RATIONALE AND METHODOLOGY IN DESIGNING CONTROLLED RECIRCULATION VENTILATION SYSTEMS

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INTRODUCTION

Mine ventilation engineers have traditionally cringed at the thought of recirculating airflows. This phenomenon has been responsible for disasters in the past such as the 1972 Sunshine Mine fire. Nowadays, a number of companies are employing the recirculation principle to improve work area environmental conditions at a lower cost than alternative schemes.

The theory and benefits of controlled recirculation (CR) are becoming familiar to ventilation specialists through technical conferences. But, the U.S. mining industry, academia and governmental entities as a whole seem to be lagging behind. Perhaps they have adopted a wait-and-see posture. Controlled recirculation does contain an element of inherent risk.

This is not a ventilation conference, but one for the policy makers; the movers and shakers of industry. Although corporate officers have plenty to worry about besides ventilation, a grasp of ventilation principles will lead to sounder operational decisions. After all, ventilation, along with materials handling and rock mechanics, is one of the classical limiting factors in the extent to which reserves of a given grade and price can be profitably extracted. Controlled recirculation has proven potential for reducing operating costs, and may extend mine life in certain situations.

WHAT IS CONTROLLED RECIRCULATION?

The Basics

Recirculation occurs when any portion of the airflow passes by the same point more than once. Controlled recirculation may be defined as the intended use of the recircul-ation principle within a ventilation system to improve conditions at the face. Applying CR to ventilation circuits was proposed by the British coal mining industry in the 1930's. The U.K. has thus been at the forefront of CR research. More recently, the South Africans and Australians have joined the fray.

One might intuitively suspect that the level of contaminants produced by mining operations will steadily rise in a CR system. But, it has been demonstrated mathematically and in practice that this is not the case. Contaminant concentration under steady-state conditions depends only on the rate of contaminant generation and the intake airflow. For unsteady-state conditions such as blasting and fan stoppings/startings, a transitory period exists while the primary circuit purges the contaminant. It has also been demonstrated at a South African gold mine (Burton 1988) and corroborated at Homestake that CR does not further delay ingress after blasting.

The Types of Controlled Recirculation Systems

The three basic types of CR are: auxiliary, district, and whole mine. Figure 1 shows a simplified CR auxiliary circuit. Since the fan is rated at a higher capacity than the incoming fresh air flowrate, a portion of the air delivered to the face will travel back to the fan inlet and mix with the fresh air.

Figure 2 shows a district CR scheme with the associated terminology. Booster fans in either the crosscut or inline position induce the CR. Recirculated air can be "treated" in the crosscut. The area containing the recirculation crosscut, the mixed intake, workings, and the mixed return is known as the recirculation zone. The ratio of recirculated to mixed airflow is called the recirculation fraction.

Whole mine CR systems are similar to district CR systems only broader in scope. The recirculation crosscut normally links primary intake and exhaust shafts at or near the surface.

RATIONALE FOR DESIGNING CONTROLLED RECIRCULATION SYSTEMS

The Principle Benefit of Using Controlled Recirculation

The only principle benefit of CR is improving work area conditions at a lower cost than other alternatives. The means by which conditions are improved depend on the type of mine and the specific problems confronted by the mine. It cannot be stressed enough that CR should only be used for improving work conditions. The primary circuit must be able to meet minimum statutory requirements at the faces by itself.

An air treatment box is shown in Figure 2. Consider for a moment that this "black box" suffers no downtime, removes 100% of any contaminant produced, and replaces the oxygen consumed in the work area. A recirculation fraction of 1.0 (no fresh air intake) would then be permissible. The primary circuit could be forsaken and the only ventilation costs incurred would be for operating the black box and the recirculation fans. In the real world, however, perfect black boxes do not exist. High percentages of dust and heat can be removed practically on a large scale, but contaminants such as methane and carbon monoxide cannot.

Specifics of Using Controlled Recirculation

Controlled recirculation increases the air quantity and velocity in work areas without dragging additional air through the primary circuit. In coal mines, higher face velocities can prevent stratification of firedamp. Increased quantities also remove dust more quickly, and may permit additional development headings in a district. The heat produced by mining equipment can be rejected to the strata if the virgin rock temperature is low enough. When air in the recirculation crosscut is treated, as for example in a dust collector, the average work area contaminant concentration will be less with CR. The actual value depends on collection efficiency.

