# Unit 21
# Mine Ventilation



Mining In Manitoba | Intro to Mine Engineering | Unit 21 - Ventilation

## About This Unit

In this unit, you will learn about Mine Ventilation and the role ventilation plays in the operation of a mine.

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# Objectives

After completing this unit, you should be able to:

- Explain the historical development of ventilation
- Explain the ventilation requirements of a mine
- Understands the nature of mine gases
- Understand the design of a ventilation circuit
- Explain natural ventilation
- Explain the design of vent shafts and raises
- Explain ventilation duct design
- Understand the selection of vent fans





## Mine Ventilation

Underground mining operations require sufficient clean air for personnel to breathe and for equipment to operate.

Air exchange is required for the removal of contaminants from :

- Explosive gases
- Dust
- Poisonous gases
- Radioactive Emissions
- Objectionable fumes

The best method for controlling these contaminants is to prevent their formation or dilute the contaminants so they are no longer dangerous.

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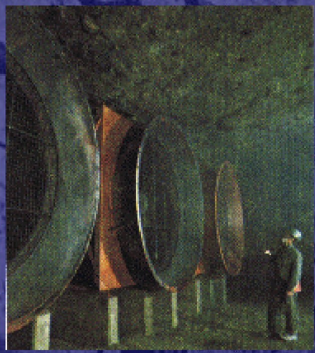
## Historical Development

Mine ventilation is twofold in purpose: first, it maintains life, and secondly it carries off dangerous gases. The historic role of ventilation was to provide a flow of fresh air sufficient to replace the oxygen consumed by the miners working underground.

Today's mine ventilation primarily deals with noxious gases (mainly generated by trackless equipment underground).



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In the past, mining occurred near the surface where natural light and ventilation was available. Fires were used to draw fresh air into the mine and exhaust shafts vented the hot smoke out of the mine.

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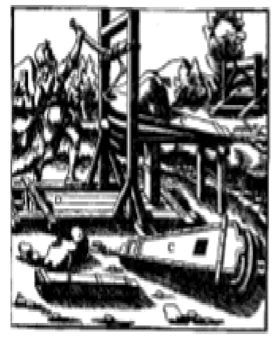
"History of Coal Mining" - by Sinclair (1672)



"Old-fashioned Exhaust Device" (1550)



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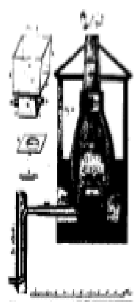
## Ventilation Furnaces



Surface furnace
Bartels (1711)

Underground furnace
Wallsend Pit (1787)

## Benchmarks in Ventilation Equipment after Agricola

| | |
|---|---|
| Natural ventilation heating baskets: | 1650 |
| Surface chimneys: | 1665 |
| Pumps: | 1711 |
| Water jets: | 1719 |
| Ventilation furnace underground: | 1787 |
| Steam engine as fan drive: | 1796 |
| Steam jets: | 1811 |

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## Benchmarks for Ventilation Theory

- 17th Century: Discovery of scalar nature of pressure, calculus, Newton's 2nd Law;
- 18th Century: Derivation of Euler's (Turbine) equation & Bernoulli's equation
- 19th Century: Derivation of shock loss (Borda-Carnot) eq.; formulation of Atkinson's (Darcy-Weisbach) eq.; ventilation network calculations; first network calculations for complex networks using iteration methods (1854)

## Temperature Pre-calculations

- 1822 – Fourier, Jean B.J.: Theorie Analytique de la Chaleur;
- 1926 – Temperature changes in airways with harmonic temperature variations at airway beginning, considering rock walls as plane surfaces;
- 1951 – Same as above, considering airways as hollow cylinders.





- Long before coal was mined in North America, collieries in Europe were sunk with dual entrances; one through which air flowed into the mine and another through which air flowed out. Initially, mine ventilation was assisted by underground furnaces, which used the practical principle that the updraft of a fire caused a suction which drew air out of the mine and this air was replaced by air which was pulled in to fill the opening

## Ventilation in the Last 50 Years

- The biggest change: Computers!
- Reliable and versatile instruments for analyzing ventilation properties and data acquisition;
- The use of computer and instruments allow data processing and ventilation network model building, that have greatly facilitated the problem solving and mine design.

