Published in final edited form as:
Min Eng. 2014 October ; 66(10): 43–.

Investigation of induced recirculation during planned ventilation system maintenance

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Abstract

The Office of Mine Safety and Health Research (OMSHR) investigated ways to increase mine airflow to underground metal/nonmetal (M/NM) mine working areas to improve miners' health and safety. One of those areas is controlled recirculation. Because the quantity of mine air often cannot be increased, reusing part of the ventilating air can be an effective alternative, if implemented properly, until the capacity of the present system is improved. The additional airflow can be used to provide effective dilution of contaminants and higher flow velocities in the underground mine environment. Most applications of controlled recirculation involve taking a portion of the return air and passing it back into the intake to increase the air volume delivered to the desired work areas. OMSHR investigated a Nevada gold mine where shaft rehabilitation was in progress and one of the two main fans was shut down to allow reduced air velocity for safe shaft work. Underground booster fan operating pressures were kept constant to maintain airflow to work areas, inducing controlled recirculation in one work zone. Investigation into system behavior and the effects of recirculation on the working area during times of reduced primary ventilation system airflow would provide additional information on implementation of controlled recirculation into the system and how these events affect M/NM ventilation systems. The National Institute for Occupational Safety and Health monitored the ventilation district when both main fans were operating and another scenario with one of the units turned off for maintenance. Airflow and contaminants were measured to determine the exposure effects of induced recirculation on miner health. Surveys showed that 19% controlled recirculation created no change in the overall district airflow distribution and a small reduction in district fresh air intake. Total dust levels increased only modestly and respirable dust levels were also low. Diesel particulate matter (DPM) levels showed a high increase in district intake mass flow, but minor increases in exposure levels related to the recirculation percentage. Utilization of DPM mass flow rates allows input into ventilation modeling programs to better understand and plan for ventilation changes and district recirculation effects on miners' health.

Disclosure
The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of any company or product does not imply endorsement by NIOSH.

Introduction

The Office of Mine Safety and Health Research (OMSHR) is examining methods to improve airflow delivery underground as mines face challenges due to production workings moving farther away from shafts, mining deeper ore reserves, increased production demands and finding additional reserves away from the original mining area. The use of booster fans and controlled recirculation are two potential options being explored.

Recirculation has been defined as “when any portion of the airflow passes by the same point more than once,” (Marks, 1989) and further as “the intended use of the recirculation principle within a ventilation system to improve conditions at the face.” Controlled partial recirculation was also defined by McPherson (2009) as “one in which a controlled fraction of the air returning from a work area is passed back into the intake, while, at the same time, the volume of air passing through the region is monitored to ensure that it remains greater than a predetermined minimum value.” This survey will analyze the effects of induced recirculation at a Nevada gold mine where shaft rehabilitation was in progress and one of the two main fans was shut down to allow reduced air velocity for safe shaft work.

Background

The subject mine operates in the Carlin Trend west of Elko, NV. Descriptions of the mine, mining methods, ventilation system and future plans can be found in Araya (2012a; 2012b; 2012c). The active mining district begins at the Carlin East Pit, trending north along multiple mining zones that were accessed as discovered, presenting a ventilation challenge commonly seen during the life of an underground mine. These additional ore zones were discovered between the pit and the main deposit, and further ore zones have been located along the trend further north. The study area mining district is part of the ore reserves between the main deposit and these north area reserves. A northern shaft is being sunk into these reserves and will be intercepted in 2015. Until then, the ventilation system is challenged to provide adequate airflow, and maintenance of the present air shafts is needed to ensure ventilation capacity until the future shaft is available.

The two main fans operate in parallel and are located on the mine level at the bottom of the exhaust shaft. Because of the high velocity associated with full airflow, shaft maintenance is difficult. Shutting down one fan lowers velocities to safely accomplish this task. During these shutdown periods, mining district booster fans (Fig.1) operate at normal pressures, inducing recirculation from the district return into the intake. After preliminary discussions, OMSHR and company employees proposed studying this ventilation district during both recirculation and normal operation to further understand system behavior and its effect on miner health and safety.

