SAFETY MANAGEMENT PLANS : EQUIPMENT FOR USE IN ESCAPE PLANS

Michael Lang.
Ass Dip Marketing
Drager Australia Pty Ltd

Summary

The need to formulate and implement escape plans in underground mining, the use and understanding of current technology for such plans is critical.

For many years the Filter Self Rescuer served the purpose of basic respiratory protection should a situation arise where the main toxic gas was carbon monoxide. The immergence of Oxygen Self Rescuer offered an alternative to filtration ,as such, to independent means of protection from the toxic atmosphere. These initial units were rather large and cumbersome and not really viable to replace the belt worn FSR. In the early 1990's oxygen self rescuers became smaller and belt worn which then offered the miner a true means of immediate respiratory protection independent of the toxic gases which now consist of more than carbon monoxide.

The wearing of oxygen self rescuers is not the sole answer to the escape plan requirements, for they offer a limited duration. There primary use is to allow the wearer immediate escape to a safer zone to either don longer, larger duration OSR or await rescue in a safe haven. To enable to planning of the escape format, mine management should appreciate what OSR can offer and their limitations, and the problems associated with refuge/ safe chambers and what should be considered when adopting them in the escape management system..

Current Practices

In the coal mining industry 95 % of the underground miners wear Filter Self Rescuers (FSR). In NSW this is mandatory according to the Mining Act, unless exemption is granted to wear OSR. QLD Mining Act allows either FSR or OSR to be worn, aslong as they are approved by the DME. The FSR offers the miner protection against the most common gas to occur in coal mining, Carbon Monoxide (CO). This gas is produced from the combustion of coal and timber, among other things. The FSR's are reasonably small and light weight, and are reasonably inexpensive to maintain . The Filter Self Rescuer's mixture of copper oxide and manganese (' hopkalit ') allows the CO to oxidise when mixed with the oxygen in the air. For the miner to have the best possible chance of survival, certain environmental conditions must exist in the mining environment.
These are :-

> The Oxygen content in the environment should be at a level normally associated with carrying out physical activity. This level can vary, the accepted ranges from 17% to 21%. Australian Standards for Confined Spaces ,AS2865, state 19.5% Vol at normal atmospheric pressure as the minimum value.
>
> CO level in the environment, if exceeding 1.5%, will cause the FSR to be extremely hot at the mouthpiece.
>
> The humidity in the environment should be as low as possible. Humidity will decrease the duration of the FSR as water vapour reduces the life of the drying agent, thus reducing the life of the chemical conversion process. Also, as the charcoal layer builds up with water it clogs, causing the breathing resistance to increase dramatically.

Other toxic gases can breakthrough the charcoal prelayer. Although protection is provided to certain concentrations, H_2S, at high levels will break through, the TLV for H_2S is 10ppm compared with CO's 30 ppm. Other toxins from burning belts (HCL, SO_2, CS_2, CO_2, FORMIC ACID), hydraulic oil, pvc piping and vehicle fires, are but a few sources of potentially lethal gases the FSR may not filter effectively.

For the last 2 years in Germany, focus has been on the development of a new FSR to minimise some of these concerns. The continued practice of wearing FSR's in the German Mining industry is mainly due to the use of fire walls, mine layout, ventilation integrity (due to single advance longwall techniques) and probably the economics in the industry ($270/ton costing currently). According to Dr Langer , Mines Rescue Essen, if the OSR was the same price as the FSR then the mining industry would seriously look at that option. With the help of the German Government and Mining industry, Drager developed the FSR 990 to exceed EN 404 criteria's. The new FSR was designed to reduce the high temperatures which can cause miners to pull them out from their mouths, and being overcome by toxic gases. The unit was also designed to protect for longer duration's , up to 200 minutes at 0.25% CO. This was achieved by increasing the hopkalit content, therefore the units size and weight increased slightly. The world mining markets may not over source the FSR 990 as most mining countries are moving towards the use of OSR.