- Canaries are said to have been used to detect gas in coal mines in the early stages of coal mining. This sensitive bird would be taken into the workings and, if it perished, the colliers would immediately leave the mine.
- However, before the 1870s, managers and qualified persons were using safety lamps to detect gas. These safety lamps soon replaced oil lamps and open flared candles as a source of working light.



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- Soon, small hand-turned fans were used to blow out gas from working places into main air currents. Trap doors were strategically placed as part of the ventilation system to guide the flow of air to or from selected areas. "Trapper" boys were posted at the busier doors to open them for the passage of coal, materials and men. "Air courses" were frequently cut through coal and rock.
- In the 1920s the hand-turned fans were replaced with air-powered small turbine fans. Large fans of the suction type were placed on the surface and gradually increased in size. Air from surface compressors was piped into the mine to power machinery and to assist in ventilation.

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## Composition of Normal Air

Pure, dry, normal air has the following composition:

| | Accurate | Respiratory Analysis Effects | Mine | Ventilation | |
|---|---|---|---|---|---|
| | By Vol. | By Wt. | By Vol | By Vol | By Wt |
| Oxygen | 20.93 | 23.02 | 20.93 | 21 | 23 |
| CO2 | 0.03 | 0.04 | 0.03 | - | - |
| Nitrogen | 78.10 | 75.50 | 79.04 | 79 | 77 |
| Argon | 0.94 | 1.44 | - | - | - |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

These percentages are lowered by water vapour present in the air. In most calculations concerning ventilation of mines, air is considered to be composed of 2 gases only.

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## Mine Gases

- **Oxygen** - no colour, taste, or smell
  -@ 21% all kinds of lamps burn
  -@ 15% breathing becomes laboured
  -@ 10% life is in danger
- **Carbon Dioxide** - colourless, odourless
  - product of complete combustion
  - causes death by suffocation
  -@ 3% breathing is difficult
  -@10% death can occur
- **Carbon Monoxide** - colourless, odourless
  - incomplete combustion
  -@0.05% is dangerous
- **Methane** - colourless, odorless, burns
  - explosive when mixed with air
- **Hydrogen Sulfide** - offensive odour
  - @.15% is fatal
- **Hydrogen** - explosive when mixed with air
- **Nitrogen Dioxide** - reddish brown colour

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- Ventilation effectiveness depends on a simple fact: "once the noxious gases are mixed with air, they will remain uniformly diffused and will never separate."
- Therefore, if the problem gases (NOX, SO2, CH4, CO, etc.) are diluted at their source with enough fresh air to render them harmless, they will remain safe until eventually exhausted from the mine.
- In the typical underground trackless mine, the amount of ventilation air required to ensure adequate dilution is far more than the amount required to replace oxygen consumed underground by personnel and diesel engines. The required amount of air is also sufficient to improve visibility and remove rock dust generated underground to the extent that silicosis is no longer a serious threat.



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- Today, LHD engines in underground hard rock mines are equipped with catalytic exhaust scrubbers to complete combustion of problem gases that is accomplished at an efficiency of approximately 90%.
- The LHD engines also produce minute solid particles (diesel particulate matter – DPM) due to incomplete combustion and impurities in the fuel.
- Unfortunately, the catalytic scrubber is not efficient at removal of these particulates and moreover they may not remain uniformly distributed in the exhaust air of the mine (they are subject to stratification).

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- The highest operating cost to provide contemporary mine ventilation is the electrical energy for the fans, which typically represents more than one-third of the entire electrical power cost for a typical underground mine.
- The minimum quantity of fresh air is stipulated in the mine regulations that apply at the mine's location. The legal minimum is normally sufficient; however, an increase may be necessary when the mine regulations are insufficient (some developing countries) or to cool a hot mine.
- Uranium mining ventilation is governed by different considerations and separate mine regulations as they deal with natural radiation.





- For common ventilation calculations, procedures assume the air is an incompressible fluid that answers to D'Arcy's equation. The formulas and calculations, based on work by Atkinson and McElroy, employ empirical "friction factors" that do not take into full account variations in pressure, temperature, evaporation/condensation, etc. In most cases, the simplified procedures yield satisfactory results; however, when mine air must be circulated over a significant vertical distance, or when air is required for cooling, a more sophisticated analysis is usually necessary. Even when the simplified formulas are used, the calculations required for analyzing the network of airways in an existing or proposed mine are cumbersome. The difficulty is exasperated because the ventilation circuit for an operating mine changes day by day. Today, most network ventilation problems are solved by computer using in-house programs or off-the-shelf commercial software.

