Introduction:

The desirability of efficient control of air currents, and the necessity of supplying metal-mine workers with better and safer working conditions, has created an active interest in metal-mine ventilation, especially in recent years. This paper discusses the subject both with regard to efficiency and economy, as well as safety and health. It is based on personal observations of the writer from over four years' study of metal mines in six States, in which more than 50 mines were visited. Many of these were studied in detail; in all several thousand working places were examined, and readings taken relative to ventilation run into the tens of thousands.

Object of ventilating metal mines:

Whereas in coal mines ventilation is generally regarded as essential, in many metal mines, especially shallow ones, the operators pay little attention to ventilation, or ignore it altogether. Recent shortage of labor, and numerous accidents to which State compensation laws have directed attention, are causing metal-mine operators to regard ventilation more seriously, especially in deep, large mines.

There is, in fact, greater necessity for adequate ventilation of metal mines than of coal mines. The latter require air currents to remove explosive gases and the fumes of explosives, but metal mines, in addition to the need of removing fumes of explosives, and occasionally explosive gases, frequently have need of removing dusts dangerous to health, reduction of high temperatures and high humidity, and removal of inert but unhealthful gases like CO₂ and nitrogen. The generally accepted superior healthfulness of coal miners as compared with metal miners, is probably due in large part to the better air circulation in working places of coal mines.

Efficient metal-mine ventilation consists, briefly, in circulating at the working face, enough pure air to enable the men to work comfortably and at maximum capacity without any ill effects.

The main features affecting metal-mine ventilation are outlined below:

Movement of air:

This involves effects of air movement at various temperatures, humidities, and with certain gases present, and the advisable velocity of current to use.

Temperature:

The temperature of the air in a metal mine is influenced by the outside air temperature, underground rock and water temperature, oxidation of ores and timbers, mine fires, friction of air due to velocity of flow, movement of ground, firing of shots, quantity of air circulating, heat from breathing of men and animals, heated air from other mines, heat from electric motors and other machinery.

Humidity:

The humidity of mine air depends on the relative humidity of surface air, wetness of shafts and workings, the velocities, quantities, and temperatures of the air circulated. Where small fan units are employed to force air through galvanized iron or canvas tubing, these also affect the humidity through absorption or deposition of moisture.

Mine gases and dusts:

The intake air is usually pure, except in rare instances where smoke or dust from surface works may be present. The air in the mine changes through breathing of men and animals, burning of lights, oxidation of ore or timber, gases issuing from strata, gases from mine fires, fumes from explosives, gases from compressed air, gases from operation of machinery, dusts from drilling, blasting, shoveling and other work.

This paper is too short to discuss all these various causes separately; that will be done in a more comprehensive paper to be published later. However some of the more important points are taken up in the following:

Velocity to be given mine air:

In the ordinary metal mine, the velocity of air at working faces is much more important than humidity, temperature, and content of gases, except when the two latter go to extremes. For example, men have climbed 100 feet out of a stope with pure still air at 79°F. and 86 per cent relative humidity, to "cool off" in a level where the air was 30°F. hotter and 5 per cent more humid than in the stope, but was moving about 150 feet per minute.

In workings with temperatures less than 75°F., a velocity at the face of 10 to 25 feet per minute, or enough to remove gases and dust is ample. At 80°F. to 90°F., a velocity of 200 feet is needed, and in confined places should be 600 to 800 feet; if the cross-sectional area of the working place is very large, a local blower fan may be needed. At temperatures above 90°F., especially in moist air, 1000 feet per minute is required for relief.
Health and safety features of metal-mine ventilation:

The principal factors of metal-mine ventilation as related to health and safety are the effects of ventilation on high temperature, high humidity, gases and dusts.

High temperature and humidity:

The Bureau of Mines and the U. S. Public Health Service, in conjunction with the investigation of mine dusts and gases are studying effects of temperature and humidity on workmen's health and efficiency. Some preliminary experiments in mines have shown that in still air, nearly saturated air, at 85°F., men at rest perspired profusely, with feverish temperature, low blood pressure and high pulse. However, where the air was moving, most of these symptoms were lacking.

In still nearly saturated air at 90°F., or warmer, men quickly experienced all the above symptoms, and in less than an hour felt headache, dizziness, and even nausea. The four investigators were in two hours almost exhausted, although they were accustom to vigorous underground climbing, and were only walking leisurely, through the hot, humid, unventilated drifts. In three days time, staying two hours each day, they had each lost 5 pounds weight and felt weak. Where one of the party sat 15 minutes in a current of air which was at 90°F., 85 per cent saturation, and moving 2000 feet per minute, his temperature, blood pressure, and pulse began to return to normal. These experiments will be repeated on a more extensive scale in the future.

