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The use of the Main Ramp as a Mine Exhaust at the Kencana Mine, Indonesia

D J Brake[1] and C Jones[2]

ABSTRACT

Faced with the need to improve workplace conditions in both its development and production headings in its existing K1 orebody, as well as its new K Link and K2 orebodies, the Kencana mine in Indonesia took the novel approach of reversing the ventilation on most of its access ramp by outcasting up the ramp to the portal. Working levels were then fed with fresh air via auxiliary fans sealed into the current surface 'egress' intake raises (ladderways) or another small surface intake raisebore rather than from fans hung in the ramp as in the past. Outcasting the portal provided a substantial increase in the total mine exhaust capacity allowing fewer levels to be ventilated in series and significantly improving conditions, especially in the most difficult workplaces to ventilate. It also reduced the consequences if there was to be a fire on a vehicle in the ramp. The same system using the ramp as an exhaust is also intended to be used as part of the final ventilation solution for the new K2 orebody which also uses a novel single surface ventilation shaft that is vertically split into separate intake and exhaust compartments using a concrete brattice. Using the main ramp as an exhaust has potential application in many other operations in Australia using surface ramps which otherwise frequently suffer from overuse of series ventilation circuits and poor working conditions at the mine bottom.

INTRODUCTION

Kencana mine is a high-grade, underground gold mine located in North Halmahera Island, Indonesia, and operated by PT Nusa Halmahera Minerals, a member of the Newcrest group. It is effectively located on the equator with the mine portal being close to sea level (Figure 1) and has a tropical climate all year. The mining methods are underhand cut and fill and small-scale, low-rise, longitudinal stoping. The orebodies lie between 150 m and 400 m below surface and dip at around 45°. The combination of near sea level elevation, year round tropical surface climate, high-sulfur Indonesian diesel fuel, and high underground diesel intensity due to trucking to surface results in an operation with high wet bulb temperatures and significant potential for heat stress.

In common with many mines using surface trucking ramps, Kencana was previously ventilated using the main ramp as the sole intake and a single surface exhaust system that is taken down in multiple short lengths (legs) as the ramp develops and the mine is deepened. There was no intake or exhaust on any level except the exhaust at the ramp bottom. Many similar mines also use the main ramp to carry all or most services (power, water, compressed air, communications) and also for trucking all ore and often much of the mine waste to surface.

There are a number of significant problems with this style of primary ventilation (Brake, 2009).

The length of the ramp system (typically at a gradient of 1 in 7) means that, for each vertical metre of mine depth, the primary ventilation intake is long (7 m) providing significant contact time between air and rock which increases the transfer of heat and moisture from the rock walls into the intake air. The heavy diesel activity on the ramp (which increases with higher t.km at depth) often means that by the time the ramp air reaches the mine bottom, it is hot, dusty and with elevated gas and fume levels. In many cases, working levels in the mine are ventilated using auxiliary fans hung from the ramp that duct the ramp 'intake' air into the workplaces and the used air from those workplaces then returns to the ramp to proceed to the next level below, to be used in series over and over again. The mine is effectively run as a single series ventilation circuit with the ramp acting as the sole 'dirty intake'.

A further complication of this system is that a fire anywhere in the mine will soon introduce toxic products of combustion into all activities in the mine below that level. Most mines employ a top down extraction sequence, so the active working places tend to always be concentrated towards the mine bottom. This often means that the majority of workplaces will be affected by a fire in the ramp. Being at the mine bottom, these are also the workplaces that have the longest and most difficult escape route to surface.