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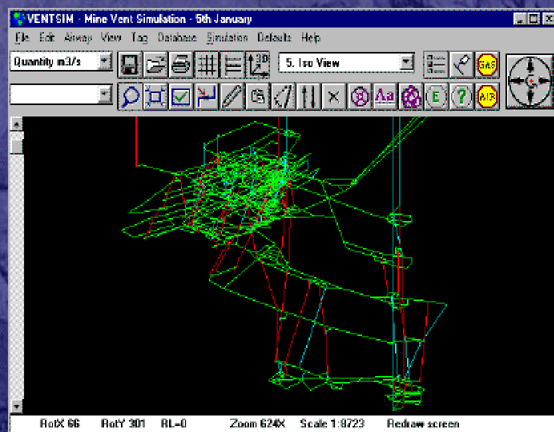


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- In temperate climates, ventilation air may have to be heated during the winter months to provide comfort to the miners and avoid freezing the workings.
- Hot mines in temperate or tropical climates typically require the air to be cooled. Deep underground mines always encounter warmer rock temperatures and the air is naturally warmed by adiabatic or auto-compression as it travels downward. Cooling by means of the ventilation air alone can become inadequate. More efficient cooling is obtained by chilling and adding ice to the process water delivered underground.
- Less efficient local (spot) cooling is provided by the release of compressed air underground and other means.

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## Design of the Primary Ventilation Circuit

- McElroy first proposed an ideal ventilation circuit for an underground metal mine in 1935. He placed the fans on surface at two return airshafts on the extremities of the ore body. Fresh air was drawn down the operating (production) shaft, which was located near the center of the ore zone. Control of airflow was provided by doors placed on either side of the production shaft at each operating level.
- Twenty-six years later, Hartman proposed a similar layout.
- "The ideal arrangement of main openings is to locate the intake airway(s) at or near the center of operations and to ring the active mining areas with exhaust airways.



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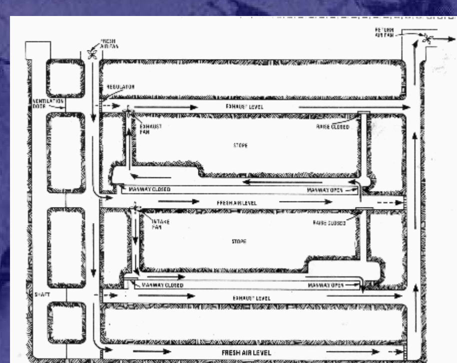

WO20 Fig. 3 Mine Ventilation

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- In the ideal case, with a simple application there is a main ventilation shaft or raise from surface at the extremities of the ore body, one for fresh air (FAR) and one for return air (RAR). With surface fans at both the FAR and RAR, the neutral point is centrally located within the mine workings and this arrangement is said to provide the best circuit to simplify the control over the distribution of air within the mine network.





- Recently, it has become popular to have the major fan installation at the RAR only. In theory, this arrangement avoids the requirement for air locks and (when there is a power failure) stagnant air from dead ends will not be drawn into active mine workings. It is also easier to eliminate velocity pressure loss with a properly designed outlet.
- The disadvantage is that the fans are more susceptible to erosion from exhaust air than clean air. In temperate climates, a small fan is usually placed at the FAR when mine air heating is required for the winter months. If the production shaft is downcast (normal preference), a separate entry into the shaft for ventilation air is provided. A small fan is installed to avoid pulling cold air down through the collar from the headframe during winter. The slight positive pressure from the small fan controls the leakage of heated air back through the shaft collar into the headframe.

- When a ramp entry is required to be downcast with forced air, it is practical to drive a vertical entry raise (or separate horizontal entry) extending to surface from a point near the portal of the ramp.
- Leakage is prevented with the installation of double ventilation doors (air lock) between the raise and the mouth of the portal. When a ramp entry is upcast, warm saturated exhaust air from underground meeting cool ambient air on surface will precipitate a thick mist or fog at the portal, which may become a significant problem.