Few mines having humid hot working places with no circulation have escaped without one or more fatalities from "heart failure," which is really heat prostration, yet proper air circulation would make these mines endurable.

In the mine where most of the above experiments were made, mules could not live, and therefore men trammed ore half a mile. Now fans are installed and the mine is a comfortable, fit place to work in.

In many mines, hot, humid, unhealthful workings have been made comfortable merely by local circulation without additional air, and many others have been converted to model conditions by installing fans at a cost of only a few thousand dollars. In one shallow mine, which had an air temperature of 90°F. at the working face, the air being loaded with smoke and moisture, heat prostration and gassing were not uncommon. Installing two small fans and some doors converted it into one of the best ventilated mines in the country, with temperatures around 70°F., doubled the output per man, and reduced consumption of compressed air one-half.

Gases in Mine Air:

Most physiologists state that CO₂ in proportions of less than 1 per cent or an oxygen deficiency less than several per cent do not affect the human system. As applied to underground work, this is doubtful. The writer and his companion investigators have frequently experienced headache and shortness of breath, in stopes where the air was stagnant, its temperature not over 70°F., and which analyzed about 0.25 per cent CO₂ and 18 to 20 per cent oxygen. Also, frequently miners working in similar air have complained of "timber gas", with
headache and dullness. It seems that in still air of 85 per cent relative humidity, 
a small content of CO₂ or a slight oxygen deficiency affects workers unfavorably, 
but such air, if moving at 200 feet or more is endurable or even comfortable.

Fumes from explosives give off CO gas and often oxides of nitrogen, all 
harmful in even small quantities, such as are frequently found issuing from muck 
piles. At the face immediately after blasting, the air contains CO in deadly 
quantities. Recently in Idaho, three men who entered a place where the fumes had 
not been removed, were gassed, fell into a sump, and were drowned. In some metal 
mines there have been annually a number of cases from gassing, with some fatalities 
from fumes and explosives. The cause is usually attributed to defective explosives 
or to improper handling of explosives, but it undoubtedly is largely due to 
defective ventilation at the working face.

In some mines where gases such as nitrogen or carbon dioxide issue from the 
strata, fatalities and many cases of gassing have occurred from inadequate ventila-
tion; the remedy is force or pressure ventilation with constant vigilance.

Many lives have been lost, as well as much property, from fires in metal 
mines; because no ventilating equipment arranged to control the air currents in such 
an emergency had been provided. Natural ventilation is dangerous and inefficient, 
and all metal mines using timber underground should be equipped with fans so arrang-
ed that the air current can be reversed at will, and all shafts carrying air should 
have doors, so placed at intersecting levels that any shaft can be quickly isolated.

Metal mines are generally regarded as being free from fire damp or methane, 
but the writer recalls three accidents from explosions of methane in metal mines in 
the past few years, one in a tunnel, with fatalities; one in a shaft, and one in a 
stopes, with severe burns.

Some metal mines, especially those with natural ventilation, frequently 
have impure air, but in general the quality of the air is better than the miners 
believe. In fact, the return air from metal mines usually shows less CO₂ and more 
oxygen than return air from coal mines, but this may be due to poorer control of 
the air and short-circuiting of pure air to return courses. The proper distribu-
tion of the air in a metal mine is essential. The analyses in the following table 
are of air from two neighboring mines where natural conditions are practically 
similar, but one of them, called mine "A", has fair ventilation and effective 
distribution of air, whereas mine "B" has natural ventilation and haphazard 
distribution. Mine "A" has extensive and deep workings, and the rock temperature 
is above 80°F., whereas mine "B" has smaller, shallower workings, and the rock 
temperature is rarely 80°F.

<table>
<thead>
<tr>
<th>Mine</th>
<th>Main Return</th>
<th>Stope faces</th>
<th>Raise faces</th>
<th>Drift and crosscut faces</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CO₂</td>
<td>O₂</td>
<td>N₂</td>
<td>CO₂</td>
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<tr>
<td>A</td>
<td>.30</td>
<td>20.25</td>
<td>79.45</td>
<td>.29</td>
</tr>
<tr>
<td>B</td>
<td>.47</td>
<td>19.61</td>
<td>79.92</td>
<td>.59</td>
</tr>
</tbody>
</table>

Note: Pure air runs about as follows:-- CO₂ 0.03; O₂, 20.93; Nitrogen, etc., 79.04.
Dusts in Mine Air:

Dust in metal-mine air probably causes more sickness and ultimately more deaths, among metal miners than any other cause. The writer, after four years' study of dust in mines, believes that any kind of dust will ultimately be harmful if breathed in large quantities, and this includes not only siliceous dust, but coal dust, which some authorities believe has no harmful effect, lead carbonate dust, and arsenical dust. The most harmful dust is probably that of free silica (quartz, flint, etc.) especially the finer sizes. The hard, sharp, insoluble particles cut and injure the lung tissue, making it more or less inelastic and incapable of expansion, and ultimately bringing on miner's consumption.