The third problem with this system is that the total mine airflow is limited to the capacity of the weakest link. Air speeds of 15 - 25 m/s can be sustained in a circular airway that does not have numerous doglegs in it and has no work or travel in it. However, high air speeds on the ramp create

1. FAusIMM(CP), Director, Mine Ventilation Australia, 12 Flinders Parade, Sandgate Qld 4017. Email: rick.brake@mvaust.com.au

2. Mine Manager-Kencana, PT Nusa Halmahera Minerals (A Member of the Newcrest Mining Group), Halmahera Island, Indonesia. Email: clive.jones@nhm.co.id

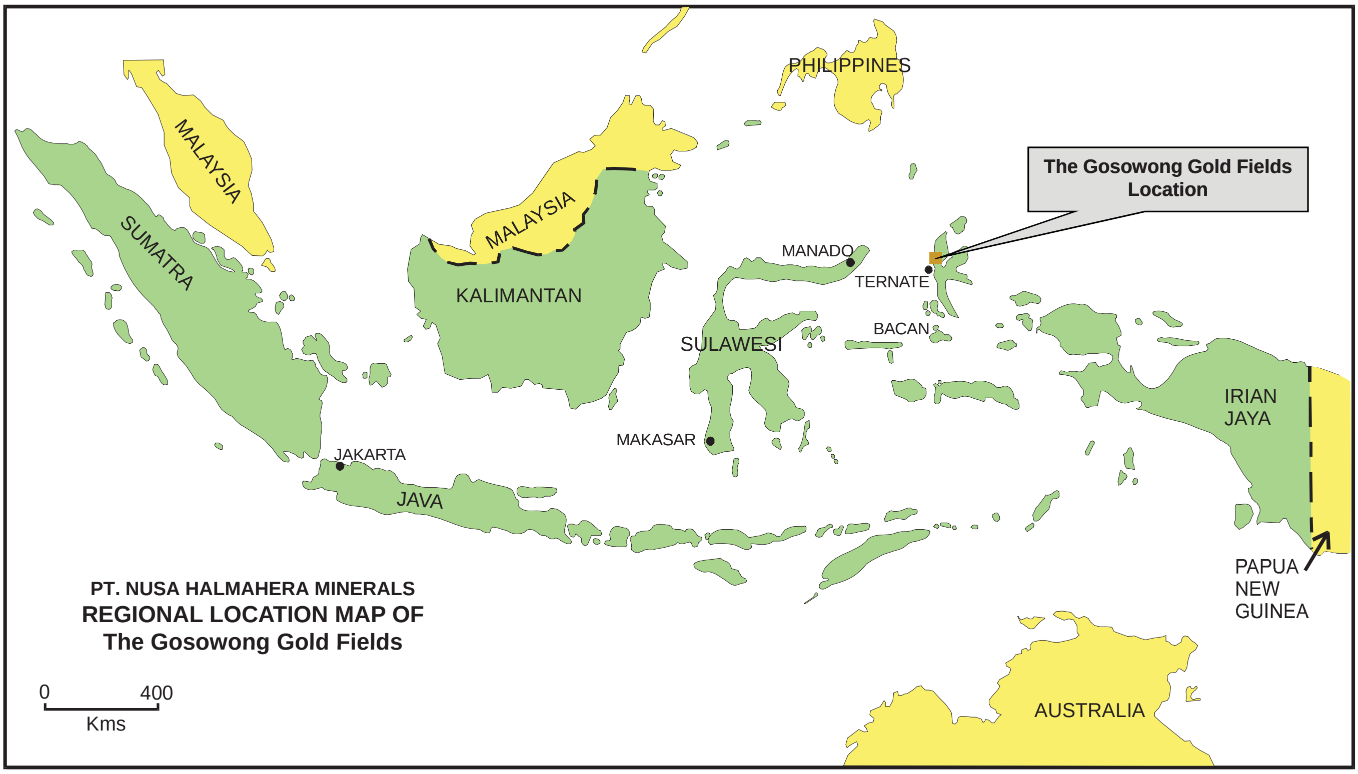

FIG 1 - Locality map for Kencana mine (Gosowong).

travel problems and aggravate the problems of dust so that the ramp is usually limited to an air speed of about 6 m/s. With typical ramp dimensions of 25 - 30 m², the total mine airflow is therefore limited to a maximum of 150 - 180 m³/s. This can be a major impediment to a mine increasing production and is one reason why a mine cannot open the exhaust circuit on each level; even if the exhaust circuit has the capacity, the mine intake (the ramp) does not. This upper limit on airflow is the biggest driver of the mine moving towards a single series circuit.

