CO_2 in underground openings and mine rescue training

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Abstract Different gases can appear in active mines, abandoned mines, adits and caves. The most dangerous gases are CO, NO/NO_2, H_2S, SO_2, CH_4 and CO_2. Although the general danger arising from these gases is mostly known some aspects are underestimated. Furthermore misleading or wrong statements exist about the detection and effect of gases on the human body. This is especially true for CO_2. On the background of a reduced number of mine rescue teams and an increased number of visitor mines the questions arose if other rescue forces can support existing mine rescue teams and if all these teams can detect a CO_2 danger in abandoned openings and old adits.

Key Words CO_2, gas detection, subsurface, fire fighter, mine rescue team

Motive

Despite other statements from former ventilation engineers CO_2 concentration up to 3.2 % have been measured in the adit "Rothschoenberger Stollen", the main de-watering adit in the former Freiberg Mining District /1/. The highest concentrations were found at outlets behind dams. One year later the big flood in Germany caused the collapse of the adit. A certain amount of water bubbled through the collapsed area and released +/-3% CO_2 and air with deadly low oxygen content. CO_2 concentrations over the limit were detected in a safety room and an underground breakfast (party-) room of a visitor mine. What would happen, if there is an accident due to CO_2? Mine rescue teams are equipped and trained for such situations. But in a few years the last enterprise with a mine rescue team in Saxony will close down. Can fire-fighters be enabled to carry out rescue operations in the subsurface? Will rescue teams recognize the special underground dangers? Do they have the equipment and will they recognize that they have to measure gas concentration even if there is no fire? These and other questions should be answered by a training rescue operation.

Effect of CO_2 on the human body

Some toxic gases are detectable with the human senses even before they become dangerous. This applies to SO_2 and H_2S but if H_2S is present the sense of smelling is lost if after a certain time (depending on the concentration). Gases like CO and NO are not detectable with human senses. Both gases are blood poisons. Especially at high concentrations symptoms for a deadly poisoning will be recognized to late. The gases combine themselves with hemoglobin leading to a lack of the oxygen supply of the inner organs like heart or brain. NO_2 is said to be detectable with human senses (irritation of throat, smell) but these symptoms are often underestimated. Slightly higher concentrations will not lead to other symptoms. Furthermore these symptoms disappear after a short time in fresh air. Nevertheless nitric acid will be formed in the alveoli. This can cause serious injuries and death after 4 – 12 hours! Rescue teams are familiar with these effects. Therefore breathing equipment is used if gases can appear.

It is also said that most people know the effect of CO_2 but accidents, a questioning of people and a literature search showed that the real effect on the human body is not known. Effects of increased CO_2 contents are doubling of breathing, headaches and increased heart beats. In the subsurface these symptoms will be not realized! All symptoms of a poisoning with CO_2 were derived from tests in laboratories or questioning people after accidents. People do not only react different to certain gas-concentrations but time is a very important factor. So you might get headaches in an atmosphere of 5 % after minutes or several hours. And even if you get headaches you furthermore have to conclude that this is due to CO_2. If you are exposed to higher concentration there will be definitely no warning and you became instantly unconsciousness. At concentrations of 30 % CO_2 people will be anaesthetized within seconds! /2, 3/. Knowing this, the following statement in a safety book is misleading and rather dangerous: "at a concentration of 20 % same warmth is felt on the naked skin" /4/. This might be true if only a part of the body is exposed to this concentration. In an atmosphere of 20 % you will die within a very short time. So this is definitely no warning sign. One of the most persistent wrong statements is that an injury or even death is caused by the displacement of O_2. People say that this is suffocation due to a lack of oxygen. This is simply not true. The effect of CO_2 is suffocation, but an inner suffocation. Persons can become unconsciousness at concentrations between 10 – 15 % CO_2. If the CO_2 concentration is for instance 10 % than it is 10 % of the total air volume. The amount of O_2 in the air is only about ⅕ of the total volume. About ⅘ is nitrogen and a small amount of other gases. So as a rough calculation you can say, that an amount of 10 % CO_2 in the air reduces the O_2 content to only 19 %! A concentration of 19 % O_2 is not dangerous and it is not suffocating. So it would be better to say that CO_2 is poisonous. Per definition a poison is a substance which can harm people due to contact or ingestion or an influence on the metabolism. In this sense it would be helpful to declare CO_2 also as a poisonous or toxic gas rather than an only suffocating gas. Cave explorers have a rule, that candles stop burning, if there is too much CO_2 in the cavern. A candle is said to be extinguished at 17.5 % O_2, but if you look to the internet you will find other values between 16 % and even 12 % /5/. Furthermore the compositions of candles have changed over the time. So a burning candle is by far not a sign for a safe atmosphere! CO_2 should always be detected by gas sensors. In former times people used canary birds for the detection of toxic gases. In a modern world this is no longer a detection method and birds would only show that there is something wrong; no conclusions on the gas or the concentration are possible. And yes, gas detectors do have their price. EC sensors cost some hundred dollars, Long-life IR sensors even more, but a lost life cannot be paid.

