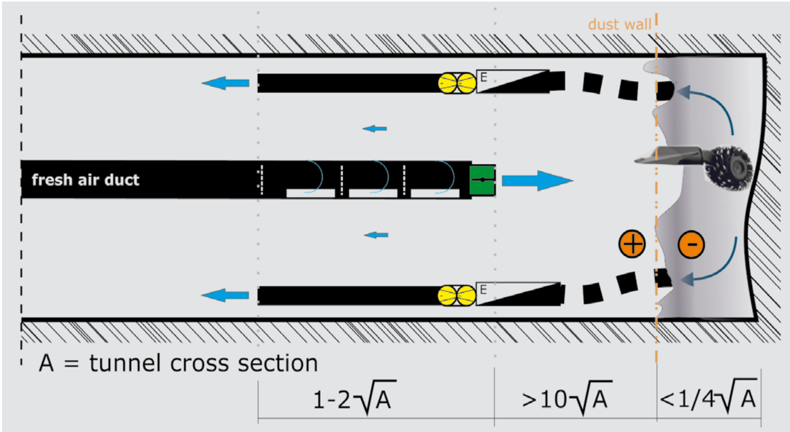


Fig. 12: System-specific distances

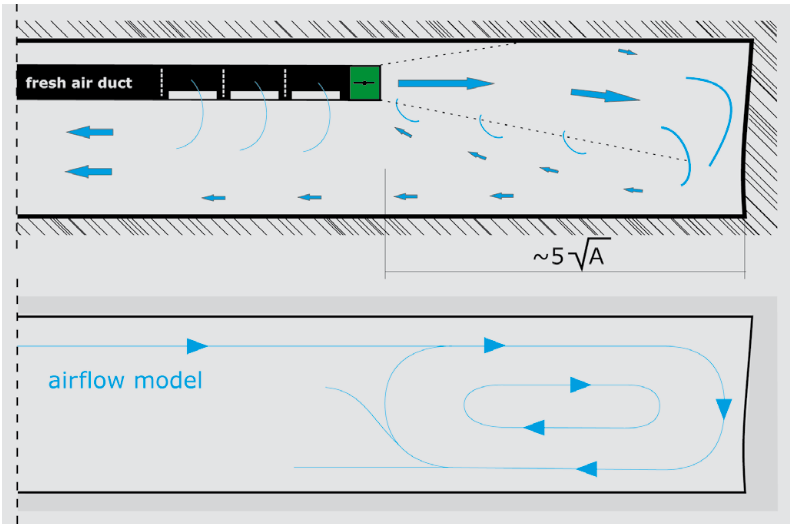


Fig. 13: Airflow model for discharge duct with open damper

- The fresh air supply is to be kept free from contaminants.
- Air ducts and supply lines are to be kept leak-free and regularly checked for damage.
- The filtered dust is to be removed from site in accordance with safety regulations and properly disposed of.
- All equipment components are to be maintained as prescribed by the manufacturer and adapted where necessary to the specific operating environment.
- Additional safeguards are to be put in place at other vulnerable workplaces, for example by installing filtered cabins for the machine operator.
- Vehicle exhaust pipes should not be directed to ground level.
- Other machines operating in the tunnel heading zone can have a local impact on the air exchange process. It may prove necessary to extend the ventilation measures, for example by installing air-jets.
- Air coolers, when required, need even more precise coordination as the climate calculations have to cor-