Local recirculation can also be a problem with this system. For example, consider an auxiliary fan hung in the ramp near the mine bottom feeding a particular level. If production blasting opens up a stope that connects the levels above and below the fan, this will result in air short circuiting through the stope, reducing the airflow in the section of ramp where the fan is located. The fan in the ramp can in these circumstances start to recirculate. In many cases, this recirculation (and the poorer workplace conditions that accompany it) is not recognised.

The extensive system of levels all ventilated in series can also result in long re-entry times before gas levels reach safe values. In addition, the fact that all headings are ventilated in series (rather than in parallel) means each heading in series should be checked for gas levels and not just the ramp and the heading that was blasted, which can result in long procedural times for re-entry checks.

Finally, the numerous doglegs in the exhaust raise system result in large shock losses that can easily double the effective resistance of the exhaust system. This either decreases the mine airflow with depth or requires new, higher powered surface fans and a higher power cost to operate.

With mines going deeper, the combined problems of this style of ventilation means the system becomes increasingly risky, ineffective and costly, as well as constraining mine production.

The presence of several of these factors contributed to the decision by the Kencana mine to convert the majority of the main mine access ramp from intake to exhaust and to outcast the main portal. This paper discusses the general issues of ramp ventilation including operating the ramp as a dirty intake versus an exhaust, and the particular factors that led Kencana to reverse its ramp, and the results of the reversal.

POTENTIAL SOLUTIONS TO THE PROBLEM

There are a range of potential solutions to the problems described above. Probably the best is to install a separate mine intake system from surface to every level and a connection into the mine exhaust from every level. Each level can then effectively operate as an independent ventilation district from the rest of the mine and from the ramp. The ramp can then effectively be run as what is called a *neutral intake*. By definition, a neutral intake receives its own supply of intake air (in this case from surface) which is used purely for its own ventilation and not in series with any other downwind activity. Hence the air from the ramp would not be used on any working levels but discharged into the mine exhaust, normally at the mine bottom. This is a very safe and effective system.

However, some orebodies have low tonnes per vertical metre, or the ore is irregular or flat dipping or with a significant plunge. In these cases, installing a fresh air connection from surface to every level can be technically problematic or difficult to justify economically.

Another option would be to use a surface fresh air shaft to ‘sweeten up’ (blend) the ramp air by injecting fresh air into the ramp at various points, and dump some of the ramp air into the mine exhaust system at other points.

Arrangements such as this either require changes in direction in the ramp air above and below the blend points (to avoid excessively high or low air speeds on the ramp), or end up blending fresh and dirty air together—not an ideal solution.

A solution not used in Australia is to operate the surface ramp as an exhaust and outcast the ramp portal, and to use the other surface ventilation connection as the mine intake, effectively reversing the normal primary ventilation system used for ramp access mines.

It is important to note that from the point of view of frictional pressure losses and primary fan power, there is no difference between operating the system with the ramp as intake, or with ramp as exhaust.

Reasons for reversing the primary ventilation system

The key justifications for reversing the primary ventilation system are described in the Introduction. However, some points warrant elaboration.

The principal advantage for running the ramp as the mine exhaust is that fresh air goes directly down a vertical intake to the mine bottom. As there is no activity in the intake, the air speed can be high, which means a short transit time and minimal pickup of dust, moisture and heat (apart from the unavoidable autocompression which affects all systems equally).

The workplaces that are most difficult to ventilate and usually have the worst conditions, and often are also the highest priority for development or production (the mine bottom), now receive the best air. As the ramp air moves back up the mine, it is increasingly polluted, but there are fewer activities at higher elevations and autocompression has a beneficial effect in *reducing* wet bulb temperature as the air rises and moves towards the exhaust rather than its normal detrimental role in increasing the wet bulb temperature as the air moves down the ramp towards the mine bottom.

It is important to note that the *average* conditions on the ramp (eg diesel gas or fume levels) will be the same or very similar whether the ramp is operated as an intake or an exhaust. This assumes the ramp has the same overall airflow and the same diesel intensity. In most cases, the average air quality experienced by persons working in the ramp all the time will be similar (eg truck drivers).