As in probably more than half the cases metal ores have a siliceous gangue, or occur within siliceous wall rock, most metal mines have siliceous dust. The finest dust, which is the most harmful, is invisible, and the dust is tasteless and odorless. It is chiefly raised in the air by dry drilling, blowing holes, dry blasting, shoveling and tramming.

The fine dust, once raised into the air, remains suspended many hours in still air, hence in poorly ventilated places the miners breathe this fine dust continually. By far the most dangerous condition is that of breathing dusty air in a hot humid stagnant place all day, and then going home in perspiration-saturated clothing through air frequently many degrees below zero.

Miner's consumption and lead-poisoning among metal miners are both caused by dust and are wholly preventable. The most effective prevention of dust in mine air, apart from elimination of dry drilling, is the circulating of pure air at the working face. Also, piles of broken ore should be wet down, and the timbers, floor, and walls of dusty road ways and working places should be sprinkled.

The effectiveness of good ventilation in preventing miner's consumption is illustrated by two mining districts in the United States. In both districts the mines have cool rock and air, dry siliceous ore easily broken into fine dust, and the miners work hard. In one district the method of mining requires constant shooting, so the mines all have moving currents of air at nearly all the working places; in the other, little or no air is circulating at working places. In the former, miner's consumption is practically unknown, in the latter it is a common disease.

This disease probably kills at least 1000 metal miners annually in the United States, and causes a loss of time aggregating millions of dollars; the misery and suffering to miners and their families can not be estimated. Yet the causes of this disease could be reduced 75 per cent if not wholly eliminated by proper preventive measures on the part of operator and miner, one of the most potent measures, as previously mentioned, is adequate ventilation.

Efficiency as related to ventilation:

In one deep fairly well ventilated mine with 82 per cent of the working places below the 2000-foot level, and rock temperatures of 90 to more than 1000 °F., out of 158 places visited by the writer, 18 had temperatures of more than 750 °F., and 136 had a relative humidity of over 85 per cent, yet 78 places or 49.4 per cent were rated comfortable by the writer. In this mine particular attention was paid to distribution of air to working faces.
A near-by mine which relied on natural ventilation, and paid little attention to air distribution, had 41 out of 87 working places below the 2000-foot level, and rock temperatures generally below 90°F. In 56 places the air temperature was above 75°F. and in 59 the relative humidity was above 85 per cent. Only 28 places, or 32 per cent, out of the 87, were rated comfortable.

In each of these mines, compressed-air blowers were used in about half of the working places. As regards the use of compressed-air blowers, it was found that in these mines the average blower consumed per 8-hour shift, about 40,000 cubic feet of compressed air, whereas the average rock drill took about 10,000 to 15,000 feet. The temperature of the air at the nozzle was as a rule only one or two degrees cooler, and sometimes several degrees warmer than the surrounding air.

The use of compressed air blowers for ventilating blind ends, a common practice in poorly ventilated mines, is not only costly but futile. The average blower delivers about 100 cubic feet of air per minute, which is usually not enough to remove fumes of explosives, or to give much relief from heat and humidity, whereas a small fan forcing 1000 feet or more per minute through canvas pipe or galvanized iron pipe will remove fumes and keep the men comfortable. Compressed air costs about 3 cents per 1000 cubic feet, as compared with 0.03 cents per cubic foot for fan ventilation. Moreover, where compressed air is used for ventilation, the drain on the air supply in the pipes reduces the pressure to 60 or even 30 pounds, making drilling difficult or even impossible. The installing of fan ventilation at one mine reduced the compressed air consumption more than one-half, established good working conditions, increased the men's output one-half, and the cost of ventilation plus compressed air was less than the former cost of compressed air alone.

On the other hand, a mine may circulate large quantities of air by fans ineffectively, unless attention is paid to proper distribution. In one large mine equipped with fans, where little effort was made to distribute air to the face, 75 per cent of the working places had no air movement detectable by a candle flame, 20 per cent showed a slight movement, and only 5 per cent had sufficient motion to afford relief to workers. There was an abundance of cool moving air in the main levels, but the working places were generally hot, humid, and uncomfortable; the lack of distribution of air almost wholly negatived the expenditure for equipment and operation of the fans.