It must be realized that CR in both coal and metal mines will slightly reduce fresh airflow from the surface. This is due to the higher quantities and the resulting higher pressure drops in the recirculation zone. Fans in the primary circuit will interpret the higher pressure drops as a higher resistance, and will operate on their curves accordingly.

In deep, hot metal mines, CR can be used to distribute the refrigerating effect, or "coolth", from a refrigeration plant to the work areas. The method is particularly suited to underground bulk air cooling techniques if heat rejection potential exists. Some advantages are:

* Cooling is distributed with airflow instead of piping systems. Since air must be routed to the stopes anyway, why not have it deliver the coolth?
* A higher air velocity increases specific cooling power, and it is usually much easier to move air than to cool it.
* Since a CR plant works on exhaust air, the percent utilization approaches 100.
* Maintainability is enhanced because all the cooling is done in one spot instead of being scattered throughout the mine.
* It has been found at Homestake that strict deployment of fresh air on the intake side is not as critical in a CR system. Even mal-distributed fresh air contributes to the recirculation fraction, is fully utilized by the plant, and ultimately carries heat up the return.

One disadvantage is that the system positional efficiency degrades as mining activities progress further from the plant. Development headings still often require expensive spot-cooling.

Removing heat is treated mathematically just like removing a gaseous contaminant, with adjustments made for temperature-dependent heat transfer. The regulatory aspect may be different, however. In coal mines, the primary circuit must be able to meet statutory requirements without the CR fans. In hot metal mines, the primary circuit may not adequately remove heat if the CR plant goes down. Indeed, intake air adds to the heat load if workings are below the critical ventilation depth (the depth at which the intake air temperature has risen to the design reject temperature). Work areas are in trouble when the plant goes down no matter what method is used to deliver coolth. At least with

CR, some cooling may be extracted from the mixed intake wallrock if it has been cooled long enough.

METHODOLOGY IN DESIGNING CONTROLLED RECIRCULATION SYSTEMS

Coal Mines

Underground booster fans are currently illegal in U.S. coal mines but other major coal-producing nations are not so constrained. Some work is afoot in the U.S. to permit booster fans. District CR is now being practiced by at least one coastal mine in the U.K. Workings extend up to seven miles under the sea. Leakage from inbye to outbye can reduce the primary circuit volumetric efficiency (the ratio of the air arriving at the faces to the total surface fan quantity) to less than 50%, even with carefully-placed boosters. Robinson (1988) reports that CR may help extend the life of coastal mines by permitting extraction of reserves up to 12 miles under the sea. The methodology developed in the U.K. includes the following:

* The primary circuit must be able to meet statutory requirements by itself.
* The recirculation fraction commonly used to date is around 0.3. Even at this relatively low value, the potential exists to cut ventilation power costs to one-third of what a conventional system would require (Robinson 1988).
* Recirculation fans should be direct-driven and be protected with vibration sensors. The crosscut should be equipped with anti-reversal doors to prevent reverse air flow when the fans are down.
* Recirculation fans in the inline position are reported to create less leakage between intake and return.
* Crosscut fans are smaller and may be more energy efficient than inline fans.
* The recirculation fan installation should be relatively mobile (when compared to primary circuit boosters) so that the recirculation crosscut can be moved up as the face advances.
* The recirculation crosscut shouldn't be too close to the face however. Extra distance in the mixed return permits some dust to fall out and some heat to transfer from air to strata rock.
* The position of boosters is more dependent on practical considerations than on theoretically optimal locations.
* Computer network analysis should be conducted on the entire system, with all the combinations of fan shut-downs and other events. The actual circuit should then be tested by measuring system response when key fans are shut down.

Metal Mines with Heat Problems

Old, deep, and extensively worked metal mines are among the best candidates for CR systems. This is especially true if they are heavily mechanized (Anderson 1988). The Homestake Gold Mine fits this bill, and the methodology used to design its system is summarized below.

* Ventilation requirements must be accurately projected. Computer climatic simulation is used for heat loads, with results continually checked against measured heat loads in existing work areas.
* Controlled recirculation must be compared against other alternatives that will also do the job.
* Recirculation zone boundaries must be firmly established.
* The methods of air flow control such as doors, regulators and auxiliary fans must be firmly established.