What exactly is the effect of CO_2 on the human body? First of all CO_2 has very important physiological functions in the human body. The regulation of the breathing is steered by inner receptors in arteries and parts of our brain (*aorta*, *medulla oblongata*) in dependence of the CO_2 concentration in our body. In the lung O_2 is transported by help of hemoglobin to the cells. From the cells CO_2 is given back to the blood, transported back to the lung, where it is released into the alveoli and breathed out. The exchange of O_2 and CO_2 is dependent on the partial pressure of each gas in the lung and the blood. Any concentrations above the normal concentration of around 0.035 % in the breathed-in air will lead to a reduction of the release of CO_2 from the lung. So the CO_2 concentration in the blood rises. If the concentration exceeds 4 % additional CO_2 is taken by the blood. The human body reacts with an increased breathing volume. If the concentration in the air rises towards 10 % people can already become unconsciousness. (On the other hand there are examples, were people stayed in an atmosphere with 10 % CO_2 for one hour without any obvious danger to their life. But it should be underlined that nobody knows this before and nobody should try this.) Furthermore CO_2 is also involved in the buffering of the human acid-base household. A change of the pH value of our blood can have additional negative effects on our body.

Organization of rescue works in Germany

According to the Mining Law (BBergG) the employer is responsible for the safety. He has to use state-of-the-art rules to protect people, equipment and environment. Furthermore the Mining Law requires the establishment of Main Centers for Mine Rescue which are responsible for the education, training and coordination of mine rescue works. These centers can oblige other employers/enterprises for a support in an emergency situation. According to the law every incident which created or could create a danger has to be reported to the Mining Authority. Because of the special dangers in the subsurface only special trained and educated forces – the mines rescue teams – are able to rescue people and machinery, extinguish fires and secure openings. Mine rescue teams consist generally of 3 troops with 4 persons plus a troop leader. In addition to this a responsible person for the equipment (breathing equipment) is necessary for every troop as well as an equipment supervisor and main-supervisor. Members of the mine rescue team should be not younger than 18 and not older than 40 years. The medical screening G26/3 (breathing apparatus) and a course in first aid are mandatory. After a basic course with theoretic and practical examination one could be admitted as mine rescue worker. Physical fitness and further education are required permanently. Every year at least 4 training rescue operations have to be carried out, three with training equipment, at least one with real equipment. Bigger active mines do have an own mine rescue team. Smaller mines must have a contract with mine rescue teams from neighboring mines. Before 1989 existing visitor mines belonged to active mines. After the reunification of both German states and the closure all ore mining operations a lot of new visitor mines opened. About 55 visitor mines and 9 other underground openings still exist only in the Free State of Saxony. These mines are not able to set up own rescue teams. On the other hand there are only two mine rescue teams available in Saxony. One belongs to a brown coal open pit, one belongs to the former uranium producing WISMUT (underground). Some of the visitor mines do have contracts with the mine rescue team WISMUT. Recently the WISMUT has contracts with 33 institutions for a support in the case of an accident. According to the law all rescue teams have to be familiar with every special visitor mine and they have to make some training in these mines. Already now this is almost not possible. Smaller visitor mines do also have contracts with local fire fighters, which could be at the mine within minutes. The WISMUT rescue teams have to be collected from different mine closure operations often many kilometers apart from the visitor mine. In a couple of years the closure operations of the WISMUT will be finished and the Wismut as well as the rescue teams will be close down. Nevertheless a rescue of people from the subsurface must be ensured. Different possibilities include the establishment of a new central rescue team or/and the inclusion of fire-fighters for rescue operations in the subsurface. With the construction of more and longer tunnels in Germany more firefighters are equipped with long term breathing equipment which is the first pre-condition for an underground rescue operation. But firefighters do not have the special knowledge about underground operations. The rules for an operation are different, and the special adapted equipment is recently not always available.

