Parallel session
Innovative energy efficiency examples of different industrial sectors -
Energy efficiency in the cement, metal and petrochemical industry

FROM 167 GWH TO 72 GWH – VENTILATION ON DEMAND IN LKAB’S IRON ORE MINE, MALMBERGET

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ABSTRACT

The Swedish mining company LKAB is the major producer of iron ore within the EU. LKAB produces high performance iron products for steel manufacture, mainly in Sweden and elsewhere in Europe, but also in the Middle and Far East. The company has three production sites and operates two underground mines located in Malmberget and in Kiruna, in northern Sweden. The annual energy consumption in the company is close to 3000 GWh, of which 350 GWh are used in the mines.

An advanced, energy-intensive ventilation system is necessary in the mines to ensure a good working environment by regulating air temperature and removing gases emitted from vehicles and blasting, other harmful gases such as radon as well as dust. The ventilation system in Malmberget consists of nine primary stations for providing fresh air into the mine and ten stations for the extraction of exhaust air. Primary fans and ventilation shafts are used to take fresh air into the mine and secondary fans, together with flexible ventilation ducts, distribute the air into the production drifts. A total of 130 secondary fans are used in the Malmberget mine.

Initially the fans in the primary shafts forced the heated fresh air into the mine and forced the polluted air from the production areas of the mine into the used-air shafts. The fans were controlled manually and operated 24 hours per day. The first step in the improvement of this system was to introduce partial time-control of the ventilation equipment.

Today, the amount of ventilation in specific areas of the mine is demand controlled. Fans in the secondary systems are controlled according to signals from carbon monoxide sensors in the mine and transmitters on the mine vehicles. The identity and properties of the vehicles are known and the fans are adjusted to the specific ventilation needs generated by each vehicle in the mine. This affects the air pressure and the primary fans are controlled according to the output of sensors which measure pressure drop.

The result of this work was a 29 % decrease in energy consumption of the fans and a 40% decrease in energy for heating the mine air. The introduction of this new system and other modifications in the Malmberget mine have led to a decrease in the annual electrical energy consumption from 167 GWh to 72 GWh.
1 Introduction

The Swedish mining company LKAB is the major producer of iron ore within the EU. The annual production of iron ore products was 22 million tons in 2003. Customers are big steel making companies in Sweden and elsewhere in Europe, as well as the Far and Middle East.

Mining, ore dressing, pelletizing and transporting iron ore involves several energy intensive operations. The annual energy consumption in the company is close to 3000 GWh, of which 1500 GWh is electrical energy and the rest comes from fossil fuels. The electricity is mainly used in processes like the hoisting of ore, ventilation of the mines and the comminution and grinding in the mineral processing. Coal, oil and diesel are used in the pelletizing plants and by trucks and other vehicles.

The annual energy usage corresponds to 10 % of the running cost of the company and was, in 2003, close to 60 million Euro. The development of the mines is toward greater mining depths and a higher degree of refinement. This is necessary in order to remain competitive but gives rise to increased energy consumption and higher costs.

LKAB, therefore, makes great efforts in adopting measures for increasing energy efficiency. The development of the new ventilation system in Malmberget mine is a good example of such measures, which have multiple benefits: decreased energy consumption, lower running costs, better internal and external environment. This paper describes this project in more detail.

2 Background

2.1 Ventilation in the Mines

The purpose of ventilation in the mine is to maintain an environment which makes it possible to work underground. The removal of air contaminants from the mine is as much a prerequisite for underground production as is the pumping of water. An aspect of particular focus at LKAB is accessibility to production areas; the availability of ventilation in the mine is an essential part of this.

Operating in an environment where air quality is challenged by gases, dust, moisture, and in some cases, high or low temperatures places great demands on the ventilation system, among other things. Exposure to poor air quality is dangerous to human health, thus the aim is always to keep contaminant levels as low as possible.

