

Hydrogen Sulfide; That Ubiquitous Poisonous Gas

Guy Wilson

Dynematics Corporation

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Recent and Ongoing Regulatory Changes

Hydrogen sulfide reporting by the oil and gas industry for the first time in history under EPCRA section 313 (40CFR372, Subpart D) for 2012 will be due to EPA and the state on July 1. EPA reported that they based their decision on an assertion that H₂S can “reasonably be anticipated to cause *chronic health effects in humans* and can reasonably be anticipated to cause, because of its toxicity, significant adverse effects in aquatic organisms” (EPA1 2012). We will briefly discuss below the evidence that there may be risk posed by hydrogen sulfide--both health and legal risk, the things that may have triggered EPA to take this action, and what can be done about sour gas in the future.

While the WHO sets a LOEFL of 2 ppm, others have pronounced that an asthma limit. The ATSDR says that while the typical environmental concentrations of 0.00011–0.00033 ppm (.11 to .33 ppb) have never been shown to cause any health effects, many individuals knocked-down (unconscious) by a brief high exposure (over 500 ppm), may have suffered permanent or long-term effects such as headaches, poor attention span, poor memory, and poor motor function--frequently referred to in headlines as *brain damage*. Most knock-downs appear to recover without incident but many do not (ATSDR 2006). H₂S occurring in natural gas at greater than 5.7 mg/Nm³ (0.25 grains per 100 SCF) results in a *sour gas* classification by EPA. While the fraction of sour wells in the US is below the global average, the US fraction generally increases with drilling depth, and average drilling depth increases with time.

In 2010, a citizen’s group in Colorado went on an air sampling campaign to police the gas industry locally, collecting air samples using strong QA/QC protocols and having the samples evaluated at EPA certified labs (GCM 2011). This approach created a level of credibility not normally afforded environmental groups. Normally companies would be faced with dealing with only negligible scientific evidence from the plaintiff’s side. One sample result indicated H₂S at 370 µg/m³ (0.5 ppm), nothing that couldn’t be intentionally ignored, but a concentration at which H₂S is known to cause irritation of the eyes, nose, and throat and is considered to be a nuisance odor by most of the population if that level is sustained over any time. One of their complaints was the lack of reporting under EPCRA (GCM 2011).

A survey of environmental websites consistently reveals complaints and references made to H₂S in regard to drilling, producing, refining, and distributing oil and gas. Of course the meat industry, kraft process pulp mills, leather tanning, coke ovens, and sewage plants have long been common targets of complaint, with the primary difference in rationale being that these mills, plants, factories, and refineries are in fixed locations often preexisting and well known, whereas drilling and new petroleum production may abruptly introduce ambient hydrogen sulfide gas into residential and popular recreation areas where exposures were historically minimal or nonexistent.

Reasons to Improve Regarding H₂S

Note that while EPA's new basis for reporting stated that hydrogen sulfide can reasonably be anticipated to *cause chronic health effects in humans*, there is no law against introducing a little hydrogen sulfide into the environment per se. All humans release at least some molecules of hydrogen sulfide constantly. The question for business becomes, "At what release levels will the company through H₂S leaks, accidents, and emissions, introduce significant toxic torts risk that can no longer be ignored? When is enough enough when it comes to fugitive sour gas?"

A company's environmental responsibilities are mostly derived from common law created by state courts in regard to nuisance or tort where no statutory obligation may exist. Legal actions can be brought to civil court on the causes of *negligence*, *nuisance*, and *strict liability*, with the following abridged descriptions based on *W. Page Prosser et al., Prosser and Keeton on the Law of Torts 550-551* (5th ed. 1984) (LECTLAW 2012):

Negligence. The common law of torts generally prohibits any person from unreasonably or "negligently" injuring another person or another person's property. The elements of a tort case based on negligence, include proving that: the defendant was required to conform to a certain standard of conduct for protecting others; the defendant failed to meet that standard by, for example, acting negligently or unreasonably; the defendant's failure was the proximate cause of specific damage suffered by the plaintiff; and the plaintiff suffered the damage...