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- The design and construction of a separate ventilation entry to a ramp or adit is usually straightforward; however, the same is not true of the entry into a production shaft. Normal practice is to sacrifice some losses by designing an entry that is safe, economical, and practical to build. The entry is best designed with a cross section equal or greater than the cross sectional area of the shaft (to avoid instability of the air stream due to expansion).
- When a right angle is required to meet a horizontal section that leads to the shaft, the outside corner is built square but later "smoothed" with falsework.
- At the shaft, the lip of the entry is permanently chamfered and small corners remaining in this "sub-collar" are filled with shotcrete.

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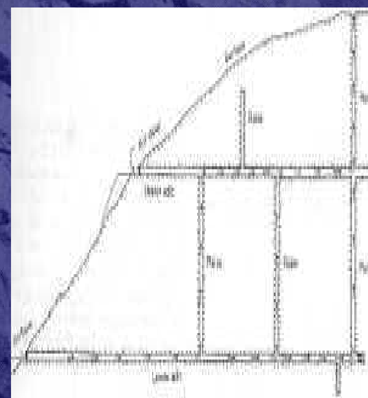
## Natural Ventilation

- In hilly or mountainous terrain, if there is a large difference between the temperature of the rock underground and the atmosphere, significant amounts of ventilation air will flow from an entry at one elevation to an exit at another. The airflow may become stagnant and then reverse direction from day to night or summer to winter. To provide reliable airflow, mechanical ("forced") ventilation is required. It should be designed capable of accommodating (and not fighting) the natural ventilation pressure.





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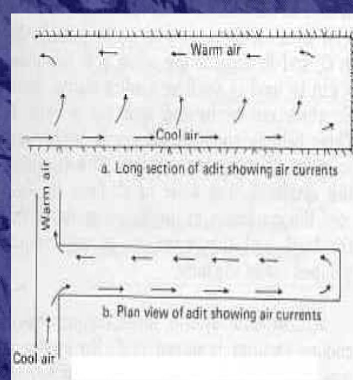
- Many hard rock miners consider that natural ventilation is of no consequence to force ventilated underground mines that have entries at a similar elevation on surface. In fact, all underground mines are subjected to the effects of natural ventilation. Moreover, each individual loop in the underground circuit is affected.
- In cool shallow mines that are less than 1,500 feet (450m) deep, the effect of natural ventilation is not reliable. The airflow due to natural ventilation can tend to flow in either direction, or not at all.

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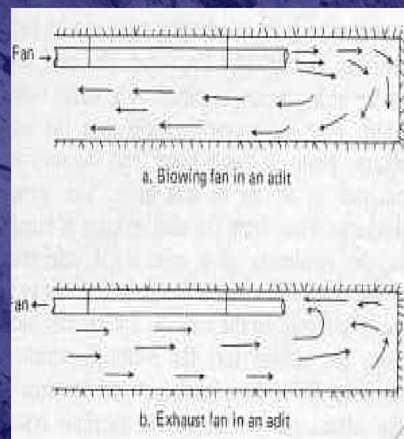
- **In hot shallow mines and in deep mines, the rock temperature is higher than atmospheric temperature, hence there is a transfer of energy to the ventilation air. The effect is to induce natural ventilation that acts in favor of (improves) the mechanical ventilation system. It may be sufficient by itself to permit safe exit from the mine in the event of a major power failure.**



a. Blowing fan in an adit

b. Exhaust fan in an adit



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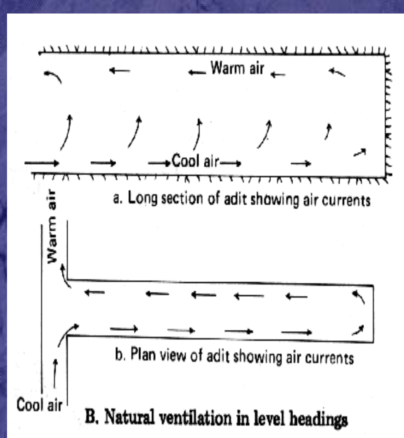
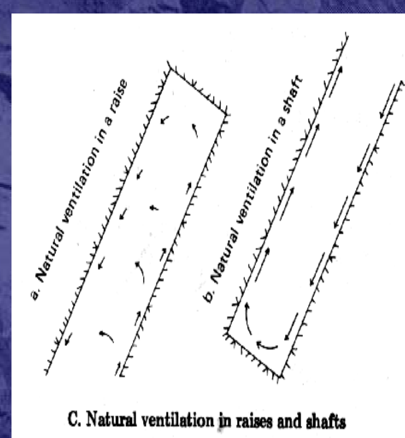


