Fatal Carbon Monoxide Intoxication After Acetylene Gas Welding of Pipes

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Acetylene gas welding of district heating pipes can result in exposure to high concentrations of carbon monoxide. A fatal case due to intoxication is described. Measurements of carbon monoxide revealed high levels when gas welding a pipe with closed ends. This fatality and these measurements highlight a new hazard, which must be promptly prevented.

Keywords: carbon monoxide; district heating; gas welding; welding

INTRODUCTION

During the last 50 years, district heating has undergone a steady growth in Sweden. Instead of every building having its own heat-generating system, district heating is supplied by a central plant, which can use advanced heat-generating methods from different fuels and modern exhaust-cleaning techniques. The central heating production is connected to homes and other premises with long pipes of steel. In 2007, the distribution net in Sweden reached 18 000 km (Bernstad, 2009). The pipes are joined together by welding and one common technique is gas welding with acetylene.

Acetylene gas welding or cutting is generally not regarded as a hazardous carbon monoxide (CO) exposure situation and to our knowledge, no fatal accidents have been reported, though it has been pointed out that gas welding carries a medium to high risk of CO generation (Burgess, 1995). This is a presentation of a fatal CO intoxication related to acetylene gas welding of pipes.

CASE REPORT

On 29 October 2009, a 23-year-old welder was installing a district heating system in the boiler room in the basement of a dwelling house. The operation carried out by the welder was evacuation of air from the newly installed pipe through a ventilating valve, which was situated in the boiler room. A colleague working about 150 m from the boiler room turned on the hot water (temperature about 88°C) to allow the water to push out the air from the district heating pipe through a ventilating valve. The welder was expected to respond when the hot water arrived at the valve in the boiler room and close the ventilating valve. The welder did not respond why his colleague went to the boiler room and found the welder lying on the floor in running hot water. The ambulance was called and resuscitation was carried out for more than 1 h. The welder was declared dead at the hospital.

This 23-year-old man was previously healthy. He had never been admitted to hospital and he had never smoked and he had not taken any drugs.

The information about the conditions proceeding and during the accident is scarce. However, it is
known that the pipe that was to be ventilated had been joined together with many welding joints.

Autopsy

Third-degree burns on the trunk below the umbilicus and burns were also observed on both legs and on the dorso-ulnar part of the left hand.

The lungs were normal. There were signs of aspiration of gastric content in the trachea and the bronchial tree. The heart, aorta, brain, liver, spleen, and kidneys were all normal.

The blood concentration of CO-hemoglobin was 46%. Ethanol, methanol, isopropanol, or acetone was not detected in the blood. No drugs or cyanide were found in the blood.

The cause of death was intoxication by CO.

EXPERIMENTAL MEASUREMENT OF EXPOSURE

Experimental design

Measurements were made under artificial conditions in a container to assess the concentration of CO during gas welding of pipes. The container had a bottom area of 6.0 m × 2.4 m and was 2.4 m high, which corresponds to a total volume of 34.6 m³. The welding was made in a 4-m long steel pipe with an external diameter of 114 mm and an inner diameter of 107 mm, which corresponds to a total volume of 0.036 m³. The steel was Quality DN 100, which is the same quality of steel as ordinary district heating pipes. The pipe was mounted in the container. The joint was placed 1.5 m from the lower end of the pipe. The container was ventilated with a flow ranging between 4 and 6 l min⁻¹. Between measurements, the container was opened and thoroughly ventilated. The exhaust air duct was placed at one of the containers’ short sides and close to the roof. Supply air leaked in via chinks close to the floor on the opposite short side. All other chinks were sealed with cling film and adhesive tape.

Measurements were made

• in the breathing zone to evaluate the welder’s exposure to CO; the instrument was held close to the welder’s head and nose, at a distance approximately not more than 2 dm.
• at the end of the pipe to study the concentrations present in the pipe.
• in the exhaust air outlet from the container to allow for calculation of the total amount of formed CO.
• in oxygen and Odorox (oxygen with an additive of 0.03% carbon dioxide and 0.002% dimethyl sulfide) in order to check for the presence of CO in the gases applied.

The measurements were made under varying conditions to study the effect on CO formation from several factors:

• Welding with both ends of the pipe open and closed, respectively. After welding in locked pipes, the pipe was opened to let out the gases formed inside the pipe.
• Welding with acetylene and oxygen compared to welding with acetylene and Odorox.
• Welding of pipes where the ends to be joined were clean and greasy, respectively.

The welding took between 14 and 17 min. The flow in the welding gun was approximately 315 l min⁻¹, half of which was supposed to contain acetylene. Measurements were also made during torch cutting in the steel pipe and soldering in a copper pipe to evaluate if CO could be formed during these operation. Torch cutting was conducted for 2 min and soldering for 9 min.

The total amount of CO generated in each trial was calculated from the concentration in the exhaust air. Based on these figures, the theoretical concentrations after 15 min of welding, torch cutting, or soldering in a 10-m³ confined space without ventilation were calculated.