Survey plan

The mine was sampled during two days with recirculation and one day where both main fans were operational illustrating the “normal” condition. The first day revealed unplanned changes in the ventilation system, so the study protocol was adjusted for the next two days.

The areas monitored were the district intake entrance, raise intake to the working level, district exhaust return from the working level, and recirculation ramp between the district intake and return (Fig. 2). Respirable dust area samples were measured using conventional pumps, cyclones and filters at 1.7 L/m, and total dust was measured using passive personal data rams (PDRs) (Volkwein et al., 2004). Sampling times were approximately five hours. Due to the utilization of diesel mining and haulage equipment, contaminants measured were carbon monoxide (CO), nitrogen dioxide (NO_2) and oxygen using a recording Industrial Scientific multi-gas meter (Industrial Scientific, 2013); average diesel particulate matter (DPM) area sample concentrations by NIOSH method 5040 using SKC DPM impactors (Noll et al., 2012; NIOSH, 2006) and real-time DPM concentrations by a FLIR/Airtec (FLIR, 2013; Noll et al., 2013). Airflows were determined using standard vane anemometer traverse methods.

Preliminary ventilation network modeling showed that the tracer gas (SF_6) released in the district intake airway during recirculation would return in a very short time due to high velocities and close proximity to the three local production areas and associated exhaust raises. A full lecture bottle of tracer gas was released just inby the district intake sample point and then sampled in the district exhaust prior to the recirculation crosscut after passing through the work areas via booster fans. Samples were taken in 10-ml evacuated bottles every two minutes in the district intake and return. Gas analysis showed varied residence times due to multiple nearby production areas and extended development headings mining towards the future shaft bottom. SF_6 data confirmed pre-test modeling, distinctly showing recirculation spikes approximately every six minutes from these nearby mining areas. There was negligible effect after one hour, showing quick movement through the system.

Airflow analysis

Figure 2 and Table 1 show results of normal and recirculation airflow measurements in the ventilation district. The district recirculation airflow results are:

Percent recirculation (25.3/(31.1+128.8-25.3)	8.8%
Recirculation district airflow change @ district exhaust/intake	−3.7/+9 m^3/s
Percent total airflow change to district — intake/exhaust	−2.3/+6%
Decrease in district intake air (121.4+29.5)-(128.8+31.1)	−9 m^3/s
Percent increase in district intake air (128.8+31.1)/(121.4+29.5)	6%
Decrease in fresh air (121.4+29.5)-(128.8+31.1-25.3)	−16.3 m^3/s
Percent decrease in fresh air (16.3/(121.4+29.5))	−10.8%

Total intake and exhaust airflow in the district was measured inby the recirculation ramp and showed essentially the same total airflow, with the intake showing slightly more and exhaust slightly less during recirculation. This was well within the accuracy of anemometer and area measurements. District fresh air composed of the intake raise and outby district intake fell from 150.9 m^3/s to 134.6 m^3/s or 11% during recirculation.

Baseline/recirculation contaminants

Mine gases CO and NO_2 showed no significant changes or measured levels during either scenario and were eliminated from further analysis.

Total dust levels, shown in Fig. 3, exhibit increased concentrations comparable to the recirculation percentage (19%), with much higher levels seen in the recirculation ramp. Airflow here reversed and increased in magnitude with the source changing from intake to return. High levels of roadway dust were noted in the district exhaust airway, which would be more susceptible to total dust from local haulage activity and much lower airflow quantities than the cooler, well-maintained, watered main drifts of the district intake. The raise intake had no mining activity the day that no recirculation was used. District intake roadways had higher traffic but were better maintained than district exhaust, as shown in total dust measurements.

Respirable dust levels, on the other hand, were either constant or decreased, except in the raise intake, which showed no production activity on the normal ventilation day (dust or DPM), as evidenced by measured dust and DPM levels (Fig. 4 and Table 1). District intake levels were constant and low, and district exhaust levels were constant and higher than most others measured as would be expected in the main return close to mining activity. The recirculation drift concentration can be related to the change in relative airflow, essentially doubling the airflow during recirculation, dropping dust levels in half. Intake dust levels show good attention to roadway maintenance and dust control.