a. Long section of adit showing air currents

b. Plan view of adit showing air currents

B. Natural ventilation in level headings



C. Natural ventilation in raises and shafts

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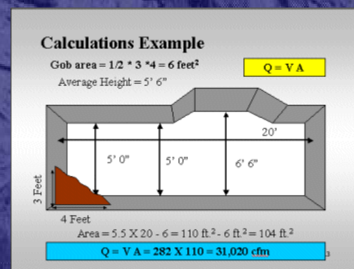
### Design of Ventilation Shafts and Raises

- The area (A) of a ventilation entry to a mine required for a given flow of air (Q) may be quickly determined with rules of thumb that provide a typical design velocity (V) and the following elementary formula:
  - Q = VA (metric or Imperial units)





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### Friction Factor for an Mineshaft

- The "friction factor" in this case includes skin friction and the frictional equivalent of turbulence (shock) resulting from disturbance to the air stream at the buntons and stations.
- The friction factor of a shaft that incorporates sets, utility lines, and conveyances is typically at least five times that of a bald shaft. This is one reason that production and service shafts are normally not used as primary ventilation airways; however, economics dictate that very deep mining operations fully utilize the production shaft for ventilation. These deep shafts normally employ an auxiliary conveyance instead of a manway to reduce resistance.

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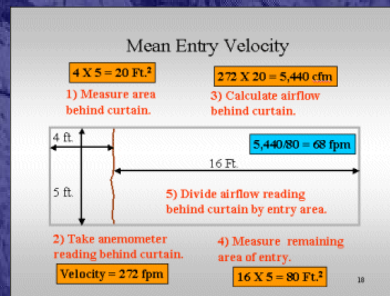
- Using basic principles, the calculation of the friction factor for a production shaft is complicated. The sets (buntons and dividers) are the culprits responsible for most of the resistance, which is one reason that shaft designers want the set spacing to be as far apart as practical. Increasing the set spacing from 5m to 6m (16½ feet to 20 feet) reduces the friction factor of the sets by approximately 8% and the shaft by about 4%. This small advantage is lost if the size of the buntons must be increased to accommodate the wider spacing.



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- By conventional wisdom, vertical installations in the shaft (guide ropes, electric cables, and pipes) ought to increase the shaft resistance because they increase the rubbing surface and slightly decrease the cross sectional area of the airway.
- If it is significant, discarded hoist rope suspended in an open ventilation shaft or raise could reduce resistance and hence power costs, for example.

**FORMULA TERMS**

- (The Resistance Of One Square Foot Of Rubbing Surface To An Air Current With A Velocity Of One Foot Per Minute)
- **{.00000002} Or {.0$^7$ 2}**
- **R** = Total Resistance of an Airway, in Pounds; Equals P
- **U** = Units of Power, in Foot-pounds Per Minute
- **H** = Horsepower; Also Given As H.P. Or H.P.

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## Ventilation Duct Design

- Ventilation ducts are required for advancing most development headings, including shafts, drifts, and ramps. (Raise drives are normally ventilated with compressed air.)
- The two common types of ventilation duct are metal tubing ("hard line") and fabric tubing ("bag"). Bag duct is only suitable for forced ventilation unless it is reinforced with spiral wiring that greatly increases its resistance.