The reversed system also allows a higher total mine airflow, as the ramp is no longer constrained to 6 m/s as any dust produced will not travel down to the main working areas, but rather up to the surface and out of the mine. Higher air speeds will require more fan power, but potentially the total mine airflow could be increased from 150 - 180 m^3/s to 10 m/s or 250 - 300 m^3/s. In this case, average conditions on the ramp will actually improve as a result of ramp reversal.

Another advantage of the reversed system concerns the risk from fire. With the ramp operating as an intake, a fire in the ramp (say near the portal) will affect the entire mine from surface entry to surface exit. Any ladderways between levels will also be affected if these are open to the ramp at any location. By contrast, if the ventilation is reversed, a surface blowing fan on the intake shaft will pressurise the entire mine. Any connection into the intake on any level of the mine (even if blocked off, with a closed pedestrian door), will provide secure, long-term fresh air and safe entrapment to any person at that location.

There is a further reason for reversing the mine ventilation. For mines that need to introduce cooling, it is very difficult to chill air entering a portal and, due to the long distance to the mine bottom where the cooler air is required, the system is not very effective. However, if the system is reversed, then it is easy to place cooling on the surface of the vertical intake, and there are no introduced heat loads in the intake system between surface and the mine bottom. Not only will cooling be more effective, but a considerably smaller refrigeration plant will be required due to the much lower thermal losses between the plant and the workplaces.

Other mines that use the surface ramp as an exhaust

Whilst this system has not been operated in Australia to date (to the authors' knowledge), it is not uncommon overseas, particularly in cold climates. Here the need to heat the intake air has created basically the same problems as chilling the intake air in Australia.

Some mines that operate this system overseas include those in Table 1.

Methods of operating the system

There are two main variations in the design of the system with the ramp as the exhaust:

1. Auxiliary fans placed in the ramp ducting air to the workplaces. All intake air goes to the mine bottom. In this system, the vertical shaft is isolated on all working levels except the mine bottom. All intake air goes to the mine bottom and the airflow on the ramp is the same from bottom to top. Auxiliary fans are hung in the ramp as before with the used air from each workplace returning to the ramp to continue upwards towards surface.
2. Auxiliary fans sealed into the intake shaft on each level with self-closing dampers ducting air to the workplaces. In

TABLE 1

Mines using the surface ramp for exhaust and outcasting the ramp portal.

Mine/company	Location	Description	Reference
Pete Bayo (Barrick)	Nevada, USA	Mine exhaust is main surface trucking ramp (mine is under development)	Arya, 2010
Rabbit Lake (Cameco)	Saskatchewan, Canada	The main ramp runs from surface to 420 level and is designed to exhaust between 44 to 88 m^3/s on surface	Gherghel and De Souza, 2008
Mattabi (Mattabi Mines Ltd)	Ontario, Canada	Surface service ramp as the mine exhaust	Hall, 2010
Trout Lake (HBM&S)	Manitoba, Canada	Surface main ramp is exhaust	Personal observations
Hoyle Pond (Goldcorp)	Ontario, Canada	Two-thirds of the mine exhaust is via the surface travel ramp	Hardcastle, 2010
Musselwhite (Goldcorp)	Ontario, Canada	Uses the access ramp and a conveyor gallery as the exhaust	Hardcastle, 2010
Rodeo (Barrick)	Nevada, USA	Uses surface truck haulage ramp as an exhaust	Arya, 2010
Meikel North Post (Barrick)	Nevada, USA	Uses surface truck haulage ramp as an exhaust	Arya, 2010
Kencana – Gosowong (Newcrest)	Halmahera Island, Indonesia	Uses surface truck haulage ramp as an exhaust	Personal observations

this system, there is only a small amount of air delivered to the mine bottom (only that which is drawn from the intake shaft by the auxiliary fans hung in the shaft at the mine bottom). Working levels above the mine bottom have auxiliary fans installed into walls at the intake shaft via self-closing dampers. All workplaces operated this way receive their own supply of fresh air direct from the intake shaft. The air returns to the ramp as before. If there is insufficient total intake air for all workplaces to receive their own supply from the shaft, upper levels may take air from the ramp as before.