Results

DPM level results are shown summarized in Tables 1 and 2, and can be visualized in previous Fig. 2 airflow and Fig. 5 DPM mass flow (ug/s), computed by multiplying average DPM concentration (ug/m ^{3}) (Table 1) by airflow (m^3/s). NIOSH 5040 analysis elemental carbon (EC) values were multiplied by 1.3 (Noll, 2013) to correlate to total carbon (TC) values, from which the U.S. Mine Safety and Health Administration (MSHA) enforces the 160 ug/m^3 DPM exposure limit (Code of Federal Regulations, 2013). Equating DPM concentration to mass flow, the contribution of mining work area emissions may be determined by difference from total intake and exhaust district airflow concentrations and flows.

DPM mass flow was used to better determine the area contributions to DPM generation. Average concentration is good for the determination of exposure level, but mass flow assists in identifying where the particulate generating sources are and in helping investigators to better understand the effect when airflow rates change, as in the district recirculation environment. Mining activity also changes shift to shift and day to day, and the effect can be better isolated by using mass flow data. DPM mass flow can then be entered as a contaminant source into a ventilation network program to better determine exposures for miner health and safety management.

Recirculated district intake location DPM concentration increased comparably (+27%) to the recirculation percentage of 19% (Table 1), but was still well below the MSHA 160 ug/m^3 DPM exposure limit. During recirculation testing, and in comparison to the normal ventilation condition, additional DPM over and above that from recirculated air was contributed from production sources outby the raise intake and from an increase in mining work area activity. Recirculated DPM mass flow (3365 μg/s) added a considerable amount to intake fresh air (4333 μg/s) — a 78% increase in DPM mass flow above district intake air — but was a relatively low concentration level (51.9 vs 41 μg/m^3) increase over normal intake airflow when compared to an MSHA-allowable exposure of 160 μg/m^3. District exhaust levels were also below allowable exposure limits in both scenarios. Mass flow information added considerably to understanding of DPM sources over that from concentrations alone.

Conclusions

Often, changes in the mine ventilation system cause upsets that may induce recirculation. At one Nevada gold mine where shaft rehabilitation was in progress and one of the two main fans was shut down to allow reduced air velocity for safe shaft work, shutting down one main fan and leaving underground boosters at normal operating pressures did result in recirculation. Consequences of that action on the mining district ventilation were investigated by measurement of SF_6 tracer gas recirculation times, airflow, mine gasses, dust and DPM.

SF_6 concentrations showed a very quick turnaround time in recirculated air due to the close proximity of three mining sublevels and high airflow velocities, confirming network modeling results, which gives confidence to using modeling for effective network predictions. This finding also demon strates the need for carefully monitoring fire contaminants and control of recirculation fans, as they will quickly enter the recirculation zone, affecting miner health and safety.

Airflow surveys showed that 19% recirculated air generated no significant change in district airflow distribution. However, the induced recirculation from shutting down one of the two main fans created a 23% reduction in district intake fresh air. Analysis of mine gasses CO, NO_2 and O^2 showed no concerns. Total dust levels increased modestly in conjunction with the recirculated air percentage except in the reduced airflow recirculation drift, where increased levels were controlled by airflow quantity. Respirable dust levels were also low. Contaminant increases noted were from the raise intake due to mining activity. DPM levels showed increased district intake mass flow but only minor increases in exposure levels related to the recirculation percentage and from work area activity.

Previous research has shown that success of a controlled recirculation is predicated on an adequate supply of fresh air. These researchers also recommend a reliable monitoring system, toward which this mine has made considerable progress (Araya, 2012c) having installed airflow, gas and temperature monitors. In this study, intake DPM concentrations increased (+27%) similarly to the percentage of recirculated air (19%), although intake fresh airflow dropped by a slightly lower percentage (11%). If intake fresh airflow and production activity had remained constant, DPM levels may have been close to the same, confirming the above.

Although the fresh air quantity was reduced during ventilation system maintenance and air was recirculated back into district intake air, only modest increases in contaminants were measured. The critical area found during the in-mine testing was the isolated recirculation drift where airflow reversed. Should the system balance be close to neutral, this area or others could encounter minimal airflow, creating an area of low airflow and potentially high concentrations. If this reversal is critical to the system, air doors or a regulator could be installed to prohibit or control recirculation.