Measuring instruments for CO

CO was measured with two portable instruments with electrochemical cells, Dräger PAC III and Dräger Multiwarn II. The instruments were calibrated with a calibration gas of 45 ppm. Electrochemical cells are known to react to acetylene and hydrogen (information from Dräger, Stockholm, Sweden). To evaluate the cross-sensitivity of the electrochemical instruments, parallel measurements of CO in gas welding gases were made under laboratory conditions with the Dräger instruments and an FTIR instrument Ecotech, Serenus 30 CO (Stockholm, Sweden). An FTIR instrument was used as standard because it measures the entire infrared absorption and calculates the concentration of the gases present using the absorption of different compounds from the built-in library. The measurements showed that the CO concentration in fumes from gas welding measured with the FTIR instrument was 30% of the CO concentration measured with the two Dräger instruments. The concentrations measured with
the Dräger instruments has, therefore, been recalculated and corrected for the cross-sensitivity.

**Combustion reaction of acetylene**

Acetylene is used in gas welding. Acetylene reacts with the oxygen supplied, in a sequential reaction (Vandooren and Van Tiggeelen, 1977). In gas welding, five oxygen atoms are required for every acetylene molecule in order to transform all carbon into carbon dioxide. Two out of the five oxygen atoms are supplied from the gas cylinder during welding and the rest from the surrounding air why the reactions according to Steps 2a and 2b depend on the presence of oxygen in air.

\[
\text{Step 1: } \text{C}_2\text{H}_2 + \text{O}_2 \rightarrow 2\text{CO} + \text{H}_2 \\
\text{Step 2a: } 2\text{CO} + \text{O}_2 \rightarrow 2\text{CO}_2 \\
\text{Step 2b: } \text{H}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{H}_2\text{O}
\]

**Measured CO concentrations**

The results from the measurements of CO during different gas welding and soldering operations are presented in Table 1. The CO concentrations in the table are corrected for the instrument’s cross-sensitivity for acetylene and hydrogen and presented as time average concentration during the operation (gas welding, torch cutting, or soldering) and as peak concentrations.

The highest concentrations were measured outside the closed pipe during gas welding with Odorox. The welding created welding gases that generated an overpressure, which caused the leakage of welding gases. Table 1 summarizes the average and peak concentrations during the welding operation. After cessation of the gas welding of the closed pipe, when the ends of the pipe were opened, measurement of the CO concentration continued. Peak concentration exceeding the measurement range of the instrument of 1400 ppm (corrected value) was registered. In the exhaust air from the 34.6 m³ container, peak concentration of 170 ppm was registered after cessation of the welding. Based on the concentration in exhaust air, it was calculated that the pipe contained 2.2 l of CO.

The measurements of CO in the oxygen and Odorox gases applied during the measurements showed no concentration of CO above 2 ppm.

**Calculated CO concentrations**

The calculated concentrations of CO generated, supposing room temperature, in the welding operations are presented in Table 2. For each case, a calculation has also been made to evaluate what the average concentration would be if the welding was done in a small room of 10 m³ with no air exchange, after 15 min of welding, torch cutting, or soldering.

**DISCUSSION**

One welder died after inhaling CO released from a previously acetylene gas welded pipe. To our
Table 2. Calculated volumes and concentrations of CO. The generated amount of CO was calculated from average concentrations (see Table 1) and measured air flows. Based on the generated amount and time for welding, a theoretical calculation of the concentration after 15 min of welding and dilution into 10 m³ was made.

<table>
<thead>
<tr>
<th>Welding method</th>
<th>Generated amount of CO in the trials (l)</th>
<th>Average CO (ppm) in 10 m³ after 15-min operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas welding with oxygen</td>
<td>0.7 during 14 min</td>
<td>75</td>
</tr>
<tr>
<td>Gas welding with Odorox</td>
<td>0.6 during 17 min</td>
<td>53</td>
</tr>
<tr>
<td>Gas welding with greasy ends joined by welding</td>
<td>0.7 during 15 min</td>
<td>70</td>
</tr>
<tr>
<td>Gas welding with the ends of the pipe locked and with Odorox</td>
<td>6.6 during 16 min including 2.2 l CO contained in locked pipe</td>
<td>620</td>
</tr>
<tr>
<td>Torch cutting using acetylene and oxygen</td>
<td>0.3 during 2 min</td>
<td>225</td>
</tr>
<tr>
<td>Soldering of copper pipe</td>
<td>1.2 during 9 min</td>
<td>200</td>
</tr>
</tbody>
</table>

knowledge, this is the first report of a fatal CO intoxication after acetylene gas welding. We are aware of another welder with a nonfatal intoxication with neurological disturbances. This case cannot be described in detail due to ethical reasons. Other welders have told about welders fainting in connection with gas welding of pipes. CO lacks warning properties as it is odorless and nonirritating. It diffuses readily from the alveolar space to the capillary blood stream and binds firmly to the hemoglobin molecules (COHb) within the red blood cells. The COHb decreases the release of oxygen from the Hb molecule. These two mechanisms impair the delivery of oxygen to the tissues. An air concentration of 1000 ppm will generate 50% COHb after 2-h exposure. Slightly higher levels will be fatal. However, high exposures (>50 000 ppm) can result in fatal cardiac arrhythmias and death before the COHb is significantly elevated (Leikauf and Prows, 2001).