Potential problems in reversing the mine ventilation

There are a number of potential problems or disadvantages of reversing the mine ventilation:

- The mine 'clears' of fumes after a blast from the bottom up rather than top down. This means the supervisor doing the blasting (firing) must start firing from the top of the mine and then work downwards, rather than the other way around. He must then wait underground until the all clear is given. Alternately the mine must switch to one of the various means of surface firing.
- The ramp may take longer to clear from fumes after blasting as it is now the return. This may also affect the ability of the re-entry crew to enter the mine to start the checking process. Note that in practice, clearance times are often no higher than operating the ramp as the intake.
- If refuelling points or magazines have been located to discharge into the return, this would no longer be possible (in most cases) without them being relocated. In some cases, relocation will not be possible which may breach local regulations.
- If there is a fire in the ramp, then mine rescue teams will need to don breathing apparatus to drive down the ramp and will need to fight the fire from the 'upwind' side. However, in most cases, there will be less urgency to fight the fire if the ramp is a return as most workplaces will remain in fresh air.
- A criticism often mounted is that trucks would overheat if travelling loaded up-ramp in the same direction as the air. This is not true as the average temperature in the ramp will be similar and the airflow and air speed will be the same, so that providing the air in the ramp is travelling either faster or slower than the truck up-ramp speed, there will be no impact on engine temperature.
- Since the surface fan on the mine will now operate as a 'blowing' fan, the heat from the fan motor will enter the mine intake. In practice, this heat is generally only a small contribution to the total mine heat load and is swamped by the advantages of removing or reducing the other mine heat loads in the intake.
- If a level that is blasted uses auxiliary fans that are sealed into a wall at the fresh air shaft, then if the auxiliary fan fails to start after firing, or the duct blows off the fan, there will be no airflow on the level to dilute the blasting fumes, and persons will need to enter the level (under breathing apparatus) to reattach the duct or repair the fan. Alternately a similar method to 'de-gassing' a heading in coal mines can be used whereby a compressed air fan is temporarily installed in the ramp and lengths of duct gradually added until the level is de-gassed safely. However, since these fans are installed into the fresh air raise using self-closing (and self-opening) dampers, if a surface fan is pushing air into the fresh air raise, then the level will be de-gassed even if the underground fan is off or the duct is damaged.

Transitional problems in reversing the mine ventilation

In addition to the issues identified above, there are some issues in changing the ramp to the exhaust for an operating mine:

- The surface fan will need to be reversed. In most cases, this will not be difficult, but in some cases it will be expensive or cheaper to simply replace the mine fan.
- Most ventilation doors will need to be removed and re-hung so they open and close the reverse direction.

CASE STUDY AT KENCANA MINE – OUTCASTING THE MAIN PORTAL AND OPERATING THE MAIN RAMP AS AN EXHAUST

Until early 2010, the primary ventilation system used at Kencana (Figure 2) had the surface ramp as the main intake. As the ramp became deeper, the surface exhaust shaft was progressively extended. All working levels were ventilated using fans hung in the main ramp with all air returning to the main ramp, operating as the dirty intake. Up to seven levels of the mine were ventilated in series in this way with each level typically having two ventilated headings. The ramp then discharged into the exhaust shaft at the mine bottom. The ventilation system was effectively a giant U-tube with all activities ventilated in series. The only other surface connection was the egress raise (with ladder). Whilst this was a reasonable size (3.1 m Φ), only a nominal airflow was allowed down it as any increase in airflow down the egress meant less airflow down the ramp, which meant poorer conditions in the ramp and on any levels fed from the ramp. At this time, the mine was constrained by the exhaust capacity in the only exhaust shaft at K1.

Conditions in the workplaces on the bottom levels were frequently poor, with wet bulb temperatures of 33 to 34° WB not uncommon in some areas. Re-entry times in the mine were frequently one to two hours (with the longer time generally applying to re-entry after production blasting).