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Unit 21 - Ventilation

- Ducts are normally circular in cross section; however, in special circumstances, oval or rectangular ducts are employed and these may be constructed of fiberglass, metal, or even concrete. These ducts may be sized for preliminary approximations on the basis of velocity. Table 18-5 provides calculated diameters required for ventilation ducts at different quantities of airflow for typical maximum design velocities. The nearest larger standard sized ventilation duct (i.e. 18, 24, 36, 48, 60, 72 inches) may be selected from the diameters shown in the tables for practical application

Table 18-5 Ventilation Duct Diameters

| | Type of Ventilation Duct | | | |
|---|---|---|---|---|
| | Hard Line (plastic/f-glass) | Hard Line (metal) | Smooth Bag (plastic fabric) | Spiral Bag (plastic fabric) |
| Typical Resistance (K factor) | 13 | 15 | 20 | 60 |
| Maximum Design Velocity (fpm) | 4,000 | 3,750 | 3,350 | 2,250 |
| Airflow (cfm) | Minimum Duct Diameter (inches) | | | |
| 5,000 | 15 | 16 | 17 | 20 |
| 10,000 | 21 | 22 | 23 | 28 |
| 15,000 | 26 | 27 | 29 | 34 |
| 20,000 | 30 | 31 | 33 | 40 |
| 40,000 | 43 | 44 | 47 | 56 |
| 50,000 | 48 | 49 | 52 | 62 |
| 75,000 | 59 | 61 | 64 | 78 |
| 100,000 | 68 | 70 | 74 | 90 |

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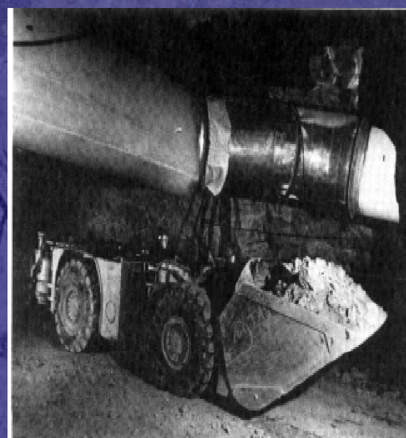

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## Selection of Electric Powered Ventilation Fans

- Fans are first designed by determining the total pressure needed (Ht) to deliver the required quantity of air (Q). Ht is the sum of the static pressure and the velocity pressure.
    - Ht = Hs + Hv or TP = SP +VP
- The velocity pressure may be ignored when designing main fans because they normally incorporate a well-designed inlet/outlet. Velocity pressure is always ignored in the case of an in-line booster fan on a hard line duct; however, the velocity pressure is normally considered in the case of a single fan installation for primary development or shaft sinking because the duct outlet is abrupt.

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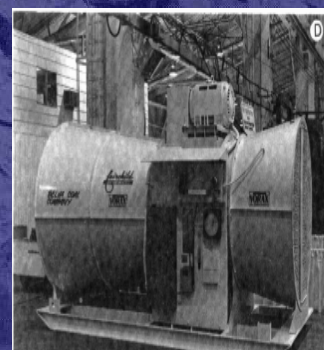
## Air Fans

- Fans that are run by compressed air are often employed for small exploration or development headings where it is not practical to provide electrical power. These fans may be purchased in various sizes up to 24 inches in diameter; however, the most common size is 12 inches.







## Testing Ventilation Fan Performance

- The best place to measure a fan's flow is just upstream where the area of the cross-section is well defined and the airflow is less turbulent. The fan manufacturer usually provides suitable openings for inserting a Pitot tube. Twenty readings are commonly taken, five in each quadrant. The depth of the readings provides equal areas covered within the inlet, so that a simple arithmetical average provides a reliable value. The air velocity may then be determined from the average pressure by the following formula.
- V =1,100 (VP/ã)½
- In which, V = velocity (feet/minute), VP = average pressure (inches water gage), ã = air density (Lbs./cubic foot

## Threshold Limit Value

- The threshold limit value (TLV) is the maximum safe concentration of a noxious gas or dust in the atmosphere underground. A SF (Safety factor) is included in each TLV value. The SF varies from 10:1 for lethal gases, such as carbon monoxide (CO) to as low as 1½:1 for irritants, such as ammonia ($NH_3$). Only about one half of the total airborne dust is resprirable. Gaseous contaminants are measured in ppm (volume) and respirable dusts are measured in mg/m3 (milligrams per cubic meter).
- TLV - Threshold Limit Value
- SF - Safety Factor
- ppm - part per million



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## Diesel Particulate Matter

- The problem of respirable DPM is a problem that has recently become a prime focus of attention by regulators and operators. The emissions from diesel engines produce minute solid particles (DPM) due to incomplete combustion and impurities in the fuel. This matter consists of impregnated carbon and a variety of organic compounds, such as paraffin (wax), aldehydes, and polynuclear aromatic hydrocarbons. Some of these compounds are recognized carcinogens. Unfortunately, the standard catalytic scrubber (oxidation catalytic converter) is not efficient at removal of these particulates and moreover the particulates do not remain uniformly diffused in the exhaust air of the mine (they are subject to stratification).