It is primarily blasting, loading and transport which contaminate the air in the mine. In conjunction with blasting, most of the gases formed from the explosions end up in the surrounding air volume. However, part of the gas volume is trapped within the rock piles; the amount of which depends on factors such as the type of explosive used, the size and structure of the blasted rock and moisture levels. Such gas can remain occluded in the rock-piles for long periods. Gaseous explosion products are mainly carbon dioxide, nitrogen and water vapour; most of which are considered as non-toxic. Besides these gases, there are a number of others with varying degrees of toxicity. The most dangerous of these is carbon monoxide. Varying quantities of nitrogen oxides (NO\textsubscript{x}) are also encountered.

Besides carbon dioxide and water vapour, diesel exhaust gases contain several different chemical contaminants – many of these with high toxicity such as carbon monoxide, nitrogen oxides, polycyclic hydrocarbons and some aldehydes.
Figure 1. Mine vehicles such as diesel front-loaders and large trucks increase the need for effective ventilation.

A vast amount of dust is generated during mining operations. The chemical nature of the dust and its particle size are important factors, which determine how harmful dust is to human health. Dust may be categorised as either active or inactive – quartz dust is an example of active dust, which can cause silicosis.

Radon is another significant concern in our mines. When radioactive radium decays, radon – a noble gas - is formed. From radon, radioactive daughter products are formed which readily attach to aerosols, which can be inhaled. Radon and the daughter products are toxic and exposure can cause lung cancer. Radon in the mines originates mainly from water draining into the mine and leaching from fixed rock surfaces and blasted stone.

2.2 Occupational exposure limits

The nature of air contaminants (such as those discussed above) and the length of exposure are what dictate the likely health effects of exposure. When setting targets for air quality in the mine the concept of occupational exposure limits was used. These are the maximum concentrations that can be considered “acceptable” for predefined periods of exposure. These are often expressed in units of parts per million (ppm) or mg/m$^3$. Guidelines for the different exposure limits for various contaminants have been established by the Swedish Work Environment Authority’s Provisions on Occupational Exposure Limit Values (AFS 2000:3), the following definitions and limits (table 1) are relevant for the most commonly encountered measurements at LKAB:

- **Occupational exposure limit value**, OEL – this is the maximum (time-weighted) average concentration of an air contaminant in respiratory air. The contaminant may be a single substance or a mixture. An OEL value is either a level limit value or a ceiling limit value.
- **Level limit value**, LLV – this is an occupational exposure limit value for exposure over a whole working day (8 hour shift).
- **Ceiling limit value**, CLV – is an OEL value for exposure during a reference period usually 15 minutes (or less for reactive of very toxic substances).
- **Short-term value**, STV – is the recommended value consisting of a time-weighted average for exposure during a reference period; usually 15 minutes.
Table 1 - Summary of exposure limit values for some relevant gases and dust

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>LLV</th>
<th>CLV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide, CO</td>
<td>20 ppm</td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide, NO₂</td>
<td>1 ppm</td>
<td></td>
</tr>
<tr>
<td>Ammonia, NH₃</td>
<td>25 ppm</td>
<td>50 ppm (5min)</td>
</tr>
<tr>
<td>Respirable dust (general, unspecified composition)</td>
<td>5,0 mg/m³</td>
<td></td>
</tr>
<tr>
<td>Total dust (general, unspecified composition)</td>
<td>10,0 mg/m³</td>
<td></td>
</tr>
<tr>
<td>Respirable quartz dust</td>
<td>0,1 mg/m³</td>
<td></td>
</tr>
</tbody>
</table>

Additionally, the Swedish Work Environment Authority’s *Provisions on Occupational Exposure Limit Values (AFS 2000:2)* gives limits for the climate in mining workplaces; these are summarised in table 2.

Table 2 - Summary of relevant limits for climate in a mining workplace

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>CLV</th>
<th>STV</th>
<th>Target in workplaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide, CO₂</td>
<td>5000 ppm</td>
<td>10000 ppm</td>
<td>1000 ppm</td>
</tr>
<tr>
<td>Temperature</td>
<td>20 °C</td>
<td></td>
<td>40-60 %</td>
</tr>
<tr>
<td>Relative humidity</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Radon:** For work underground, the limit value is 2.5 MBq/m³ per year. For 1600 hours underground per year this corresponds to a level of approximately 1500 MBq/m². This level applies to the measurement of radon gas or radon daughters. There are factors (according to the Swedish Radiation Protection Institute) which may be used to estimate the relationship between radon gas and radon daughters.