Mine rescue training

A mine rescue training was set up to test if different forces (mine rescue teams, fire fighters, police, emergency doctors, Mining Authority and Main Centre for Mine Rescue Operations) can work together. Camera and video teams took pictures and videos from all locations. All included rescue teams did not know that it was "only" training, but realized it of course, when they arrived at the mine. It was assumed that 4 miners had to repair a water sensor in the adit "Rothschoenberger Stollen". The location was only 65 m apart from the shaft "Reiche Zeche". A hoisting cage is available from the surface to the 1. level in a depth of 150 m. The miners had to climb down further 80 m to the adit via ladders. The miners were instructed about CO_2, the mine director and all responsible persons were informed about the task and the return time of 9:00 o'clock a.m. One miner forgot something at the platform in the adit, went back, slipped out and broke his leg. After a short discussion what to do one miner should go back to ask for help. Meanwhile the CO_2 content in the adit exceeded the limit of 0.5 %. Because of the hurry and other factors this miner missed a wing of the ladder and felt down, unable to move. Meanwhile the return time run out. According to the emergency rules mine alarm was given at 10:15 am. The mine director called the mine rescue teams of WISMUT enterprise and local rescue teams over the European-wide emergency number 112. From there emergency doctor, medical fast response team, fire fighters and police were alarmed. The WISMUT alarmed its rescue teams in their underground mines in Aue and Koenigstein, both about 80 km apart from the shaft "Reiche Zeche". Furthermore the Mining Authority and the Main Centre for Mine Rescue Operations in the city of Leipzig – 90 km apart – were alarmed. At the shaft all gates were closed for people who are not involved in the rescue operation. The staff prepared for the arrival of the rescue teams and prepared places for vehicles and teams. An operation centre was established, further telephones were plugged in and mine planes were prepared. A secretary had to record all actions and orders. Local firefighters arrived and got the order to search for the miners under breathing equipment. The emergency doctor prepared his team for the rescue; the police blocked the area and guided the rescue teams to the shaft. At first the fire fighters found a dead person! But there was no dead person in our plan. We asked again and got once more the reply: confirmed, dead person, perhaps a student. Did things changed from training to a real emergency? Fortunately they found only a dummy we hided from the fire fighters. The dummy should be used later for the transport in the shaft instead of a real person. Some minutes later the fire fighters found the first injured miner. Up to this point all CO_2 values were under the limit, so the emergency doctor could go into the mine. But the injured miner told the rescue team, that in the adit concentrations of CO_2 were over the limit. For this reason the fire fighters alarmed further teams with long term breathing equipment and the great height rescue team in the city of Dresden – 35 km apart. The great height rescue team – a special troop of the fire fighters should secure the vertical transport of the second injured miner in the shaft from the adit to the first level. They arrived almost together with the mine rescue teams. The chief of the rescue operation – which is in Germany by law the mine director – had to coordinate the rescue operation together with the chiefs of police, firefighter, doctor, Mining Authority, Main Mine Rescue Centre, Freiberg University (as owner) and the chief of the technical staff to secure energy and tools supply. Furthermore he had to give statements to the press and he has to secure the supply of the rescue teams with drinks and food (mandatory if breathing equipment is used).

Already in the planning stage the question arose whether rescue teams are allowed to drive with blue light and signal if it is only training. After a consultation with the ministry they decided: yes they can. Than the same question for the mine rescue teams: no they cannot but we got an exception for this case. During the reunification of both German states it was forgotten to regulate this in the law. Than fire fighters and mine rescue teams do work under different legal aspects. According to the Mining Law the mining director has to be the chief of the rescue operation, due to fire fighters law the first fire fighter team has to lead the rescue. If they were not especially told fire fighters come without gas measuring instruments. In the training the mine had to give them an instrument (Multiwarn II) with O_2, CO, Kat-Ex and IR-CO_2 Sensors. Nevertheless it is seen in the videos, that the fire fighters find the injured person, take off their masks and first than read the values on the instrument: 0.05 % CO = 500 ppm! For CO it would be far over the limit! Here they mistake CO for CO_2. Furthermore it became obvious that the principles for a rescue are different. Fire fighters get their order on surface and start their operation. Mine rescue teams establish an operational point nearby the accident in a safe region and give a feedback of every step directly to the operational centre. In difference to other rescue teams mine rescue teams are also equipped with chest waders (water tight pants), water tight light, field telephone and self rescuers for injured persons.

At the end more than 20 hours of videos and hundreds of photos were recorded. It should be remembered once more, that we did not take videos for the public or for the press; we took videos for an interpretation of the training. Despite the error with CO and minor errors, like stepping on the foot of the injured person, the training has been very successful. Especially because we could uncover some basic problems like the use of blue light and signal by mine rescue teams or different organization structures of rescue teams. The video gives a good impression on the operation with approximately 80 involved persons. After the alarm at 10:15 a.m. the last person left the mine at 4 p.m. The assumed accident happened in an operating teaching mine only 65 m apart from the shaft. A complete infrastructure, mine plans and communication were available. Long distances to visitor mines or remote openings as well as non-existent infrastructure and communication increase the duration of an underground rescue operation. The safety of the rescue teams combined with the establishment of a steady communication (handy and walky-talky do not work!) are the first principles of every underground rescue operation. For this reason underground rescue operations do need much more time than surface rescue operations.

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