Nuisance. The common law of nuisance generally prohibits any person to use their land or property in a way that unreasonably interferes with the enjoyment and use of another person's property. Thus under common law nuisance theories, a property owner may be able to sue a neighbor for damages caused or threatened to their property by, for example, air or water pollution.

Strict Liability. In some states, hazardous waste disposal or similar activities may be deemed ultrahazardous activities. Plaintiffs damaged by such activities are allowed to sue under a theory of strict liability. In strict liability cases, it is not necessary to prove that the defendant did anything wrong or negligent. Rather, the plaintiff must demonstrate that the activity was inherently dangerous or unreasonable under the circumstances and that the injuries were caused by the activity. Examples of ultrahazardous activities have included drilling oil wells, excavating near the ocean, emitting toxic substances, crop dusting with pesticides, and using or transporting explosives or flammable materials.

The *goals* of tort law are (Pontius 2003):

1. Assignment of responsibility to those creating a risk that results in harm.
2. Compensation for loss.
3. Deterrence from further hazardous conduct.

The judge establishes the standard of conduct for care, under which punitive damages, the amount of which may be determined by a jury, are employed to compensate and deter further risk of harm. Lawyers often work for part of the award, investing contingent on success and thus requiring a large fraction of a monetary settlement. This makes class actions more attractive, where a class genuinely meets criteria for certification and will not be decertified.

For instance, if someone claims their real estate sale was interfered with by the odor of hydrogen sulfide, this claim might be easier to prove on the Nuisance basis than the Strict Liability basis [or not, depending on the details]. Limiting the company's liabilities entails proactive measures to avoid nonfrivolous legal actions to the extent practical. As potential plaintiffs become more sophisticated in their scientific knowledge and bases of attack, a ten-thousand foot level view of what evidence might be brought to bear in the form of data and relevant information is insufficient as a responsible defense for the company.

The risk of action must be understood and contemplated in order for it to be prevented, because the company's *intent* to harm was not required for the success of a toxic torts claim. While the general hazards of hydrogen sulfide has been well known for over a century, recent attention has revealed more details and new perspectives. Thus we will re-examine some of the old information as well as some new data, focusing on low and chronic exposures, since the lethality of this poisonous gas was always unquestioned at high concentrations.

Overview of the Hazard

Data does not exist regarding the chronic toxicity or carcinogenicity of hydrogen sulfide. This should not be interpreted to mean that long term exposure to low levels is known to *not* cause any toxic effect and does not cause cancer—but rather only that a defensible conclusion cannot be drawn in either way. The Health Agency (Cush 2011) states that “Data on the effects in humans following repeated exposure are limited and difficult to interpret because of *co-exposure to other chemicals*. There is some limited evidence to suggest an association with spontaneous abortions, but the effects seen were small and confounded by exposure to other chemicals, therefore no conclusions could be drawn.”

Humans metabolize hydrogen sulfide through oxidation, methylation, and most often by reaction with metalloproteins or disulfide-containing proteins. Hydrogen sulfide may directly inhibit cellular enzymes, such as cytochrome C oxidase, the final enzyme in respiration which is involved in cellular oxidative processes and energy production. Such enzyme inhibition leads to disruption of the electron transport chain and impairs oxidative metabolism, leading to anaerobic metabolism, decreased ATP production and generation of lactic acid. The major detoxication pathway for hydrogen sulfide in humans is via oxidation in the liver.

Hydrogen sulfide is rapidly eliminated from the body in the form of sulfate in urine, but some may be excreted unchanged in exhaled air and, in feces and flatus. The major oxidation product is thiosulfate, which is then converted to sulfate and excreted in the urine with peak levels around 15 hours after

exposure. Urinalysis is the best way to confirm significant exposures. The methylation pathway also serves as a detoxification route. Some of the toxicity of hydrogen sulfide is a result of its reaction with metalloenzymes. Nervous and cardiac tissues, which have the highest oxygen demand, are especially sensitive to the disruption of oxidative metabolism. In the central nervous system, this effect may result in death from respiratory arrest. (Chou, 2003; Cush 2011).