Homestake's system has two distinct components: recirculation and refrigeration. The recirculation component has been a real blessing. The refrigeration component has experienced difficulties (averaging 50% load), but problems are being worked out. Fortunately, full plant capacity is not yet needed. The recirculation fraction is 0.65, the recirculated quantity is 360,000 cfm, and the plant is rated at 2300 tons(R). The six recirculation fans in two bulkheads are rated at 450 total horsepower. The 3000-hp surface fan for this circuit is operating at 530,000 cfm @ 26" static water column, and is drawing 2500 hp. Supplying the additional 360,000 cfm from the surface without new airways would require an astronomical 73" static pressure and 11,800 hp. That is out of the question.

Cold Climate Mines

Hall (1985) reports that heating intake air at Canadian mines costs considerably more than ventilation. The annual heating bill in 1985 averaged $2067 Canadian per m^3/s. Subsequent work has demonstrated CR to be best alternative for reducing heating costs by mixing up to 25% of the exhaust air with the intake. Basically, the reported methodology is:

* A whole mine system is preferable to a district system.
* The intake and exhaust airways should be fairly close.
* In mines dependent on the drill-blast-muck cycle, the CR system should be shut down during blasting time.
* A variable air quantity CR system is recommended over a fixed quantity system despite its higher cost. The variable quantity system can maintain tighter control on contaminant levels.

Research Topics

Research on CR has been picking up. Current topics center around predicting environmental conditions and modelling the dispersion of contaminants in transition periods. Investigations are continuing into the role it will play in ventilating ultra-deep (greater than 4 km) South African mines. And, safety-related aspects are receiving well-deserved attention.

SAFETY-RELATED ASPECTS OF CONTROLLED RECIRCULATION SYSTEMS

Recirculating fire by-products is considered to be the highest risk factor. This applies to both coal and metal/ nonmetal mines. Every reported case study on CR has dealt rigorously with monitoring and risk reduction, and rightly so. It is imperative that designers be continually haunted by Murphy's law: if anything can go wrong, it will.

Controlled recirculation safety-related aspects can be divided into two components: 1) preventing or quickly suppressing fires, and 2) minimizing the effect if a fire does get out of control. Homestake's design methodology is:

* Combustibles and sources of ignition are surveyed. At Homestake, the greatest fire risks in the recirculation zone involve diesel mechanization (timber is only used for chutes and track ties). Diesel fuel, oils, greases and solvents are stored in special protected areas. The vehicles themselves are protected by on-board fire suppression systems.

* The recirculation zone is confined to a specific stoping area. Intake air is provided from both sides of the area and from multiple levels. Ample opportunity exists for miners to escape to a fresh air base if anything were to happen.

* A state-of-the-art computerized monitoring system has been installed. Four carbon monoxide sensors in the recirculation crosscut work on a polling system, and three others within the zone provide analytical data. Two additional sensors monitor intake and return air. The recirculation fans can be shut down automatically by the computer, from the surface by the electrical load dispatcher (manned constantly), or from the plant site. Independent hard-wired shut-down capability is being installed from a nearby winze hoistroom. The circuit reverts back to a once-through system when the recirculation fans are down.

CONCLUSION

Controlled recirculation can improve work area conditions at less cost than conventional alternatives in certain circumstances. It also has the potential to extend mine life. The best candidates are mines with limited access to the surface. These include coastal coal mines and deep, hot, usually older metal mines. The principle can also be used to reduce heating costs at cold climate mines.

Although safety-related aspects have been dealt with diligently in the systems installed to date, the final verdict on safety is still out. Authorities discuss the benefits and risks with caution. For example, the South African Government Mining Engineer, J. Raath, has stated "I believe that controlled recirculation of air should be the exception rather than the rule. It can be used provided it is very well planned and carefully monitored." (Journal of the Mine Ventilation Society of South Africa, November 1988).

Companies contemplating the use of CR must bear two design factors in mind. The first is that the principle cannot be used as an excuse to "get by" with less intake air than is required to remove contaminants. We have found this to be a tempting siren at the Homestake Gold Mine. Miners outside the recirculation zone continually request more fresh air because miners within the zone enjoy superior work conditions.