When these ventilation events are envisioned, suitable ventilation surveys and modeling exercises should be undertaken in advance of events to ensure a safe and healthy environment is maintained. Critical areas in the ventilation system are not usually in main airways, but sampling information from face workers in conjunction with knowledge of total fresh air intake dilution capacity should drive decision making regarding production levels affected by system ventilation upsets. Should face mining area exposures be near the allowable limit, activity should be reduced. Utilization of DPM mass flow allows input of contaminant flow into a ventilation network model, giving a better idea of potential contaminant levels during ventilation changes and district recirculation. Should a permanent system of controlled recirculation be used, the design should monitor for and minimize the recirculation of mine fire contaminants to assure the safety of miners.

Acknowledgments

Dr. Gerrit Goodman, Dr. Charles Kocsis and John Marks were instrumental in reviewing the manuscript. Thanks to Ken Strunk for graphics support. Many thanks to mine company officials and employees for field support.

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Figure 1.
Study area underground district booster fan (photo by NIOSH).

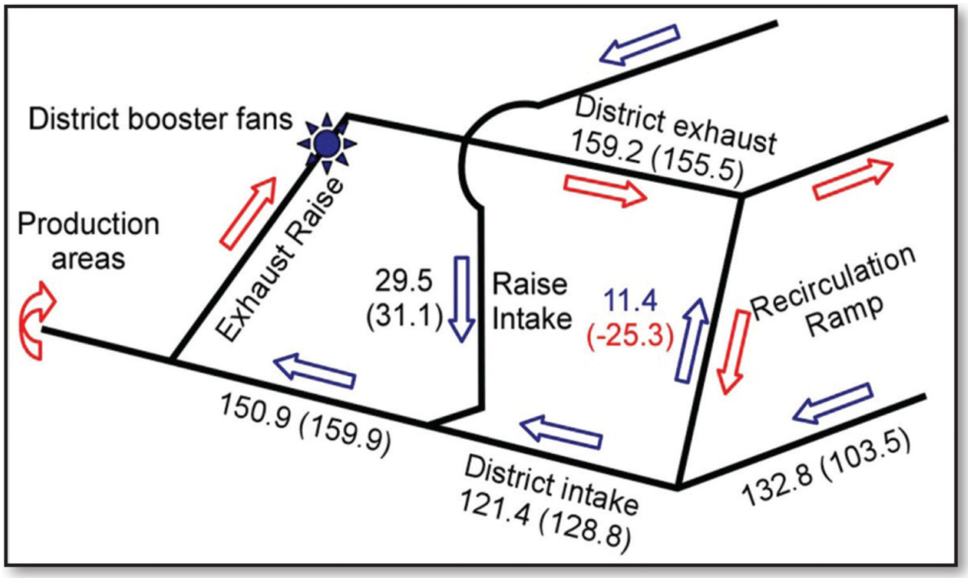

Figure 2.
Survey schematic — Airflow m^3/s: Normal (recirculation). Intake (blue), return (red).