In February 2010, a new split ventilation shaft (intake and exhaust compartments separated by vertical concrete brattice, (Brake, 2010) was commissioned at K2 orebody which was connected to K1 orebody via an underground ramp. However, until the final K2 surface exhaust fan is commissioned on the new split shaft, the overall operation has a substantial surplus intake capacity consisting of: the main ramp, the K1 egress, the surface raise-bore system installed to develop across to K2 and the new K2 dual-compartment shaft compared to exhaust (K1 shaft). Total intake capacity is in excess of 340 m^3/s and total exhaust capacity is only 270 m^3/s. After appropriate modelling and analysis, it was decided to change the ventilation system as follows:

- Auxiliary fans in the deeper areas of K1 (with poorer conditions) would be removed from hanging in the ramp and sealed into the K1 egress with self-closing dampers. The workplaces fed by these fans would therefore receive much higher quality isolated intake air directly from surface.
- Both compartments of K2 shaft were allowed to downcast and auxiliary fans would be installed in the shaft to pull even more intake air down this shaft.
- The surface raise-bore system would also continue to downcast intake air under a push-pull system (Brake, 2010).

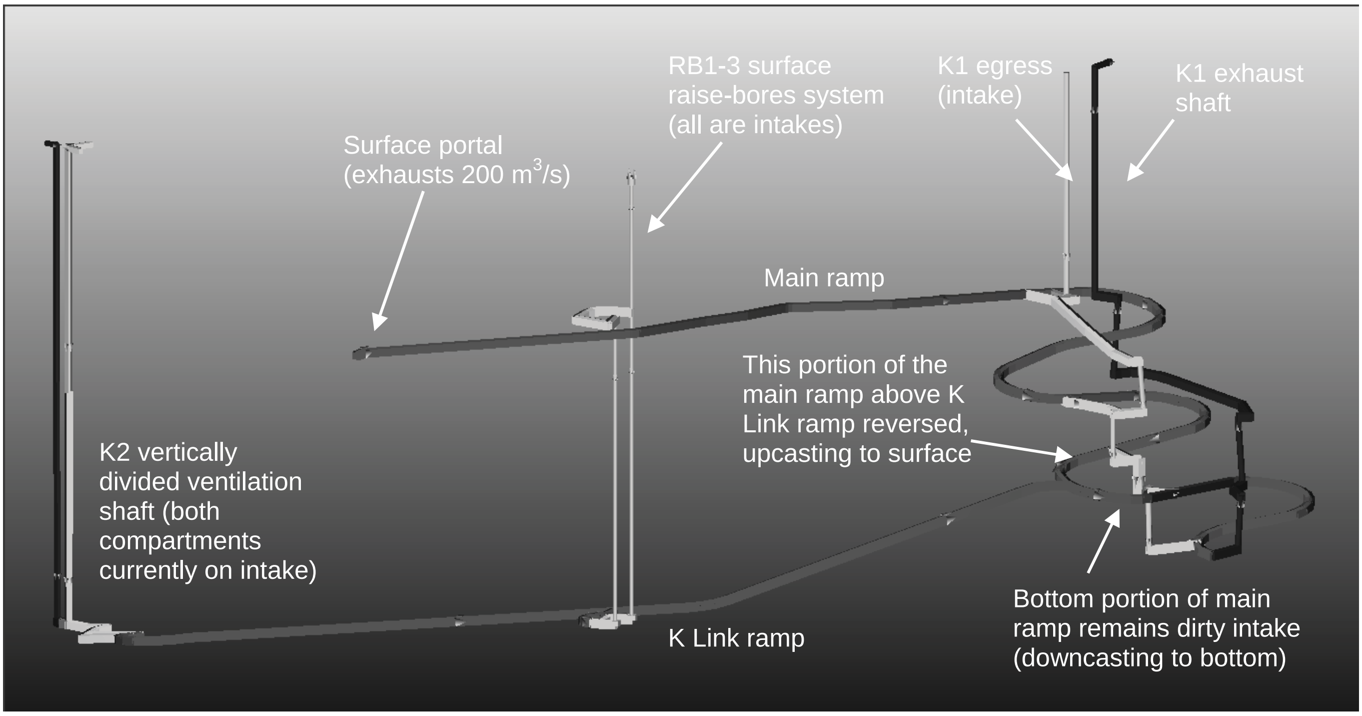

FIG 2 - Schematic of Kencana mine ventilation system (orebodies and stoping removed for clarity).