Using urine thiosulfate, forensic investigators after an industrial exposure were able to clearly differentiate based on thiosulfate blood and urine levels between fatalities and high dose survivors. H₂S gas was never measured at the site where the workers were exposed. Thiosulfate in urine was the only indicator of H₂S exposure in a sole survivor (Kage 2002). Thiosulfate is always expected in urine at 2.9±2.5 mcg/mL based on an average creatinine concentration of 1 g/L. (Mayo 2012). This test creates particularly obvious results when used in high exposures into the lethal dose range. There was no question of hydrogen sulfide exposure in the investigated case.

H₂S targets the respiratory system first, and the nasal tissue suffers pronounced attack. In one experiment, sets of young Sprague-Dawley rats were subjected to a nose-only exposure of either air or 280 ppm H₂S for 3 hours daily for one or five consecutive days. Microdissected sections of nasal tissue exposure sites were laser captured at the epithelial level and gene expression profiles generated at 3, 6, and 24 hrs. post initial exposure and 24 hrs. post 5th exposure. (McQueen 2010). The result of gene ontology enrichment analysis revealed that the gene expression normally associated with a spectrum of bioprocesses, including all cycle regulation, cytoskeletal reorganization, protein kinase regulation, and biogenesis were all interrupted by H₂S exposure at this concentration (McQueen 2010).

Background Levels and the Risk of Belief of Harm

Like many deadly substances, hydrogen sulfide is always present in very small and rarely lethal quantities in nature. It is created in the human body naturally in the brain and smooth muscle and is constantly generated by bacteria on the tongue and throughout the digestive tract. There is no way to achieve a *zero* discharge goal for hydrogen sulfide, which would always be released in the exhaled breath of any human plaintiff in court. What's a little poison gas among friends?

Persistent generation of hydrogen sulfide has been reported to result in risk of harm to communities, in which the harm was either actual or believed, and differentiating between actual and believed is impossible and may be moot regarding harm as viewed in court. Be assured that believed harm can be real harm. Psychosomatic injury is real injury. Before dismissing the threat of perceived harm, carefully consider the poster example of psychological stress and perceived harm, the Three Mile Island event in 1978. Overwhelming evidence indicates the public *did not* receive sufficient radiation exposure to have any detectable effect whatsoever, but they were psychologically stressed by their fears and perceptions nevertheless, which was actual harm. Stress effects human health. In March, 1982, the *American Journal of Public Health* reported: "During the first two quarters of 1978, the neonatal mortality rate within a ten-mile radius of Three Mile Island was 8.6 and 7.6 per 1,000 live births, respectively. During the first quarter of 1979, following the startup of accident prone Unit 2, the rate jumped to 17.2; it increased to 19.3 in the quarter following the accident at TMI and returned to 7.8 and 9.3, respectively, in the last two quarters of 1979," wrote Dr. Gordon MacLeod, Secretary of the Pennsylvania Department of Health.

Table 1: Reported Effects and Limits for Low Levels of Exposure to Hydrogen Sulfide

Concentration (ppm)	Length of exposure	Reported Effect or Limit ¹
0.0057	Community/chronic	Eye and nasal symptoms, coughs, headaches and/or migraines
0.0106	24 hr.	World Health Organization limit for protection of the eye.
0.008	Brief Exposure	Some subjects detect and are annoyed by nuisance rotten egg odor
0.01	Community/chronic	Neurophysiological abnormalities
0.025	Chronic	Eye irritation and possible serious eye effects.
0.30	Brief Exposure	All subjects detect and are moderately offended by odor.
0.1 – 1	Not reported	Abnormal balance with closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength
2	Brief Exposure	Lowest observed adverse-effect level (LOAEL) in sensitive (asthmatic) individuals for respiratory and neurological effects according to the World Health Organization.
3.7	Repeated Exposure	Significant number of workers with eye complaints.
1 – 5	Not reported	Abnormal balance with open and closed eyes, delayed verbal recall, impaired color discrimination, decreased grip strength, abnormal simple and choice reaction time, abnormal digit symbol and trail making.
5	8 hrs	UK and EU long-term exposure limits (LTEL) for 8 hour per day exposure of workers to hydrogen sulfide. Also threshold of measured increased blood lactate concentration, decreased skeletal muscle citrate synthase activity, decreased oxygen uptake.
2 – 8	Community	Malaise, irritability, headaches, insomnia, nausea, throat irritation, shortness of breath, eye irritation, diarrhea, and weight loss
10	10 minutes	Recommended Exposure Limit to Workers by the National Institute of Occupational Safety
17	8 hours one time	EPA’s Acute Exposure Guideline Level -2 means the general population, including susceptible individuals, could experience <i>irreversible</i> or other <i>serious</i> , long-lasting adverse health effects or an impaired ability to escape.
20-50	Chronic (Several Days)	May result in significant damage to human eyes.
30	1 hour one time	Emergency Response Planning Guideline (ERPG-2) The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual’s ability to take protective action.

