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ORIGINAL ARTICLE

"Death may come on like a stroke of lightening ..."

Phenomenological and morphological aspects of fatalities caused by manure gas

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Abstract Due to the decomposition of biological material, hydrogen sulphide (H_2S) is produced. In low concentrations, the well-known smell of "rotten eggs" is associated with H_2S. In higher concentrations, H_2S is an odourless and colourless gas that may cause rapid loss of consciousness, neurological and respiratory depression and imminent death—"... like a stroke of lightening".

Hydrogen sulphide poisoning is an un-common incident that is often associated with colleague fatalities. In this study, 4 fatal accidents with 10 deceased victims are reported and the morphological and phenomenological aspects are presented. In these cases, the morphological findings, namely, discolouration of the livores, pulmonary pathologies and sub-mucosal or sub-serosal congestion bleeding were found in nearly all cases. Also the impending threat for colleagues, first aid helpers and professional rescue teams is demonstrated.

The suspicion of a fatal H_2S intoxication should be based on a precise scene analysis with respect to the possibility of life-threatening H_2S intoxication for the helpers, the typical scent of rotten eggs, which may be noted on the corpses and the abovementioned morphological findings. The diagnosis should be confirmed by a qualitative and, if possible, quantitative analysis of H_2S.

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Introduction

"Death may come on like a stroke of lightening, as in HCN poisoning, but usually there are first symptoms of irritation of the nervous system, which occur even earlier than the formation of H_2S–hemoglobin."—This vivid description of the lethal effects of hydrogen sulphide (H_2S) was given by Alice Hamilton in 1925 [12]. Hydrogen sulphide—also known as manure gas—is one of several gases produced by the decomposition of biological material and a by-product in industrial plants [10].

Whilst in industrial sites the safety management of hazardous by-products is a matter of course and accidents are quite rare, they are reported more commonly in rural areas due to manure pits—even despite the safety regulations of employer's liability insurance associations and government safety organisations [3, 4, 7, 16–20, 23]. In agricultural operations, manure pits are very common as they are an economical method of handling animal excrements. Storage pits are also common in biogas plant operations. Due to decomposition, different gases are formed. These gases are used in biogas plants. On average, the concentrations of these gases are approximately 60 vol.% methane (range 50–80 vol.%), approximately 38 vol.% CO_2 (range 20–50 vol.%) and small amounts of other gases like O_2, N_2, NH_3, CO and H_2S (range 1–5 vol.%) [4]. Even in these low percentages, H_2S can reach a toxic concentration of 4000 ppm and above. Under anaerobic conditions—typical of most pits—hydrogen sulphide is given off [2, 3, 15, 26, 30]. The physical and chemical properties and the principal hazards of hydrogen sulphide are given in Fig. 1 [5].

Physical and chemical properties:

Molecular weight	34
Melting point	-86°C
Boiling point	-60.2°C
Relative densitiy (gas)	1.2 (air = 1)
Relative density (liquid)	0.92 (water =1)
Solubility (mg / l water)	3980 mg / l
Appearance	colorless gas odor of rotten eggs in low concentrations inodorous in high concentrations
Autoignition temperature	270°C
Flammability range	4.3 - 45.5% in air

Principal hazards:

Very toxic by inhalation
Extremly flammable / can form explosive mixture with air
Hazardous to the environment

Fig. 1 Physical and chemical properties of hydrogen sulphide

The danger of H_2S poisoning is enhanced by the fact that the well-known warning odour of rotten eggs is only present in low concentrations. A person's olfactory ability to detect the gas is affected by the temporary paralysis of the olfactory tract. This means that the disappearance of the odour could indicate increasing concentrations. Owing to this unique property, the danger in high concentrations is easily under-estimated [6, 10, 13].

Due to the higher density than air, H_2S accumulates on the surface of un-disturbed manure in pits. The greatest danger of exposure to H_2S is present during agitation and pumping of the pit content [2–4, 26].

Acute poisoning to H_2S causes four dose-dependent responses: hyperpnoea, un-consciousness, apnea and death [1]. High concentrations will rapidly lead to acute poisoning and death due to respiratory arrest. Exposure to lesser concentrations will result in mucosal irritations, headache, nausea, vomiting, excitement and un-consciousness (Table 1) [1, 2, 6, 8, 25]. The toxicity of H_2S is similar to cyanide by inhibiting the cytochrome oxidase system [9].