The second factor is to leave no stone unturned regarding safety. Combustibles and sources of ignition should be isolated, protected or eliminated. An extensive top-grade monitoring system is mandatory. And, the integrity of escapeways out of the recirculation zone must remain inviolate.

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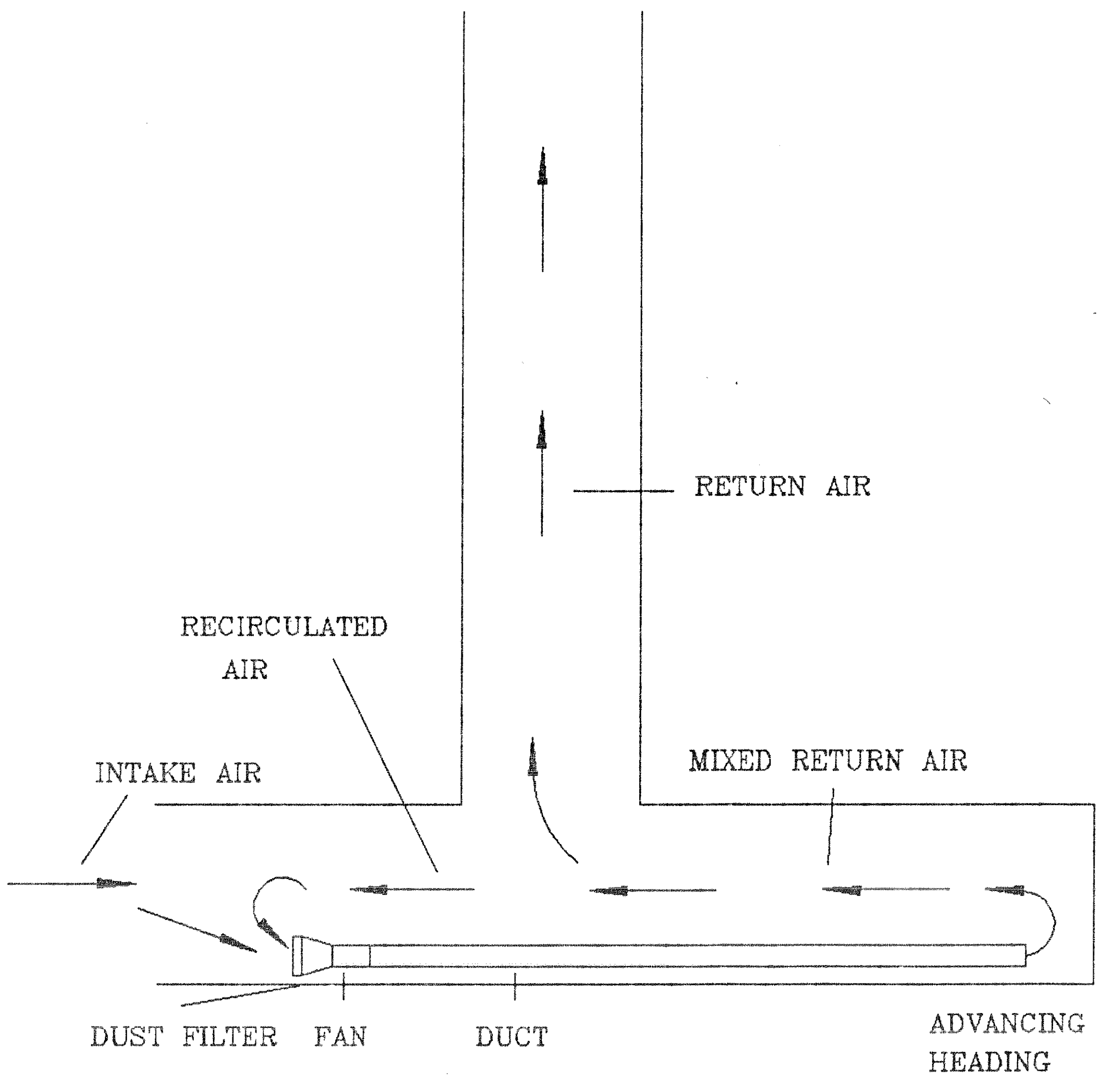