- This air would then proceed back up the K Link ramp to K1 (Figure 2). Due to the shortage of exhaust capacity at K1, the main ramp was reversed, out-casting the portal.

The system was implemented in May 2010.

It is important to note that Kencana did not reverse the main K1 exhaust shaft. Rather it used surplus intake capacity (due to the new K2 ventilation shaft being completed) to reverse the main ramp, effectively creating two main exhausts from the mine: the existing exhaust shaft and the existing main ramp. Note also that the lowest portion of the main ramp was not reversed, which allowed the exhaust shaft to continue to operate as an exhaust. However, workplaces in this lower region were no longer fed dirty intake air from the ramp (series ventilated), but from isolated fresh air direct from the K1 surface egress (parallel ventilated).

Implementation issues

The main issues in implementing the new system at Kencana were:

- Ensuring sufficient exhaust flow out of the portal. The K1 surface exhaust fan actually consists of two fans in parallel. With both K1 surface fans operating (total mine exhaust of 270 m^3/s) and all the mine intakes operating as required (340 m^3/s), the portal was outcasting around 70 m^3/s. Conditions in the workplaces on the levels improved significantly, but conditions on the ramp (with less airflow than before) were worse, affecting gas levels and also resulting in some over-heating of the trucks. One of the K1 fans was shut down, reducing the K1 exhaust to around 140 m^3/s, but increasing the outflow through the portal to around 200 m^3/s. Once the ramp airflows were increased back to higher levels, these problems were eliminated.
- Finding sufficient room for the required number of auxiliary fans in the K1 Egress. On some levels, it has been difficult finding the room to retrofit the required number of auxiliary fans into the K1 egress.
- Leakage. A key issue was that the existing large ventilation doors connecting the main ramp to the egress were now 'hanging' the wrong way. Leakage and hence recirculation increased to unsatisfactory levels. The doors were sealed up with shotcrete reducing overall leakage into this system from around 20 per cent to around five per cent with a commensurate reduction in recirculation.
- Getting fresh air for the upper level was problematic, but resolved by ducting the air some distance.
- Re-entry times. Whilst the clearance times for blasting gases are no longer than before, the actual time to complete the re-entry checks is slightly longer as the re-entry crews (checking gas levels) do not enter the mine portal until the gas levels leaving the portal are within safe levels. This time is being used effectively for toolbox talks and cross-shift handovers.
- Higher pressures across doors and higher air speeds in egress making access more difficult. Indonesian law limits air speeds in egress routes to 12 m/s. The high airflows drawn down the egress to feed workplaces has increased differential pressures across the entries into the egress (solved by installation of airlock pedestrian doors as required) and also limited the number of auxiliary fans that can draw air directly from the egress.

SUMMARY, RESULTS AND CONCLUSIONS

With the majority of the main ramp reversed and most workplaces now fed air directly from surface intakes, wet bulb temperatures in the worst areas of the mine decreased from 33 - 34° WB to 29° WB, a reduction of 4 - 5° WB. This was a dramatic improvement in temperatures. Gas and fume levels in the workplaces have also substantially reduced.

There have been no incidents of heat illness since the ventilation system was changed, compared to four cases in the previous 12 months with the earlier ventilation system.

Re-entry times have remained about the same, despite needing to wait until the portal is clear of fumes before re-entry checks can start underground.

Effective work time 'on the job' and overall productivity is increasing, due to conditions being more satisfactory for manual work.

Reversing the ramp system at Kencana has allowed the mine to move to a higher total mine airflow, to almost eliminate the use of series circuits, and allowed the use of fresh air direct from surface to feed most workplaces underground.

When the ramp is reversed, there must be sufficient airflow on the ramp to avoid the situation in which conditions on the levels improve, but conditions on the ramp become unacceptable.

Transitional problems in converting the main ramp to exhaust (such as leakage through doors) will occur but can be reasonably overcome. Many of these problems would not be issues if the mine was designed for the ramp to be the exhaust from the start.

ACKNOWLEDGEMENTS

The authors would like to thank PT Nusa Halmahera Minerals (a member of the Newcrest Mining Group) for permission to publish this paper.

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