Oxygen Self Rescuers

Up until the early 1980's Oxygen Self Rescuers, OSR, were designed for a minimum use time of 45 to 60 minutes. Most of them used the principal of compressed O_2 as the main source of respirable O_2. This made the units too heavy and also expensive to maintain . Therefore most units were kept in storage areas or in refuge chambers. In 1984 legislation in South Africa for the wearing of OSR in coal mines, gold mines and other underground operations pushed the need for smaller belt worn units .

With the demand in South Africa exceeding 200,000 units, several key manufacturers designed smaller OSR. The requirements from the Sth African mining industry were simple,

- 30 minutes duration at 30L/min
- Maximum inhalation temperature 85C dry air, 40 C water saturated air
- Small
- Light
- Worn in the mouth
- Robust
- O_2 supply demand based
- O_2 available within 10 seconds from removal from case
- Life expectancy 5 years

With these specifications in mind, the likes of Drager's OXYBOK K, Auer's SSR30/100, Fenzy Spiral 1 and the Siza Moya were developed. Interestingly enough, 10 years onwards the Sth African mining industry has discovered one other very important criteria that should have been included was vibration resistance. Testing carried out recently by the CSIR, found units suffering from the continuous wearing and jolting, with a KO_2 and CO_2 chemical breakdown causing a reduction in use time. Only those manufactures who took this into consideration in development received favourable duration results, the same as the day they were purchased.

So what constitutes the current OSR.

1. The KO_2 cartridge.

KO_2 is manufactured from raw materials from several places around the world. Grades of KO_2 differ, and the manufacturers of the OSR refine the product into either pellet shapes or granulated form. The grade and final form of the KO_2 dictates the reliability of the CO_2 adsorption and humidity conversion to O_2. If this product is broken down, the properties of conversion will be affected. By altering the size and composition of the KO_2, the chemical conversion process can be increased, therefore increasing the amount of O_2 produced for the same amount of KO2. The absorption of CO2 is also an important component. Some cartridges can still absorb CO2 when they no longer produce O2, ensuring low levels of CO2 when the unit is almost depleted.

The packaging of the KO2 cartridge requires quality controlled reproducability. The cartridge should be packed tightly to reduce the effects of vibration and shock resistance. If this is not achieved then the KO2 granules will abrade against each other and create dust particles, reducing the ability to produce oxygen. The size and shape of the KO2 particles are critical. Square or straight edge granules will break apart more readily than pelletised materials.

The size and shape of the packaging plays a critical role in the production of O2. If there is a low height to diameter ratio on the cartridge, then the time the KO2 cartridge is exposed to the exhaled air is low. This in turn slows down the rate of oxygen generation and respectively extends the duration of the OSR. A large breathing surface area will also lead to a better utilisation of the KO2 material and a lower breathing resistance due to the more evenly distributed air flow through the cartridge.

2. <u>The Breathing cycle</u>.

The breathing cycle is important to the effectiveness of the OSR. The heat dissipated from the chemical process is reduced by the flow of the inhaled and exhaled breath through the heat exchanger. The flow either inhibits or increases breathing resistance, aswell as the purification of the breathable oxygen. The OSR's either use a Uni directional or Bi directional flow. The most common is the Bi-directional flow. This means the exhalation and inhalation cycle flows through the KO2 cartridge further purifying the content. This also means the cyclic flow passes through the heat exchanger twice to further reduce the temperature of the inhaled breath. The exhaled air (37C) cools the heat exchanger , absorbs the heat and conveys it to the KO2 cartridge. The inhaled air is dry due to the KO2 absorbing the moisture.

3. <u>The Breathing bag</u>

The breathing bag is the reservoir for the converted oxygen from the KO2 cartridge. The different sizes of the breathing bags reflect the oxygen generation flow from the KO2 cartridge. The KO2 cartridge will produce excess oxygen therefore the breathing bag requires a relief valve which allows flow off. From the wearer's viewpoint it is critical that the breathing bag is protected from tears and puncture points. This bag must be sized accordingly. Once the oxygen generation reduces and the CO2 no longer absorbed, the residual CO2 level will increase throughout the breathing bag. The duration of the OSR should end with the bag collapsing before the CO2 value increases above the 3 % Vol. The increasing inhalation resistance will also indicate the life of the OSR is near an end.