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## Diesel Particulate Matter

Following is a list of remedies that have been contemplated in anticipation of proposed new regulations.

- Electronic ignition (usually provided on new LHD equipment) to improve combustion efficiency.
- Exhaust filters (sintered metal or ceramic based exhaust after-treatment devices).
- Fuel borne catalyst (as opposed to an exhaust-based catalyst) to improve combustion efficiency.
- Very low sulfur diesel fuel (reduces sulfite particulates).
- "Biodiesel" fuel derived from vegetable oils (about 3 times as expensive as ordinary diesel fuel).
- Engine replacement at 4,000 hours of service (expensive).
- Increase mine ventilation capacity (often not practical for an existing mine).
- Ban smoking in hard rock mines (after-smoke is detected as DPM).
- Eliminate rock drill oil for hand-held pneumatic drills and replace with semi-solid grease (oil mist may be detected as DPM).
- Dust masks, respirators, etc. for miners.





## Heat Generated by the Auto-Compression of Air

- When air descends in a mineshaft, it is heated by auto-compression. The potential energy possessed by the air at the top of the shaft is converted into heat energy by the time the air reaches the shaft bottom.
- The increase in dry bulb temperature = Q/Cpa = 0.981/1.02 = 0.96°C. This value corresponds closely to the rule of thumb that states that the dry bulb temperature will rise by one degree C. for each 100m that air descends in a ventilation airway. The wet bulb temperature (determined from a psychometric chart) will rise by approximately half this amount (assuming no transfer of moisture from the shaft wall to the air stream).

## The Required Capacity of a Mine Air Heater

- In cold climates, it is usually required to heat the ventilation air above the freeze point, otherwise ground water seeping into the ventilation entry will freeze. (In some cases, the ice build-up has been sufficient to eventually choke the airway.)
- Most mining operations in temperate climates are required to heat the ventilation air during the winter with heaters using natural gas, propane, diesel fuel, or electricity. For this purpose, off-the-shelf mine air heaters may be purchased for development projects or small mining operations. Larger installations usually require custom-built heaters.



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## Heat Load

- Miners working in a hot environment may sweat two to three gallons of water in a shift. To help avoid heat stress, this water should be replaced with cool drinking water.
- The natural rock temperature near surface of an underground mine is equal to the mean annual temperature on surface. The rock temperature rises about 1 degree C. for each 100 m. of depth; however, in hard rock mines, the gradient will vary as much as 50% higher or lower depending on the conductivity of the earth's crust at the mine location (exceptions exist). Ventilation alone may not be sufficient to remove the heat generated from freshly broken rock and new faces when the natural rock temperature reaches approximately 95 degrees F. To determine the amount of additional cooling necessary for a particular mine, a heat balance calculation is often made.

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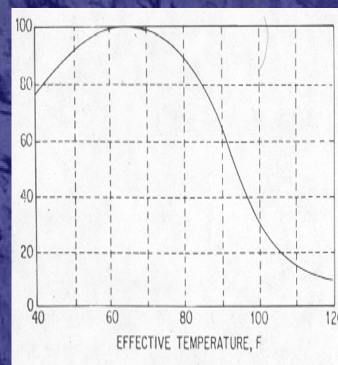
## Mine Cooling

- Various types of cooling devices are employed for underground workings ranging from a simple atmospheric cooler ("swampy") to a mechanical refrigeration plant that produces ice on surface for delivery underground (usually in the service water). As a general rule, the deeper the mine workings, the more sophisticated the cooling plant.

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- Because mechanical refrigeration is very expensive, it is considered the method of last resort and every effort is expended in mine planning to avoid it or reduce its requirements. Following are some of the methods employed.
  - Increase the mine ventilation capacity
  - Route intake air through old workings near surface
  - Reduce the amount of broken ore left underground in stopes and bins
  - Convert diesel powered trackless equipment to electric
  - Conduct heat tolerance testing for work applicants
  - Provide a five-day acclimatization schedule for new hires
  - Provide slightly saline (0.1%) drinking water for the miners
  - Convince miners to drink more water than required to slake thirst
  - Provide ice vests for the miners
  - Provide air conditioned lunch/refuge rooms for rest breaks
  - Replace ditches with sealed pipes
  - Seal off old workings
  - Provide air conditioned cabs for equipment operators
  - Provide remote stations for equipment operators
  - Increase the compressed air capacity of the mine (and provide "air movers").