In one cool mine with abandoned workings above an adit level and active workings below at various levels to about 1000 feet, natural ventilation was used with fairly good results in cold or warm weather, but with little circulation in spring or in autumn, or in early morning in summer. When the writer visited this mine a few years ago in the fall, the air was so low in oxygen that a candle would not burn at any point below the adit level, and walking a few hundred feet in a drift caused quick breathing. Miners shunned this mine, while adjoining mines turned men away. After some years, two fans were installed and the mine is now well ventilated, and the output per man per shift is 7 tons, as compared with the former record of less than 3 tons.

In a large deep mine with rock temperature over 100°F. on the 3200-foot level, men would not work more than a few shifts in certain drifts and stopes. After a fan was installed at the 3200-foot station blowing into the
workings and a number of small auxiliary fans were placed to blow air through canvas pipes to blind ends and working faces, these places were comfortable and in demand among the miners.

At another mine where a shaft was being sunk in rock over 100°F., the substitution of a fan and canvas pipe for ventilating the shaft, in place of compressed air, resulted in increasing the monthly rate of progress from 50 feet to 130 feet.

In driving a 2500-foot cross-cut in damp granite rock with temperature about 750°F., and using compressed-air ventilation, the working crew had to be changed several times weekly because of nausea from explosive fumes and impure air. Finally a small electrically driven fan was placed. This fan delivered completed saturated air at 79°F. through canvas tubing, at a rate of 3700 lineal feet per minute. The rapid current completely removed all explosives fumes from the face, and from muck piles as fast as liberated by shovelling, and afforded distinct relief to the workers. The cost per linear foot of driving was reduced from $15 to less than $9, and the rate of progress more than doubled.

Every company employing men underground should install mechanical ventilation, with effective control of underground air circulation at all times. This may seem drastic to mines apparently having good air through natural circulation, but the utter helplessness of naturally ventilated mines in combating mine fires with attendant loss of life and property from fires, has been evidenced in many instances. On the other hand, the ability to reverse and control air currents as desired in times of mine fires, has often resulted in immense saving of property and of many lives.

Many officials of mines with hot, humid, stagnant working places admit that the men can not work at more than 50 per cent efficiency, and the writer has observed men working in places where the maximum output was less than one-third normal, although the expenditure of an amount equal to a few days wages of the men, would have made the places comfortable and healthful.

Miners' consumption alone, which is largely caused by poor ventilation, probably costs the mining companies of the United States many million dollars annually, through inability of the afflicted men to do a full day's work. Moreover, many metal-mine bosses, selected because of experience, are so afflicted with miners' consumption that they can not climb ladders. As a result hundreds of raises are driven without inspection above the first 100 feet.

Conclusion:

This paper will be concluded with a few recommendations as to methods of properly ventilating metal mines.

Each mine should have its ventilating equipment and system installed by some one thoroughly familiar with the subject. The main fan should be in fireproof housing, equipped for quick reversal of air currents in event of necessity. Air currents should be split underground by a system of doors, overcasts, regulators, etc., in such way that air is quickly removed from the mine after passing through one or two levels, and in event of mine fire in one part, that
the fumes may be removed without contaminating any other part of the mine.

The chief object in ventilating a mine is, however, to bring the moving air to the working face, the most difficult places to ventilate being blind ends. For such places the best results are obtained with small auxiliary fans directly connected to electric motors (1½ to 10 E.P.) and forcing 1000 to 5000 cubic feet per minute at a velocity of 1000 lineal feet per minute to the working place or face. Blower fans are preferable to the suction type, as they provide rapid movement in addition to removing impure air. Either canvas or iron pipes can be used with blower fans. Canvas pipes are more convenient and flexible, but iron pipe lasts longer. The last 50 feet at least should be of canvas for bringing air directly to the face, and for quick removal before blasting and quick replacement after the blast.

The most essential feature of metal-mine ventilation is probably that of competent supervision of equipment and practice. Good results can not be attained if the ventilating system is left without attention as is the case in many metal mines, nor if left to a mine foreman, who frequently knows little about ventilation. Progressive companies are realizing the value of efficient ventilation at working faces, and in general find the best results are had when ventilation is placed in the hands of one man who devotes all or most of his time to this work. Where this is done the returns in improved safety and health of employees, and in dollars and cents to the company, far outweigh any costs entailed. -- U. S. Bureau of Mines, Reports of Investigations.