¹ Detailed references to original research on which the summarized limits or thresholds are based (including that subject to valid criticism) can be found in (Skrtec 2006, Guilotti 2010, and Lambert 2006) unless a source is provided as part of the reported effect or limit.

Although absent any actual public exposure, TMI's owners and builders paid more than \$14 million for out-of-court settlements of personal injury lawsuits. While the largest settlement was for a child born with Down's Syndrome, there was of course no direct connection of that birth to radiation exposure. In February, 1981, a \$20 million fund was set up to pay over 15,000 claims and another \$5 million is set up to establish the TMI Public Health Fund. 2,000 lawsuits pending in court were dismissed based on ten test cases where again and again, experts testified that there was no basis for any claim of significant radiation exposure. Keep in mind the damage here is believed to be and therefore is, very real, regardless of any significant radiation exposure. Even without fear or psychological stress, an evacuation causes inconvenience that within itself constitutes some degree of harm. After 34 years, a case is still lingering in 2012 regarding seventeen businesses who were evacuated, prevented from operating, and thereby lost revenue, in the 1978 TMI event.

The general population may easily be exposed to hydrogen sulfide by accidental release from natural gas wells during drilling operations near residential areas (Layton 1987; Layton 1986; Leahey 1986; Layton 1983). In a 1982 well blowout in Alberta, maximum reported hourly concentrations were 15 ppm near the source and concentrations 60 miles from the source were below 100 ppb, but over a thousand complaints were filed. On Christmas Eve, 2011, odors were reported 80 miles from a pipeline leak in Michigan (BMF 2012). The dose-response relationship is not well characterized to these extreme low levels of exposure (low ppm to low ppb) that are detected through smell, but generally, chronic exposure to low-level concentrations of hydrogen sulfide has been associated by some researchers with neurological symptoms that include fatigue, loss of appetite, irritability, impaired memory, altered moods, headaches, and dizziness.

At persistent concentrations of 0.250 to 0.300 ppm (250 to 300 ppb), some report the malodorous stench alone as creating a nuisance to communities and affecting the quality of life through headaches, nausea, and sleep disturbance. At 0.008 ppm some will notice the rotten egg odor and proclaim it a public nuisance, but at precisely what level chronic exposure leads to definite health effects unassociated with response to smell has not clearly been determined and may never be. The public attitude regarding odor varies from smell having no importance at all to smell being the sole basis for regulatory limits. A toxic torts case might rely on proving harm has been caused and that the activity is inherently unreasonable because it could easily have been prevented and juror's attitudes regarding the issue of smell may be hard to gage in advance.

Other Chemicals Present Complicate Toxicological Study of H₂S

At very low levels, the effects of hydrogen sulfide in humans have been considered difficult to differentiate because other chemicals are generally present. Maori residents of the City of Rotorua in southern New Zealand that are exposed to natural high levels of hydrogen sulfide from geothermal vents have been identified as having statistically significant excess deaths from both central and peripheral nervous system disorders, but there is also a high level of carbon disulfide there which is likely a contributor to a least a fraction of the mortality, making it impossible to differentiate an exclusive cause (Guidotti 2010). Mercury and radon are also high and could play a role. When water workers were compared to sewer workers, the latter showed greater respiratory-related problems (ATSDR 2012) which *could* be attributed to H₂S, but obviously many other chemicals are also present in sewers.