Table 1 Effects of hydrogen sulphide in humans

H_2S (ppm)	Sensations and symptoms
0.02–0.13	Olfactory perceptibility (odour of rotten eggs)
>50	Mucosa irritations (eyes and airways)
>100	Irritation of the throat
>100–150	Loss of the scent
250–500	Excitement, headache, cyanosis, pulmonary oedema
500–1000	Ataxia, nausea, dizziness, impaired consciousness, tachypnoea
>1000	Knockdown, apnoea, nervous system paralysis (death within minutes)
>5000	Imminent death

Modified after Beauchamp et al. [6].

Materials and methods

Autopsy files of the Department of Legal Medicine, Hamburg from the year 1980 to 2005 were evaluated regarding fatalities caused by H_2S. Morphological findings and reconstructions of the technical services of police and fire departments were available in these cases.

In total, 4 incidents with 10 fatalities were analysed. On behalf of the public prosecutor, an autopsy was performed in all cases within 36 h after the incidents. The autopsy files were evaluated with respect to the morphological findings.

Case reports and results

Case 1 On a farm, a 3-year-old boy (victim 1) watched his father pumping manure from a pit to an agricultural vehicle. The boy was left un-attended for a short while and opened the wooden cover of the pit. Due to the escaping gases, consciousness was rapidly lost. The father found the lifeless child directly beside the open manure pit with vomit beside and on his face. Despite immediately initiated cardiopulmonary resuscitation, the boy died during transport to the hospital.

Case 2 On another farm, two victims were recovered; one dead and one in a life-threatening condition. Criminalistic investigations showed that a father (victim 2) and his adult son tried to clean a clogged connection pipe between the manure pit and an aboveground tank. The father entered the pit and the son went to the farmhouse to get some tools. On his return, he found his un-conscious father upside down in a residue of manure. To rescue him, the young man entered the pit, lost consciousness and fell backwards directly with his face under running fresh water from a hose. This position probably saved his life—although the father could

only be recovered dead, the son survived after intensive care therapy without consequential damage.

Case 3 Another tragic accident causing a death toll of four persons took place on a cattle farm. The reconstruction by the police elucidated the course of incidents: in the morning, a farmer (victim 3) and his farm worker (victim 4) started to clean a clogged connection pipe between a manure pit and an aboveground tank.

The farmer entered the pit filled with about 30 cm of manure. Knowing the danger of manure pits, he positioned the farm worker with a rope at the entrance of the pit. However, the farmer collapsed inside the pit, un-able to catch the rope and fell into the manure. The farm worker tried to rescue him and entered the pit but also collapsed. At noon, the mother of the farmer (victim 5) went to the pit. She found the victims and climbed down at once, but she also fell un-conscious into the manure. Two hours later the son of the farm worker (victim 6) arrived at the pit and recognised the victims. He also climbed down, lost consciousness in the entrance area of the pit but got stuck in a ladder in the entrance opening, so he did not fall into the manure.

The young man was recovered shortly after he entered the pit by three other persons but died despite resuscitation at the scene. The remaining three victims were recovered by a special force of the fire department using an external air supply (Fig. 2). During autopsy, the forensic pathologists and police officers also suffered from a mild form of H_2S intoxication due to the fact that the autopsies were carried out in an insufficiently ventilated autopsy room. Fortunately, all symptoms, such as lack of concentration, nausea and dizziness were reversible after a short time.

Case 4 The scene of the incident was a biogas plant operation. In the morning, a road tanker with chaffed porcine intestines from a pharmaceutical plant was emptied into an indoor pit in a large hall of this plant. During this procedure, two employees standing at the edge of the open pit suddenly collapsed (victims 7 and 8). A colleague immediately ran towards the victims but collapsed as well (victim 9). The driver of the truck recognised the danger, ran to the nearby office and asked a waiting truck driver to call an ambulance. Then he went back to the hall and collapsed as well (victim 10). The next truck driver was able to warn the rescue team not to enter the hall without external air supply. Then, he was taken to an intensive care unit. He survived un-harmed after a few days in an artificial coma. The other victims were retrieved from the building by firemen with external air supply. Whilst victims 7 and 8 could only be recovered dead, victims 9 and 10 were successfully resuscitated at the scene and taken to hospital. However, due to the inhalation trauma and the duration of hypoxia, both died the next day in multi-organ failure. These rescued victims received first aid in a tent outside the plant. Due to contact with the victims, the paramedics at the scene and nurses in the hospital suffered from mild intoxication symptoms such as nausea, irritation of the eyes and airways and irritation of the skin. The firemen who went to the hall of the biogas plant reported that all metal material they were carrying became oxidised.