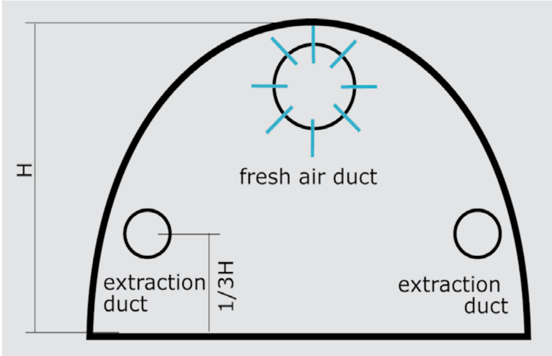


Fig. 14: Perforated fresh air duct

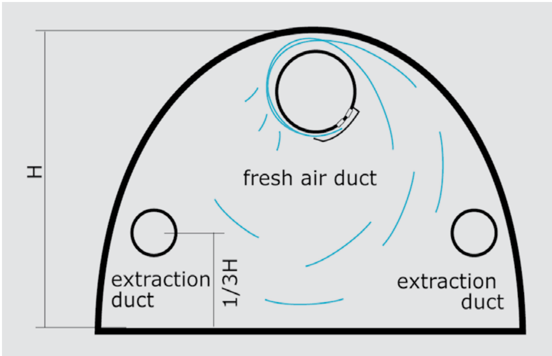


Fig. 15: Effect produced with spiral-wound ducting

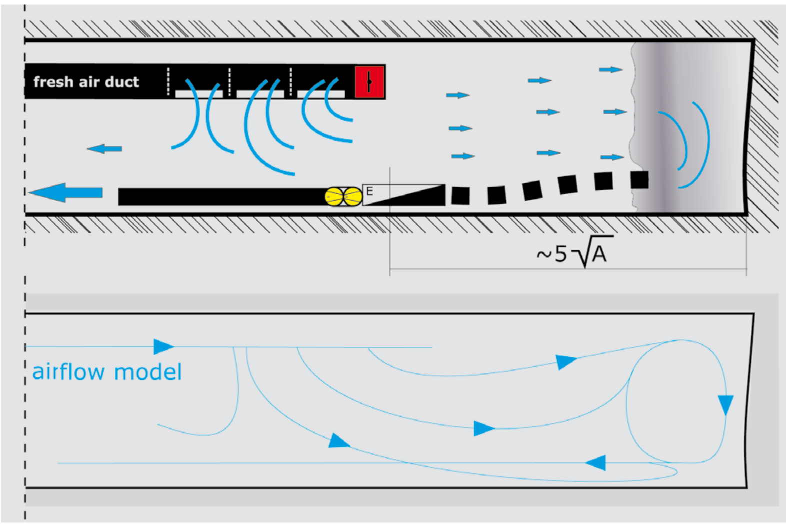


Fig. 16: Airflow model with spiral-wound ducting

respond exactly to the airflow quantities and temperatures.

- Tunnels that are being driven in a potentially explosive environment require additional ventilation measures, such as air reversal or air flushing following gas ingress. This may entail further changes to the air conduits to ensure that the components can perform to maximum reliability.

Current dust regulations and threshold limits stipulate that ventilation systems have to be properly planned and designed to ensure that health protection requirements are complied with as the tunnelling operation proceeds efficiently. This not only requires dedusting components designed to a high technical standard but also calls for fully qualified and trained personnel who understand the technical correlations and can both act in response to a risk analysis and assess the ongoing effectiveness of the actions taken.

References

This article is based on a paper presented at the 5th Freiberg International Colloquium on Dust and Dust Control and the German version of the article in Geo-Resources Zeitschrift 2-2022:

Kegenhoff, J.: Zusammenhänge der Sonderbewetterung mit staubintensiven Arbeiten. In: Mischo, H., und Krichler, T.. Beiträge zum 5. Internationalen Freiberger Fachkolloquium, Stäube und Staubbekämpfung, Freiberg, 2021

Kegenhoff, J. (2022): Zur Sonderbewetterung bei staubintensiven Arbeiten. GeoResources Zeitschrift (2-2022), S. 33–38. Online: https://www.georesources.net/download/GeoResources-Zeitschrift-2-2022.pdf

[1] Graumann, K.; Düpre, G. (1978): Die Bewetterung im Bereich von Vortriebsmaschinen mit Entstaubungsanlagen. Bergbau 6/1978

[2] Schweizer Ingenieur- und Architekten-Verein (1998): SiA196 Baulüftung im Untertagebau

[3] BauIndustrie / Bauen Agrar Umwelt / BG Bau (2019): Branchenlösung Staubminimierung im Tunnelbau

[4] Reuther (1989): Lehrbuch der Bergbaukunde. 11. Auflage, Verlag Glückauf

Dipl.-Ing. (FH) Jens Kegenhoff

is Managing Director of Korfmann Lufttechnik GmbH, Witten, Germany

Contact:
jens.kegenhoff@korfmann.com