The air measurements were performed to investigate if gas welding could produce high enough concentrations to cause unconsciousness and asphyxiation. The measurement results should, therefore, not be interpreted as representative of the exposure during such operations, as concentrations may vary a lot due to the circumstances in each case. The measurements showed that CO was formed both during gas welding and torch cutting on steel and soldering in copper. The measurements indicate larger formation of CO during torch cutting and soldering, which may depend on the use of larger nozzles and gas flows. The concentrations of CO exceeded the Swedish short-term occupational exposure limit of 100 ppm (Swedish Work Environment Authority, 2005). The CO concentrations were about five to eight times higher during gas welding a pipe with closed ends compared to other gas welding operations. This is explained by the lack of oxygen needed to oxidize CO inside the closed pipe. In real life, district heating pipes can be very long, sometimes several hundred meters, and consist of many pipes, joined through welding. The joints often occur approximately every 5–10 m. In our experiment, only one joint was welded, but in real life, many joints are welded. Often the pipes are open during welding, but in joining long pipes, oxygen deficit may occur. Compared to our trials, the pipes may in real life contain even larger amounts of welding gases containing CO. The amount of CO will vary a lot according to the length of the pipes, the number of joints, and access to oxygen, which depends on the ventilation rate of the room and the air exchange in the interior of the pipe. Factors such as greasy joints and use of Odorox instead of oxygen have negligible additional effect on the CO concentration.

Another possible source of CO may be contamination in the gases applied. Oxygen and Odorox were checked for CO and none of these gases contained CO in concentrations above 2 ppm. It was not possible to measure the acetylene gas for CO, as the electrochemical cells are cross-sensitive and indicate presence of CO if acetylene is present. However, if the acetylene gas contained high concentrations of CO, this would not explain the very high concentrations of CO when gas welding the pipe with closed ends. We conclude that it is highly unlikely that the gases used in gas welding are contaminated with health significant concentrations of CO.

Several measuring instruments for CO are cross-sensitive, so the results from such instruments must be interpreted with care. In the measurements, we found that the real concentration measured with FTIR was 30% of the concentration measured with the electrochemical cells. We have used the factor 0.3 to calculate the ‘real’ CO concentrations.
concentration from the concentrations measured with the electrochemical instruments. Depending on the composition of the welding gas, this correction factor may of course vary.

Propane is sometimes used instead of acetylene. If the concentration of propane is the same as acetylene, 10 oxygen atoms are required in order to achieve complete combustion. Consequently, propane may increase the risk for CO generation.

\[
C_3H_8 + 5O_2 \Rightarrow 3CO_2 + 4H_2O
\]

Further studies are needed to evaluate the CO risk when applying propane as welding gas.

Acetylene gas welding or cutting has been associated with asphyxiation after intentional inhalation of acetylene (Williams and Whittington, 2001) and pulmonary edema caused by nitrogen dioxide generated in the welding process (Norwood et al., 1966). Welding, in general, is not associated with hazardous CO exposures. However, there are some operations where CO exposure must be considered. In MAG (metal active gas) welding with shielding gas containing carbon dioxide, the carboxyhemoglobin concentration in blood has reached 20% (De Kretser et al., 1964). The CO concentrations may reach 100 ppm in the breathing zone during arc-air gouging with a carbon graphite electrode (Sanderson, 1968).

We recommend that when planning the venting of district heating pipes, the risk of CO poisoning has to be considered. Measures have to be planned in order to reduce exposure. We suggest that the primary measure is to attach a hose to the venting valve in order to evacuate welding gases from the breathing zone of the operator. The welding gases should be lead from boiler rooms or other confined rooms outdoors where dilution can occur. Applying this measure, the welding gases are led outside without passing the room. This measure can be combined with a direct-reading alarm that will give alarm if the CO concentration exceed the TLV (threshold limit value), indicating leakage of CO into the room.

If this measure is not possible to apply, the operator must be equipped with a fresh-air breathing apparatus or gas masks equipped with chemical cartridges for CO, which have been developed recently and are available on the market. These respirators should also be used as backup measures if the other measures fail.

It is not enough to have one auxiliary operator standing at a distance watching the operator evacuating to welding gases. If the operator falls unconscious due to CO intoxication, it is impossible for one man to carry him away without breathing.

**CONCLUSIONS**

During gas welding, CO is generated. Oxidization of CO will not take place if there is a deficit of oxygen and the result will be high concentrations of CO. Welding of district heating pipes and evacuation of newly installed pipes are expanding operations where high and fatal concentrations may occur. This risk has not been recognized previously and consequently information is the first step along the path of prevention.

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**REFERENCES**