The same issue is presented by studies of workers and local residents exposed at paper mills, where there seems to be an H₂S dose response relationship at very low exposure levels, but it cannot be attributed exclusively to hydrogen sulfide with other chemicals present as well (Cush 2011). Another paper mill study showed correlation, but was inconclusive regarding H₂S alone because methyl mercaptan, and methyl sulfides were also present (ATSDR 2012). Likewise a retrospective epidemiological study on residents of Beijing, China showed an association between spontaneous abortion and exposure to hydrogen sulfide and other petrochemicals, but hydrogen sulfide alone could not be differentiated as an exclusive cause (Skrtic 2006). In deriving their reference H₂S concentration of 0.002 mg/m³, EPA states that “Little is known of the concentration-response relationship at low levels of chronic exposure. Occupational studies have been confounded by *exposure to other substances* and inadequate monitoring to establish cause-effect relationships (EPA2 2003). Nevertheless, in 2011 EPA was able to determine that reporting of hydrogen sulfide by the oil and gas industry under TRI was appropriate to begin in 2012 (EPA1 2012) after complaints from citizens waving real air sampling results around (GCM 2011) followed a 2009 letter from the Sierra Club (Carmen 2009).

An ideal study would compare a very large sample of people breathing only ultrapure air plus completely mixed reagent hydrogen sulfide at constant known concentration to their genetic twins living in a parallel world containing identical life, food, occupational, and health experiences who also breath only ultrapurified air but without the H₂S component. Since a study like that can and will never happen, all future studies will be subject to criticism just as all those in the past were. It’s the nature of epidemiological studies absent of laboratory controls. Table 1 above summarizes some of the thresholds and limits frequently identified in the literature examined, much of which can be subjected to criticism, and some very valid criticism, with other chemicals present being one of many bases of attack.

Odor Also Complicates Studies

As humans evolved, we can surmise that the ability to be offended or repulsed by the odor of hydrogen sulfide acted as a mechanism of natural selection. Those who tended to be repulsed by hydrogen sulfide’s stench did not eat spoiled toxic food full of anaerobic bacteria and thereby lived to reproduce while those without the ability to respond to this specific odor stimulus had genes that for obvious reasons are no longer represented among today’s surviving human population. Because of this critical role H₂S played in human evolution, hydrogen sulfide is now viewed as a noxious poison perceived as a threat or signal of danger that induces an involuntary defensive response of disgust in most humans.

The disgusting odor provokes aversion and a physiological response such as nausea which *in itself* directly affects human health. If the human *perceives* a health threat, the very real physiological response may be discomfort, anxiety, disturbance, and even headaches and these effects may be difficult to separate from other toxic effects that would have occurred without the odor. Once the subject smells it, it’s too late. This wrecks fair evaluation of effects on communities. The study of toxicity at very low levels becomes fairly impossible because it is so overshadowed by the psychological and physiological response caused by exposure to the nuisance of noxious odor. Studies cannot be executed blind because participants will always detect and respond to the odor first. Because the stimulus is odor, and the American public has a somewhat lighthearted view of issues of odor, people are full of mixed signals varying from alarm and disgust to complacency.

The toxicity of chronic exposure that would have occurred had the population not experienced the effect of odor can never be established with any precision, so given no convincing proof of harm at very low exposures, the question becomes whether toxic tort claims could ever be successful based on the psychological and physiological effects of odor alone. It is clear that societal attitudes include contradictory thought that may at times place either very minimal or at other times high importance on odor.

Certainly claims of community brain damage, a position that appears to be suggested by some of the literature, would have a greater impact on the magnitude of jury award than merely degradation in the quality of life resulting from an inescapable offensive stench. Many researchers consider those studies that report health impact unrelated to odor at exposure levels below 1 ppm to be very weak or flawed, especially those associating brain damage with such low doses of gas.