Each of these procedures is beneficial, but only the first two are of major significance. The second of these is limited in application to those mines with suitable old workings.

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- Increase the Mine Ventilation Capacity
- Increasing the volume of ventilation air for a deep hot mine is only significant if it increases the velocity of air in the workings. There is a marked improvement in the comfort and work efficiency of the miners with increase in velocity.
- An economical limit exists to the size of air entries and development headings to accommodate high air volumes. The economical limit seems to correspond to a maximum practical ventilation rate of approximately 250 cfm per ton of ore and waste rock broken per day. For an operating mine going deeper into hot ground, it can be an extraordinary expense to provide new ventilation entries. One solution is to re-circulate a portion of the underground air, passing it through filters and scrubbers.

Table 18-9 Mine Ventilation Capacity

| Velocity of Ventilation Air | Maximum Desirable Wet-Bulb Temperature[1] |
|---|---|
| 50 fpm | $75^0$ F |
| 100 fpm | $81^0$ F |
| 200 fpm | $84^0$ F |
| 300 fpm | $85^0$ F |

[1] (Relative values based on approximately equal comfort and work efficiency)

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- Route Intake Air through Old Workings Near Surface
- Drawing the fresh air through old workings, pit rubble, or caved workings has proven the most successful way of avoiding mechanical refrigeration in temperate climates. For example, this method is applied at deep mines in the Sudbury, Timmins, and Red Lake mining areas of Canada with success. Not only does it provide cooling year around, but also the requirement (and expense) of heating the fresh air during the cold winter months is avoided.

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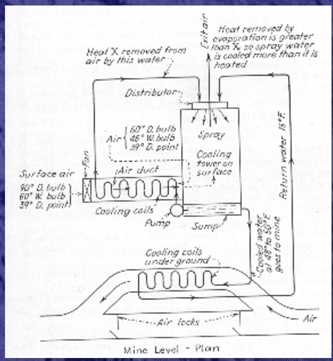
## Mechanical Refrigeration

- The heart of a refrigeration unit is a compressor that pressurizes and thus heats a suitable gas, such as ammonia. The hot compressed gas is then cooled with a water spray in a condenser until it becomes liquid. Subsequently, it is allowed to expand through a valve, which cools it and restores it to a gaseous state. The cold gas is used to cool ventilation air on surface and chill (or provide ice for) service water by means of a heat exchanger. The cold service water, sometimes containing ice particles ("frazil ice"), is sent underground for drill water, dust spray, and use in underground bulk coolers (water spray) for localized air-cooling. Like air, water descending in a mine will lose potential energy and become warmer.

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- In the past, primary mechanical refrigeration units were often installed underground. Today, refrigeration units are invariably installed on surface, for a number of reasons. One is that freons (CFC refrigerants) are no longer employed as the refrigerant gas in accordance with the Montreal Protocol. Alternative refrigerants, such as ammonia are a potential hazard underground. (It is reported that at one mine in South Africa this problem is to be overcome by locating an underground refrigeration plant that uses ammonia in the foot of an exhaust shaft.)
- The capacity of a mechanical refrigeration plant is traditionally measured in tons. A ton of refrigeration will freeze one short ton of water at 32 degrees F. in 24 hours. This is equivalent to 200 BTU/minute or 3.157 kW.

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## Measuring the flow of Air

### A) Velometer

- This is a small portable device with a hinged vane attached to a pointer which moves over a scale . The instrument is connected by a short length of tubing to one of several different jets, which are held where the velocity or pressure of the air is to be measured. The pressure of the air against the vane moves the vane and its pointer.

### B) Anemometer

- This device is like a little windmill. The revolutions of the wheel are indicated by a pointer on a dial. By noting the revolutions made per minute, the speed of the air can be determined.

### C) Other devices include : Pitot tube, Inclined Gauges, and Micromanometers.



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## You have reached the end of Unit 21

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