The technical analysis led to the following reconstruction: The closing mechanism of the pit had a defect and was open overnight. This caused an insufficient ventilation of the pit. Due to this defect, a cloud with highly concentrated toxic gases was pressed into the hall because the introduction of the chaffed pigs' intestines raised the liquid level in the pit.

Morphological findings The livores in all the victims that died immediately (victims 1–8) were of grey-greenish colour and in some cases characteristic findings in the eyes and in the thoracic organs could be found (Figs. 3 and 4a–c) (Table 2). In all cases, no relevant pre-existing findings were detected. In victims 9 and 10 who were initially

Fig. 2 Victims of case 3 after recovery from the manure pit

Fig. 3 Findings on external examination: discoloured livores in victim 7

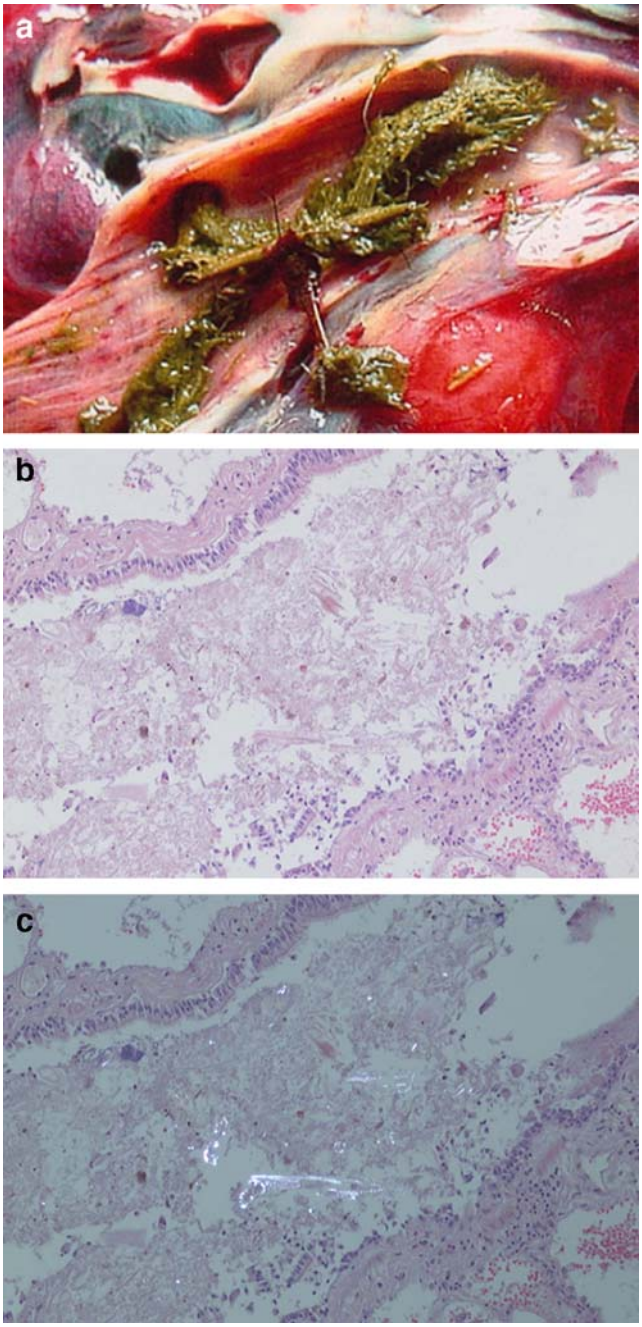

Fig. 4 Autopsy findings. **a** Aspiration of manure in victim 4 (macroscopic aspect). **b** Aspiration of manure in victim 4 (histological specimen H&E staining). **c** Aspiration of manure in victim 4 (histological specimen H&E staining, polarised light)

resuscitated successfully but died the next day, signs of hypoxic brain damage and multi-organ failure were present. The livores of these two victims were normal.

In cases 1 and 2, only qualitative measurements of the relevant gases like methane, ammonia, carbon dioxide and hydrogen sulphide were performed with high positive result for hydrogen sulphide. In cases 3 and 4 (victims 3–10), measurements with Dräger® quantitative indicator tubes for H_2S performed in the trachea directly before autopsy (Fig. 5) resulted in concentrations over 100 ppm (24–36 h after the incident) in victims 3, 4, 5, 7 and 8.