FIGURE 1. SIMPLIFIED CONTROLLED AUXILIARY RECIRCULATION VENTILATION SYSTEM

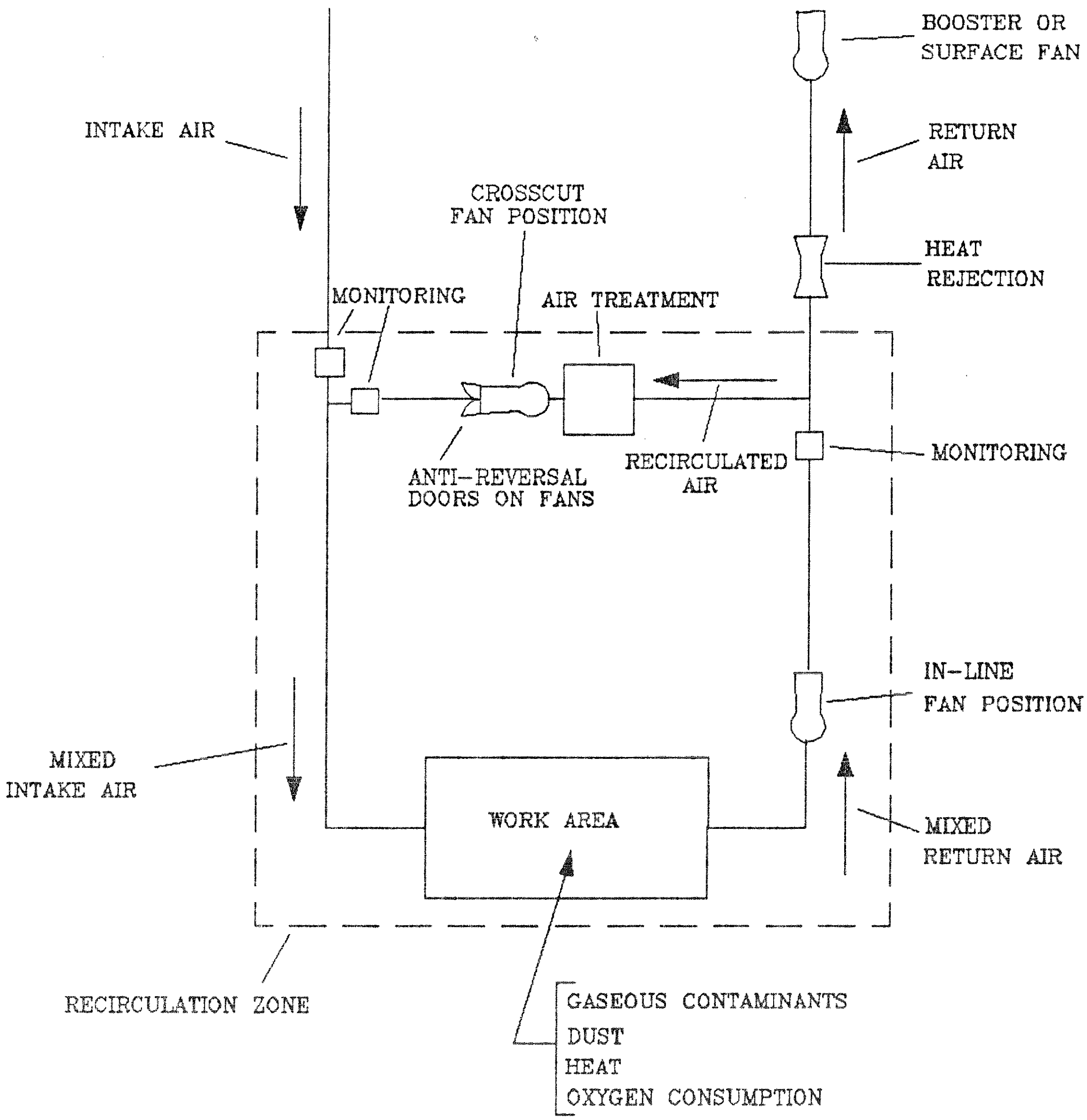

FIGURE 2. CONTROLLED DISTRICT RECIRCULATION VENTILATION SYSTEM