4. <u>The Carry case</u>

Due to the nature of the wearing of the OSR, whether it be on the person or on vehicles, the need for vibration and shock resistance is important. To help reduce the effects of these outside variables the construction of the carrying casing is critical. Keeping in mind the need for the weight to be kept as low as possible, new improved materials are used. The environment in which theses units are used are harsh and extreme. The pressure differences in which the units are carried and used (ie. 4000m underground) is another variable to be considered. Therefore the casing must resist :-

vibration
shock
deformation from pressure differences
deformation from other forces
impact
electrostatic charging
water ingress

All this and still remain as small , light and as non obtrusive as possible.

Unlike FSR there are some major differences between various models of OSR. Some of these are:-

- Whether O_2 is produced by KO_2 Chemical or compressed O_2.
- Whether there is a separate scrubber for the CO_2 .
- The inhalation temperatures
- The sizes of breathing bags
- The duration's achieved at rest, work and higher consumption rates
- The vibration resistance
- The water tightness
- The maintenance requirements
- The size and weight
- The life of the units

Which unit will serve the best protection for the miner will depend upon the mine escape plans.

If choosing a compressed oxygen type OSR, consideration should be given to the possible leak points , and the higher cost of maintenance. This is why most manufacturers have adopted the use of KO_2 cartridges.

The duration's achieved are generalised to either 10, 35 and 70 lpm consumption rates. This is not oxygen consumption but total air. In real terms when using OSR's the oxygen consumption is more important. This issue is currently being tested in both USA and Australia. If the O_2 consumption rate is known, the duration of the OSR can be calculated therefore allowing individuals the knowledge that their particular unit will allow them so certain escape time at walking , running and resting rates.

Testing of OSR

In the world today there are 3 major standards which include requirements for OSR.

EN401 and its derivatives eg, BS EN 401	European
MSHA/NIOSH	USA
GME	South Africa

EN401 is the only standard specifically designed for chemically generated OSR. The basis of this standard is the testing of OSR's with a closed circuit lung simulator. There is scope for man tests but ideally the bulk of the requirements are based on the bench tests. Meanwhile, the NIOSH/MSHA testing is centred around man tests incorporating some bench testing.

There are some major differences between the use of man and bench testing. Bench testing offers a consistent testing process, parameters can be measured to a degree of accuracy and the testing is completely impartial. Man testing is purely subjective, that is to say, measurements on temperature, resistance, CO_2 levels and oxygen levels can only be surmised from the experience of the test subject and the results are qualitative , not quantitative. Breathing bag air samples can be taken during man tests to be tested at a latter stage.

From test carried out on units which achieved 60 minutes duration approval with NIOSH ,they receive only 40 to 50 minutes approval when tested to EN 401. This is due to the testing parameters of inhalation temperature and resistance, and CO_2 levels.

Currently the only units that I know of having EN 401 approval are those from European manufacturers. Those who manufacture in the USA seek only NIOSH approval.

Comparison of Approvals

Type of Approval			EN401		NIOSH /MSHA	GME
	Ambient temperature C		23		27	22
Bench test	Breathing rate lpm		35		40	30
	Exhalation CO2% Vol		4.5		5	4
	Exhalation temperature C		37		27	37
Parameter	O2 concentration	%vol	21		19.5	>21
	CO2 concentration	%vol	1.5 average	3 max	2	<2.5
	Inhalation temperature	Dry C				<80
		Wet C	55		Man test < 52	<46
	Inhalation resistance		10mbar <30min	7.5mbar >30 min	Differ b/ween Exhal& 996Pa	<600 Pa
	Exhalation resistance		10mbar > 30min	7.5mbar >30 min	<498 Pa	<600 Pa
	Sum resistance		16mbar	13mbar		
	Duration rating		As parameters are met 5 min steps up to 30 minutes 10 min steps over 30 minutes		As per duration received in Man Test no.4	As Parameters are met

Unfortunately the only problem with all standards currently being used is the lack of required batch testing after the many years in service. Most world standards called for FSR's to be tested around the 4th year of use and thereafter yearly. If the proper care and maintenance of the FSR is followed the units can be effective for many years (currently in NSW and QLD the units are given in total 8 years life). The lessons learnt from the batch testing of OSR's in South Africa should be adopted by other countries. Due to the nature of the chemical process, batch testing should be imposed after years in service to ensure the KO2 cartridge performs as specified by the manufacture.