The criticism of H₂S toxicity studies offers some entertainment value beyond their many references to smell. When criticizing these studies, it might be a wiser legal maneuver to claim the “other chemicals are always present” position, which is a fairly universal truth, or to criticize the selection of a control group if there even was one, than to take a position that could appear to the jury to involve blatant prejudice—such as that the workers studied tended to be too uneducated, poor, or dumb for anyone to possibly be able to detect brain damage in them. The “unreliable narrator” position seems equally unwise insofar as juror reception, based on the stance that any testimony by brain damaged individuals would be unreliable by definition and therefore should be dismissed in cases where a plaintiff is claiming to have suffered brain damage. Closely consider the references made to odor in these reports:

After a valve leaked hydrogen sulfide on Christmas Eve in northern Michigan, Brietburn Energy spokesman and executive vice president Greg Brown stated to the Gaylord Herald Times:

“We apologize if anybody was alarmed. We don’t believe there is any danger. [It was] just a bad smell.”

“But in 1997, amid other H₂S releases and consequent harms to people in Manistee and Mason Counties, Dr. Kaye Kilburn, Professor of Medicine at the University of Southern California, told the Muskegon Chronicle ‘Hydrogen sulfide poisons the brain and the damage is irreversible....H₂S is dangerous any time you can smell it.’” The Sunday Muskegon Chronicle, 12/7/97).

Quotes of both papers here are taken from a secondary web source that keeps newspaper articles posted by a group called “Ban Michigan Fracking (BMF 2012).

Does Odor Alone Pose Any Real Legal Risk?

In the Ban Michigan Fracking website quotes we see the position implied that “just a bad smell” (and presumably all the associated psychological and physiological impact and nuisance) is considered, at least by some people, as perfectly acceptable whereas brain damage (presumably even some slight brain damage associated with only a temporary H₂S leak) would be considered quite unacceptable in contrast. There appears to be so little chance that the brain damage allegation would ever be provable in a court action involving low exposure that the Ban Michigan Fracking group refers to brain damage but no injured class proceeds in action, while the existence of the smell was both openly admitted and assumed

to be dismissible by the company spokesman, and that summarizes the pervasive conclusion about hydrogen sulfide in general—it has a stench all right, but we don't know of any nonstench-related injury for sure.

The criteria of “just a bad smell” is the basis for the World Health Organizations recommended community exposure limit of 5 ppb (Chou 2003). *Odor* is the basis for California Ambient Air Quality Standard, and researchers evaluating the standard suggested that children *hypersensitive to odor* should be considered when setting standards (Collins 2000). The IPCS stated that “The malodorous property of hydrogen sulfide gas is well recognized and *this characteristic alone* is believed by many to be capable of producing impairment of human health and wellbeing” (WHO 1981).

In a letter to the EPA asking that the TRI reporting be reinstated, Sierra Club pointed to odor as a nuisance quoting “headache and nausea in *response to odor*” in suggesting an REL at 8 ppb based on the CAAQs, going on to say that H₂S is “more than just a stinky chemical triggering bad headaches, nausea and discomfort at citizens’ home environment. The oil and gas industry have downplayed for decades the toxic effects of smelly H₂S emissions when citizens have to breathe horrible, nauseating rotten egg odors, while industry officials allege it’s *little more than a foul smelling odor* with no harmful effects at sublethal low concentrations.” Note that this letter (Carmen 2009) illustrates through implication the position that while smell is extremely distasteful (or shall we more accurately say, it may even be odorous) that the smell is not *in itself* a sufficient grounds on which to base a claim of significant harm.

Of course, the standards for worker exposure are set in the ppm range, not because it is believed that workers have no sense of smell or that their health would be unaffected by chronic malodorous stench, but possibly because it is assumed that the benefits or financial compensation for employment far outweigh the effects of “just a bad smell” at work. The extension of this reasoning can be seen even when the compensation is indirect or not apparent. After teachers and children “shelter-in-place” because of refinery odors, the response of the school district was to plan relocating the school rather than attempt to bring action against the refinery for nothing more than smells (Collins 2000).

Is Brain Damage a Defensible Claim?

The jury may be out on high exposures with sustained repeated knockdowns, but probably *not* out when it comes to the nuisance odor ppb range. When as children we learn about the repeatability and consensus involved in the scientific method of establishing theories we get a false sense of simplicity that can lead us to expect agreement among the scientific community, an agreement that is often lacking, especially when economic interests could be at stake. Of course as in most things, there is really good research and research that is not so good, but the jury members of toxic torts cases cannot be expected to adequately differentiate between the two. This creates risk. Between mortality and survival, there may be a spectrum of effects that cannot be extrapolated to low levels.