3 Mining Operations in Malmberget

The mine in Malmberget consists of about twenty ore bodies, of which ten are currently active. The main transport levels in the mine are at 350, 600, 815 and 1000 meters below the surface and give access to reserves estimated to extend at least to 2011. Most of the deposits are of magnetite ore, although deposits of hematite ore are also found and have been mined again since 1998. During ore refining and the production of blast-furnace pellets, 10% hematite ore is blended with magnetite ore.
Large-scale sublevel caving is a flexible and relatively safe method for mining ore and is the main method used in LKAB’s mines. The process consists of a number of phases, which are depicted, in figure 3 below. The first phase of preparation or development is the accessing of new sections of the mine by the blasting of dead-end tunnels or drifts into the ore body. From the development drifts production drilling is carried out. By drilling upwards from the development drift, a number of slightly sloping, fan-shaped ‘slices’ are made with regular spacing – this is production drilling. Charging and blasting is carried out ‘slice by slice’ – explosive is injected into the drill holes of a fan-shaped array and detonated, after which the area must be ventilated before loading of the ore can start. Large loaders move the ore to vertical shafts or ore passes. The load of about 17-25 tons drops down the ore pass into bins just above the nearest main transport level at 600, 815 or 1000 m. Haulage in the transport level is by trucks which are loaded from the vertical shafts. Drivers control loading from inside the cab of the truck. The fully loaded truck is then driven to a discharge station and the ore is emptied, sideways, into a crusher bin. This is also controlled from the cab of the truck. The ore is fed into the crusher and crushed into lumps of about 100 mm in diameter. From the crusher, the ore is conveyed to a skip shaft and hoisted to the surface.
4 Previous Ventilation System

The ventilation system is essential for ensuring a safe working environment in the various phases of production. Two main ventilation principles are usually applied for minimising environmental problems associated with contaminants:

- **dilution**, where clean air is introduced at the same time as the polluted air is evacuated. The aim is to dilute contaminant concentrations to below their relevant limit values.
- **extraction**, on the other hand, focuses on removing the contaminants at their source (using extraction hoods, for example) before they can mix with the surrounding air volume.

Mine ventilation usually consists of primary and secondary ventilation systems. The primary system serves to convey air to and from the mine and consists of underground installations such as shaft and tunnel systems. Ventilation walls and primary fan stations are also part of the primary system.
The secondary system consists of fans and associated ventilation tubing and ducting which may be adapted to suit the future activities within specific areas of the mine.

The original underground ventilation system in Malmberget was planned and built starting from the beginning of the 1960's up to the mid 1970's. The most recent fresh air shaft to be completed was Dennewitz F9B in 1975. The system was thus planned and adapted for mining activity down to a depth of only 600m.

When the transport level at 815 m was established in 1987, the existing ventilation shafts were extended from 600m. Over the years the ventilation system has been further adapted and extended on a number of occasions to accommodate changes in production. Even modifications to the distribution system have been made due to leakage into areas of caving or damage from blasting.

**Factors motivating the installation of a new system**

The ventilation system as it was suffered from some serious shortcomings. Short-circuiting of fresh and extracted air resulted in large volumes of air needing to be circulated. Despite these volumes and the associated high energy consumption, air quality and thus the working environment was poor, which led to increased disturbances to production. As is the case today, the ventilation system was made up of fresh air stations and extraction stations,
however, without any regulation. The ventilation shafts were not continuous but consisted of a “staircase” of vertical shafts between each 20m level with some (varying) horizontal offset between each shaft. This gave rise to significant backpressure in the system, and much of the fresh air followed the lowest pressure, which was into the extraction system. The existing system also suffered from problems with leakage between levels at 350 m and 600 m, which led to high heating costs.

The result of all this was that all the fans were running at maximum capacity, large volumes of fresh air were being heated yet still insufficient air volume of insufficient quality were reaching the areas where it was needed. Airing and extraction of explosion products, diesel gases and dust were also insufficient for attaining acceptable levels for accessing production areas (within acceptable time scales).