In many countries the escape plan incorporates the use of Fresh Air Bases, refuges. These bases can be found as part of the crib rooms, near the working face or in strategically placed areas.

Fresh Air Bases

The Fresh air bases is not a new concept in Australia. Metalliferous mining have incorporated them in their escape strategy for many years. The most common system of respiratory protection employed in the base is the mine air. In some cases this is filtered for oil, water and particulate, very rarely CO and CO_2 and silencers are not in common use. Other system incorporate the use of high pressure air cylinders and full face respirators. Most bases are small with the seating capacity of 6 - 10 persons. There are no particular standards for these fresh air bases, the closest being AS 1716 for use of compressed air line systems. If the bases are pressurised they can be classified as pressure chambers which must comply to certain standards.

The two major concerns with fresh air bases are :-

- Supply of Oxygen
- Removal of Carbon Dioxide

The supply of air can be calculated dependant upon the variables -

number of miners to be supplied

duration of supply

the required consumption rate of the miner

The consumption rate of the supplied air can vary . For persons at rest, the levels can be between 10 to 20 lpm. "Person at rest" respiration rate will differ according to the situation they find themselves in. Waiting for rescue in a 3 * 3 *2 steel box, a fire raging out of control nearby and communications broken down does not instil the most relaxed atmosphere. There also is a need to consider ingress of toxic atmosphere and the needs of added personnel. There are many variables to be considered when a risk analysis is conducted.

The ideal situation for a fresh air base is to allow the largest number of personnel for the longest period of time. If using compressed air, the number of cylinders required is considerable, making this option unworkable. Using compressed mine air is not guaranteed at the time of need, and so the only other options are the recirculated methods.

Recirculated respiratory systems have been in use around the world for some time now. The closed circuit breathing apparatus used in Mines Rescue and fire Fighting are prime examples of this system. The oxygen is supplied via a cylinder at a regulated rate and the exhaled CO_2 is adsorbed by sodalime. The recirculation of the system is achieved by the lungs. The same concept can be transposed into a fresh air base, although there is one major problem - the lungs are not sufficient to drive this larger system. The answer is to have a pump drive this system. Here is the problem: we need an intrinsic supply to power the pump. These are available but the cost of such units that will supply power for the longest possible time can turn this proposition into a uneconomical one.

Another problem associated with the confinement of persons in an enclosed space for a period of time is the build up of latent heat. This is the heat given off by our bodies. There is also the heat from the fire outside the base to be considered. There could be possibilities of a 'pressure cooker' in the making. This problem again is not an easy one to solve as the only way to remove this heat is by airflow or cooling the air. The air flow required adds to the respiratory requirement and the sum of supplied air becomes quite large. If using a cooling process, power is required , which must be intrinsically safe.

Conclusion

Current parameters established by the mining industry for escape apparatus are under review. In NSW the Act has provisions for approving FSR only, while the QLD Act allows for either FSR or OSR. The approval requirements for FSR are consistent and enforceable. With regard to OSR the Standard is leaning towards EN 401. If this is so, then the units that comply with the required duration ratings are few. Manufacturers who only produce OSR to the NIOSH/MSHA Standard , may find the use duration's will differ to that of EN401.

Once units are in service there should be requirements similar to those for FSR's for the retesting at certain intervals. Manufacturers recommend life subject to vibration and total life, this should be able to be confirmed by technical data, directly or independently. This will then not only prove the reliability to the wearers, but also ensure any faults that may exist can be found and rectified.

The small belt worn OSR currently in use around the world may not protect the miners for the duration required to travel from most working faces to the pit top. There needs to be a system which incorporates the placement of storage areas of longer, larger OSR, within reaching distance of those who wear belt mounted units. The wearing of longer duration units is possible although the size and weight are restricting factors. Fresh air bases are another alternative to be included in the escape strategy . Consideration should be given to the supply of oxygen and the removal of carbon dioxide. Latent heat removal is also an issue to be considered.