There is a study providing some evidence of brain damage (Kilburn 2003) and one based on sewer workers where some brain function appears to have been potentially compromised (Farahat 2010), with the former study eliciting criticism for dose-response assumptions and the latter study humorously eliciting criticism from subsequent researchers for the subjects being too poor and uneducated to believe their intelligence could be quantifiable. Other researchers found no statistically significant association between brain function and low chronic H₂S exposure (Inserra 2004) even among the poor and

uneducated, but while reporting that their control group was nonideal because of difficulty in finding participants. Some studies have been criticized for making false oversimplifying assumptions about the nature of the dose response function, others for the presence of gases other than hydrogen sulfide mixed into high purity air, others for the control group selected, and finally with a little opportunity for humor, for the low economic class and poor education level of those being studied. When the smoke clears, the claim of brain damage appears at best very weak and should not be extrapolated down into the low ppb range at which public groups tend to protest nuisance odors. This says nothing about whether a class action case might be made based on the obvious nuisance of the odor itself. That is a more profound question, but certainly public attitude does not seem capable of supporting such an action.

The Eye Protection Standards

Based on a thorough and rigorous review of all studies currently in English plus some translations, some researchers report that the human eye should be protected down to far lower levels than those associated with general toxicity, down to 25 ppb (Lambert 2006) while regulatory standards permit routine exposure of workers into the ppm range. If the odor nuisance can be dismissed as posing no legal liability because of societal attitude is too inconsistent to ever successfully litigate, then the odor-based regulatory thresholds set by WHO, the State of California, and others should be dropped because they appear to have no practical meaning. A standard of 25 ppb would protect eyes while still allowing odor exposure. Litigating a class action based on brain damage seems unlikely until there has been additional research supporting H₂S as the proven cause.

Part of the apparent confusion over eye response seems to stem from basing generalizations on what were essentially side comments or observations about eye response taken from studies never intended to measure eye effects to begin with. Other false conclusions come from relying on studies that did not examine the eye using magnification or staining, techniques which may have been done first by Henrik Sjorgen in Sweden in 1939 (Lambert 2006). Because they were never intended to specifically look for eye problems, many subsequent studies made sideline observations about eye sensitivity or damage from the macroscopic view without using these techniques.

Where Does the Sour Part Go?

Refining gas that originates from the Rectisol, Selexol, or Perisol process or from amine scrubbers in refineries, natural gas processing plants, gasification or synthesis plants, usually go to the Claus process plant. When hydrogen sulfide content is less than 25%, other schemes are triggered with the same end. The main Claus process is one combining oxygen and hydrogen sulfide to produce sulfur and water. It is considered over 99% efficient based on wt% sulfur recovered from acid-rich feed, but not as efficient for the lean feeds, so a variety of modifications have been made to compensate, and many work well (McIntyre 1997).

Note that in the Claus process the hydrogen of hydrogen sulfide ended up in water. As a result, an array of competing processes have been developed or are under development that recover the hydrogen as a useful product. These are based on pyrolysis, thermochemical, electrochemical, and photochemical cycles (Gangwal 2008). Some of these processes are tolerant of very lean feeds. The SWAPSOL process uses hydrogen sulfide as part of flue gas cleanup (SWAPSOL 2012). A variety of metal membranes have been used to reduce H₂S to hydrogen gas and sulfur (Ackerman 2007).

Sulfuric Acid Production

The wet sulfuric acid process can take H₂S from amine treatment, tail gas from a Claus Plant, Rectisol off gas, sour water stripper gas, flue gas, and other sources. After oxidizing the hydrogen sulfide to sulfur dioxide, it oxidizes the SO₂ to SO₃ using a vanadium oxide catalyst. The SO₃ is hydrated and condensed to liquid sulfuric acid. All reactions are exothermic and steam is produced for energy recovery or other industrial use. This process is over 99% efficient on a per unit sulfur mass converted basis and is tolerant of a huge range of possible feeds.