Victims 6, 9 and 10 died despite cardiopulmonary resuscitation. The H_2S concentration at time of autopsy were 5 ppm in victim 6 who was declared dead at the incident scene and un-detectable by the indicator tubes in victims 9 and 10 who died 1 day after the incident.

H_2S measurements at the scene by technical experts were performed in case 4. The concentration of the H_2S was estimated as being more than 2000 ppm near the pit in the biogas plant at the time of the incident.

Discussion

Morphological aspects

In cases with suspected acute intoxication, the external examination of the victims is a very important step for planning further procedures. Authors of case reports described greenish discolouration of the livores but in most cases the victim was submerged in the manure [28, 31]. In our cases, a greenish discolouring of the livores was present in all cases where death was instantaneous whilst the two victims with a relevant survival time had livores of normal lividity.

Another sign of H_2S exposure could be found in the eyes. Whilst the non-submerged victims of case 4 showed chemical burns of the sclera and cornea, in cases 2 and 3 contact with manure was present. In the first case, no description of the sclera and cornea was available. This phenomenon gives an impression of the reactivity of H_2S. Knight and Presnell also described this finding in their case report where both deceased were described as “not submerged” [20].

If the concentration of H_2S is lower than 5000 ppm, death may not come instantly, but a knockdown effect is most likely a consequence of concentrations over 1000 ppm [25]. Most of our victims had findings of aspiration and/or acute oedema of the lungs. This implicates a briefly functioning respiration even after loss of the ability to act. This remaining respiration and the consecutive circulation dysfunction may lead to the petechial bleedings under the mucosa, serosa, in the conjunctivae and the facial skin. In our cases, we found spot-like bleedings in all victims except victim 2. This phenomenon, which indicates a possible suffocation, is also described in a case report by Kimura et al. [19]. Whilst resuscitation effects are still a controversial causative mechanism of petechial bleedings [14, 21, 24], Kimura et al. [19] described a short survival time of the victims and cardiopulmonary resuscitation of these victims is to be assumed in these cases. In our cases,

Table 2 Morphological findings

Victim	Livores	Pulmonary findings	Petechial bleedings	Other findings
1 (male, 3 years old)	Grey–green	Massive aspiration of gastric content, hyperemia, oedema	Pleura	Cerebral oedema, anemia of the spleen
2 (male, 67 years old)	Grey–green	Acute emphysema, oedema of the basal parts of the lungs	None	Status post-implantation of a mechanical aortic valve and a pacemaker, myocardial hypertrophy, cerebral oedema
3 (male, 34 years old)	Grey–green	Acute emphysema, haemorrhagic oedema	Conjunctivae, eyelids, larynx, pleura	Washerwoman palms, cerebral oedema, anemia of the spleen
4 (male, 45 years old)	Grey–green	Deep aspiration of manure, acute emphysema, oedema and hyperemia	Epicardium, pleura	Washerwoman palms, cerebral oedema, anemia of the spleen
5 (female, 59 years old)	Grey–green	Deep aspiration of manure with complete tamponade of the major bronchi, acute emphysema	Conjunctivae, eyelids, buccal mucosa, larynx, pleura	Cerebral oedema, anemia of the spleen
6 (male, 19 years old)	Grey–green	Discrete aspiration of gastric content, acute emphysema, partial high-grade oedema	Conjunctivae, epicardium	Washerwoman palms, mild cerebral oedema
7 (male, 43 years old)	Grey–green	High-grade haemorrhagic oedema	Conjunctivae, larynx, epicardium	Cerebral oedema, chemical burns of the sclera in the region of the opening of the eyelids
8 (male, 28 years old)	Grey–green	High-grade haemorrhagic oedema	Conjunctivae, larynx	Cerebral oedema, chemical burns of the sclera in the region of the opening of the eyelids, emphysema of the thoracic skin
9 (female, 32 years old)	Normal	High-grade oedema	Conjunctivae, larynx, renal pelvis	Pleural effusion (200 ml both sides), ascites (250 ml), multiple ulceration of the intestinal mucosa, chemical burns of the sclera in the region of the opening of the eyelids
10 (male, 50 years old)	Normal	High-grade oedema	Conjunctivae, larynx, renal pelvis	Ascites (200 ml), multiple ulceration of the intestinal mucosa

we found these bleedings not only in the face but also in the thoracic organs in 90% of the victims. Five of these victims were declared dead at the scene without any resuscitation attempts.