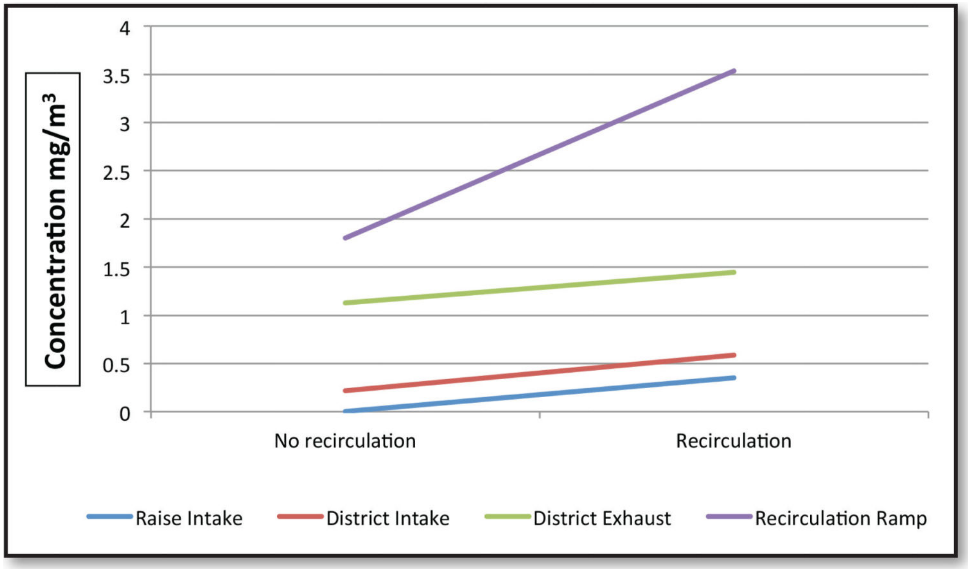

Figure 3.
Total dust levels during normal and recirculation ventilation.

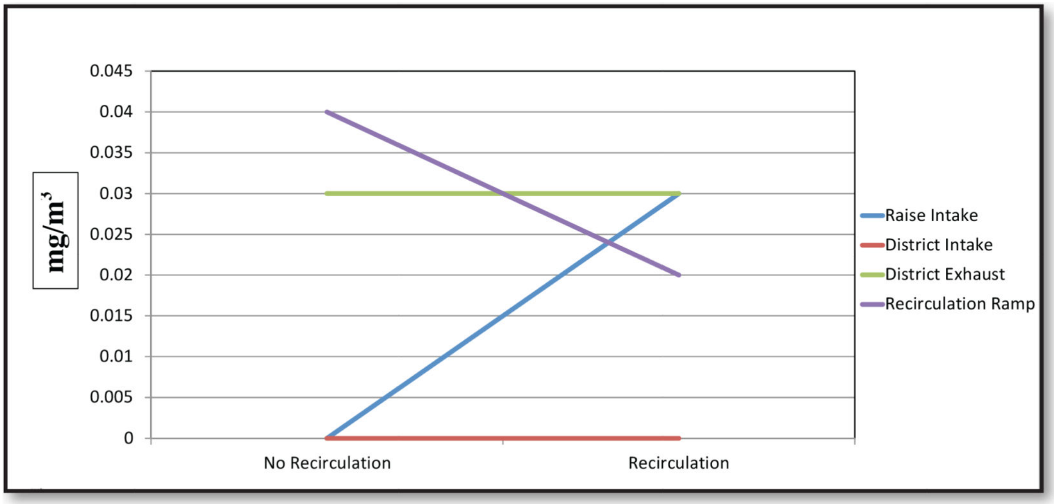

Figure 4.

Respirable dust concentrations during normal and recirculation conditions.

Table 1

Normal and recirculation airflows with measured and mass flow rates of DPM. DPM was corrected from 5040 method elemental carbon (EC) to total carbon (TC) by multiplying by 1.3 (Noll, 2013).

Normal airflow	**Airflow m^3/s**	**DPM - 5040 EC* 1.3 $\mu g/m^3$**	**Total DPM Mass flow- µg/s**
District intake	121.4	41	4979
Raise intake	29.5	0	0
District exhaust	159.2	87.2	13879
Recirculation ramp	−11.4	76.9	875
District fresh air	150.9		
Recirculation			
District intake	128.8 (103.5 Fresh)	51.9	6685 (3320 Fresh)
Raise intake	31.1	32.5	1012
District exhaust	155.5	114	17722
Recirculation ramp	+25.3	132.9	3365
Total district fresh air	134.6		

Note: + Airflow is towards intake

Table 2

Mass flow of DPM (μg/s)—Airflow (m^3/s) times average NIOSH 5040 concentration (μg/m^3).

	Intake (Fresh)	**Exhaust**	**Recirculated**	**Work Area**
Ventilation	DPM μg/s	DPM μg/s	DPM μg/s	DPM μg/s
Normal	4979	13879	N/A	8900
Recirculation	4333	17722	3365	10025
Recirculation ramp	−11.4	76.9	875	
District fresh air	150.9			