There are other places that H₂S *might* go, but the main ones are for sulfur and sulfuric acid production.

A Compound Under Heavy Fire

While often belittled as nothing more than a nuisance poisonous gas, hydrogen sulfide provides the starter materials for sulfur used in medicine, agriculture, and hundreds of useful products. Hydrogen sulfide itself may be found to be of medical use in the future (Guidotti 2010, Physorg 2007). It appears to have anti-inflammatory properties (Guidotti 2010). It was shown to prevent heart tissue death in mice and to suspend tissue in animation for potential organ transplant use (Physorg1 2007). Exposure to hydrogen sulfide was shown to extend the lifespan of nematode worms significantly (Physorg2 2007).

Some people don't even get too upset about the smell. The mild analogues we get from smell and taste of sulfur-rich food are highly popular. The daily production of hydrogen sulfide and other sulfide gas in the human body from such sulfur rich foods such as garlic, onions, leeks, ramps, broccoli, cauliflower, sweet potatoes, nuts, chocolate, coffee, beans, peas, cabbage and Brussels sprouts (to mention but a few) is viewed with reactions that vary from distaste to comedy, but no one worries about brain damage. Hydrogen sulfide is common in flatulence, and flatulence is produced heavily by cattle. The Kyoto Protocol placed an unflattering flatulence tax (not a flat tax either) on New Zealand for their cattle flatulence (Reuters 2003). A class action suit claiming damage by hydrogen sulfide odor alone would probably get similar response from the public as inspired by the flatulence tax, which gave the media headlines a hay day of jokes, or maybe not—recalling that regulatory limits and guidelines have been set based on odor alone.

Methods of Control of Hydrogen Sulfide

Leaks can occur at well casings, wellheads, piping, separators, storage vessels, valves, flanges, collars, unions, fittings, compressor stations, pipelines, flares, pumps, heater-treaters, pressure relief valves, rupture discs, and basically any item serving as a containment boundary between oil and gas and the atmosphere. Leaks are avoided or the release minimized through robust design, the choice of alloys that resist corrosion and hydrogen sulfide stress cracking, effective maintenance programs, failure mode predictions, root cause analysis, vibration control, continuous improvement, spare parts management, response readiness, and a good quality program. This is the case for methane leaks whether hydrogen sulfide is present or not, even though methane leaks might not produce as much public complaints.

Unfortunately, many existing and aging systems are already leaking, subject to frequent leaks, and many problems trace to design choices that might be different if they were being installed today. Many systems need gas leak recovery installed now, and recovery for some would be a profitable decision. Infrared cameras used by experts have proven highly effective in locating leaks (Hybon 2012). Capture of fugitive

gas from leaks can often prove highly profitable (Hybon 2012). Leak recovery has worked for agricultural sources (Whirlwind 2012). Highly efficient low-maintenance compressors are often used, but there are creative compressor-free designs such as using produced water jet pumps if the configuration is suitable (Hybon 2012). Vapor recovery rental units are offered for emergencies (Zink 2012). Flare gas recovery can reduce process energy requirements for refining (Nash 2012). Of course for new systems more expensive alloys can reduce future hydrogen sulfide stress-cracking induced maintenance issues but at greater capital costs.

Conclusions

There remains no clear definitive evidence of a quantitative dose-response relationship for chronic low level exposures to hydrogen sulfide. Given the pervasive presence of other chemicals and the genuine physiological and psychological effects of the odor, this may never be resolvable.

The single thing that everyone can agree on is that hydrogen sulfide is malodorous, but what that means in terms of nuisance and health impact is not clear, and the societal and regulatory response has been very inconsistent, at times setting standards based on odor alone while at other times appearing to marginalize the issue of odor tongue in cheek. Given this irrational public psychology, the potential threat of a successful toxic torts action based on odor alone is unclear.

Nevertheless, it would of course be prudent to reduce gas leakage especially where there will be hydrogen sulfide odor detection by the public to the extent practical. Vapor recovery, leak reduction, expensive alloys in new designs that will resist hydrogen sulfide stress cracking, and high quality maintenance programs are already the trends nationally and globally, but complaints can be expected whenever accidents and equipment failures occur.

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