5 The new Ventilation System

Disturbances to production, interruption to loading etc which resulted from insufficient ventilation and the projected needs for the new 1000m level prompted the decision to build a new ventilation system in the Malmberget mine. The new system Vent 2000 was taken into operation during 1999-2000. An overview the system is shown in appendix 1. A single primary fan station was built with 2 fans, each with a capacity of 350 m$^3$/s. These are driven by 1.3 MW, variable-speed electric motors. Air is distributed via two drilled shafts with diameters of 4.5 m.

These shafts take in air from the surface down to 840 m where it is distributed to various areas in the mine via bored, 2-5 m diameter secondary shafts. From these shafts air is pushed, via secondary fans, to the ends of the production drifts. Extraction is via fans mounted in extraction walls and extraction stations with raise the pressure of the air for transport up to the surface.

Figure 7. Fan installation at Dennewitz
Figure 8. Air intakes for primary shafts (4.5 m diameter)

5.1 Construction and installation

The investment in the new ventilation system can be divided into the following five phases:

- Installation of an air intake into the existing primary system from Kapten’s boiler facility. A ventilation shaft was drilled and connected to the existing transport drift at 500m between Uppland and Kapten. Raise boring of a 3.5 m diameter air supply shaft and the installation of an auxiliary fan (for raising the pressure) for the ventilation of Printzsköld to
820 m and future increases in depth. This phase included construction work such as foundation, fan walls, doors etc. The installation has a capacity of 250 m³/s and is equipped with need-based control from BEVUJ (described in more detail below).

- Installation of a primary air supply, consisting of two 4.5 m diameter raise bored shafts, from Dennewitz' surface to the new distribution level at 840 m. At the distribution level, a secondary system of shafts supplies fresh air to Alliansen, Vitåfors/Ridderstolpe, Parta, Dennewitz and the smaller Eastern Mine. At the end of the drifts, in Vitåfors/Ridderstolpe, Parta and Dennewitz, barrier walls with doorways have been installed. In Alliansen a manually operated drive-through and a walk-through doorway have been installed for easier access to the system for inspection and service.

- At Dennewitz' surface a new fan station (2 x 1300 kW) with was installed with a fan capacity of 2 x 350 m³/s and equipped with heat exchangers for heating the air. The capacity of the boiler facility has been increased from about 12.3 MW by the addition of an oil-fired boiler of 6 MW and an electrical furnace of 0.3 MW giving a total output of approximately 18.6 MW. As a result of this capacity increase and the discontinuance of production at Tingvallskulle, the Uppland boiler facility could be closed-down. The fan station is equipped with pressure drop measurement at level 840 m as part of the regulation of the primary fans in the need-based control system (BEVUJ).

- In total 7 air supply and 5 extraction channels connect the distribution level (840 m) to the new transport level at 1000 m (M1000). As the construction of M1000 progresses, these channels will be connected to the new production levels. Fabian is not yet connected to a secondary system but work is currently underway to connect this to the need-based system (BEVUJ).

- An approximately 1000 m long tunnel system at the 820 m level has been constructed for the production areas of Printzsköld and Hoppet. Parts of these are now in use for preparation and development work and as secondary ventilation for M1000.

In addition to the above installations, parts of the previous system remain in use for ventilation. Parts of the previous fresh air supply system are now built into the extraction system for transporting exhaust air up to the surface.

As a result of the new installation, new possibilities were opened for monitoring and controlling the facilities. The primary system must ensure a pressure differential in the mine’s ventilation, which depends on how many secondary fans are in operation. Thus, in order to optimise the operation of the primary fans, the secondary fans also need to be regulated.

5.2 Need-based mine ventilation (BEVUJ)

LKAB has developed need-based ventilation in order to optimise the use of air, provide a good working environment yet minimise energy consumption. The BEVUJ control system is currently supporting mining operations at Alliansen, Dennewitz, Parta and Vitåfors /Ridderstolpe (Eastern Field) and installation is underway in the Western Field. The control units are mounted in an electrical container for the fan units and thus follow the mining activities as they progress downward. Each new installation requires only the laying of telephone cable from the carbon monoxide sensors and transmitter-receivers to the control unit. Repairs or replacement of the remote equipment can be carried out rapidly and at low cost in the event of damage from blasting or other activity. Frequency inverters (50 to 60 Hz) fitted to the fans increase output pressure and flow capacity by about 17%.
The fan units have been modified for variable speed operation with the capability for local, time-controlled override. There are sensors for the detection of CO and transmitters and receivers for the distribution of signals. This is all steered locally from microprocessor control units, which means that in the event of failure of or disconnection from the main system, the local units will still function according to their default settings.