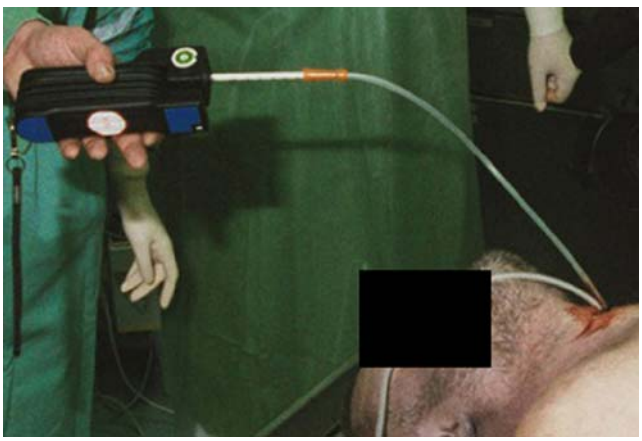

Fig. 5 Measurement of H_2S in the trachea of victim 8 before autopsy by Dräger® indicator tube

Phenomenological aspects

In cases of corpses found in manure pits, there are always the questions: "who are they?", "how did they get in?" and "what is the cause of death?" Whilst homicides with disposal of the bodies in pits have rarely been reported [22, 29]. Case reports on occupational accidents have been reported more often due to their relevance for occupational safety. In many of these cases, more than one victim—fatal or non-fatal—is to be bemoaned [11, 17–20, 27, 31]. In our cases, this phenomenon was also seen and the immanent threat, even for rescue teams is shown. Whilst the other reported cases involve accidents in/on pits, the last case gives a vivid impression of the hidden danger of H_2S even in a large hall with "only" biologically valuable resources. For rescue teams and crime scene investigators, a scene like this must be dealt with using the utmost possible self-protection and the knowledge that rash decisions may be fatal.

In most cases, the characteristic mechanism of injury was evident: sudden collapse of at least one victim, immediate rescue attempts by first aid helpers, collapse of the helpers, next course by second helpers or professionals. These first aid helpers are mainly motivated affectionally

and act despite or without knowledge of the immanent danger. The high toxicity of H_2S carries the highest risk in the described situations. The loss of the perceptibility in higher concentrations, the accumulation at the bottom of pits and the short distance between the victim and the first aid helper (relative, friend, colleague) may lead to the fatal error in believing that the victim can be rescued without taking a breath. Due to the high reactivity to mucous membranes (eyes, nose, mouth and airways), a single breath is often taken involuntarily and may lead to helpless situations. As demonstrated by the cases 3 and 4, an impending threat in a milder form is also present for the forensic pathologists, paramedics, nurses and emergency physicians who have to deal with the fully dressed body in H_2S-soaked clothes. It should be mandatory for handling a patient or a body from any poisoned area to secure best ventilation conditions for the staff.

The quantitative measurement of H_2S is especially difficult at the incident scene due to the fact that the measurement takes place after recovery of the victims, which generally means that a mixture of the external air with the atmosphere at the scene has already taken place. Whilst toxicological investigations of specimens taken from the victims are time-consuming procedures, measurement of the airway gas by indicator tubes gives a valuable estimation of the possible toxic gases.

Conclusions

In the presented cases, different incident scenes are shown. These comprise of manure pits, an outdoor open space beside a manure pit and inside a biogas plant. In most cases, colleagues or family members of the initial victim of the incident were also bemoaned.

Although the incident scenes differ in the cases described, the pulmonary pathologies were similar in all cases. In addition, the morphological findings of a greenish discolouration of the livores and congestion bleedings were found regularly. Toxicological analysis remains difficult, but for an estimation of the H_2S concentration, commercial indicator tubes are available and can be used at scene and during autopsy.

The abovementioned problems quantifying H_2S concentrations and the morphological signs of suffocation in combination with aspiration should be taken into account in such cases to clarify the cause of death and the course of the incident.

Finally, it should be mentioned that the danger of H_2S is well-known but due to its high toxicity and the short distance between the rescuer and the victim it is easily but fatally under-estimated. Mostly, the distance to the victim, e.g. at the bottom of a pit is less than 5 m, which leads to the erroneous assumption that the victim can be reached without breathing. In high concentrations of hydrogen sulphide, a single breath may however lead to a loss of consciousness. The risks for all helpers are very high because “Death may come on like a stroke of lightening ...” [12].

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