The fans are started and stopped according to CO sensor measurements or by radio transmitters mounted in the mining vehicles and machinery. If the CO levels exceed preset levels, the fans are started automatically irrespective of what time of the day it is. The machine mounted transmitters also activate the local fans 1-2 minutes after contact with the local receivers.

Each vehicle that is used in the mine is equipped with a transmitter with its own identity. This enables ventilation to be adapted according to the needs of each particular vehicle or machine. For example, when a diesel loader enters a particular area, fans in the area respond with full effect whereas an electrical loader in the same area only requires 20% of the maximum ventilation capacity.

The system can be controlled from a control room, by timers or completely automatically. The control system enables monitoring of each fan installation in the mine and information on operation and energy consumption is displayed on process diagrams. Fuel consumption and CO₂ emission data are also logged and can be used for emissions estimates, environmental reporting etc.
Figure 11. Functional overview of BEVLU showing the primary fan station and boiler facilities at the surface. Three underground levels are shown with a spacing of about 30 m between them. The first level from the top is the distribution level at 840m. The transmitter shown in the distribution level is part of the pressure differential measurement, which controls the operation of the primary fans. In the two lower production levels the secondary fans, mounted in a fresh air ventilation wall, are controlled by transmitters in the production machinery and by CO sensors.

6 Significance of the new System

The need-based control system gives the ability to steer the supply of fresh air to where it is needed. Frequency adjustment of the fans, to 60 Hz, increases airflow and pressure drop, which increases the effectiveness of the secondary system. Primary fans are started and stopped based on the number of secondary fans active, enabling balance between primary and secondary systems.

In the new system, individual fans can be monitored online and continuously which increases system availability and gives greater potential for optimising operations. Energy consumption in each part of the system can be recorded which means that maintenance can also be optimised.
The system can be steered from a central control room allowing flexibility in meeting the needs of production. Local control with timing and time-delay is also possible.

The system is flexible and the existing telephone network is used for system communications.

### 6.1 Energy consumption

Since the introduction of the new ventilation system the total flow of air in the mine has decreased – instead of fans operating around the clock, operation is now controlled. This has resulted in a considerable decrease in the use of electricity and oil for the heating of air (see figure 12) and significant reductions in fan energy consumption (figure 13).

![Energy Mwh for Heating Mine Ventilation](image-url)

*Figure 12. Development of heating energy requirements since 1999*
Figure 13. Development in ventilation fan energy requirements since 1999

6.2 Environment

By steering the flow of air to where it is needed, together with the ability to introduce a greater air volume and more effectively extract exhaust air implies significantly reduced levels of contaminants in the air and an improved working environment. The reduced overall energy requirements are of course significant for the external environment.

6.3 Economy

The total investment in the ventilation system, was about a € 0.5 million including development costs. The most recent installation in the Western Field and Printzsköld cost an additional € 0.25 million. The energy savings of 54000 MWh per year imply a payback time of 1.3 years for the more recent investment.

7 Conclusion

When mining at LKAB’s Malmberget mine made the transition from open caste to underground mining, ventilation became necessary. This consisted of fixed-speed fans with manual start-up and shut-down. As the mining operations grew, ventilation channels and boiler facilities for warming the air were needed and installed. From the 1950’s to 70’s oil and electrical energy were relatively cheap, besides which, techniques for the speed control of fans were not fully developed. With time, the need for more effective use of energy has grown, as have the demands on a good working environment. In the late 1990’s the drilling of ventilation channels and tunnels for a new ventilations system started. In order to achieve the goal of the best possible working environment in an energy-effective manner, a need based mine ventilation system (BEVUJ) was developed. Here the primary and secondary systems are steered according to the local needs of separate production areas.
Appendix 1. Overview of mine ventilation system